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Cultural Practices Mitigate Irrigated Rice Insect Pest Losses in the Philippines

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On-farm research trials evaluated three agronomic practices where farmers were at variance with national recommendations to determine if crop compensation to insect pest loss could be a reason for the differences. Due to the popularity of early maturing varieties, we also tested the effect of plant maturity on the physiological process of compensation. Farmers fine-tuned these practices by trial and error and sought higher yields. The probable reason for the differences between national recommendations and farmers' practices is that agronomists undertake trials under insect free conditions in a reductionist approach when performing trials. In regard to plant density, the farmers' practice of transplanting 6 seedlings/hill has merit in increasing the crop's tolerance to insect pest pressure over the recommended 3 seedlings/hill. Farmers were also correct to note that using N rates above 100 kg/ha gives high yield, the fact that they do not perform trials to compare varying rates does not allow them to know the optimal levels. Trials showed that researchers were correct in recommending younger transplanted seedlings (20-d-old), but farmers failed to do so in part because such young seedlings cannot be easily pulled without being ripped apart due to the hard soil. Finally, a compromise between longer and shorter maturing varieties is called for. The former have less ability to compensate from pest damage, whereas the latter, despite possessing the greatest compensatory capacity, to their discredit enhance pest buildup, thus medium maturing rices are preferred.

Key Words: crop compensation, crop maturity, integrated pest management, nitrogen application, plant density, plant physiology, rice insect pests, transplanted seedling age, yield components, yield loss

INTRODUCTION

Surveys have shown that Filipino farmers, although are high adopters of modern rices, deviate substantially in their management practices from national recommendations (Litsinger et al. 2009). Several research programs at the International Rice Research Institute (IRRI) in the Philippines, notably the Farming Systems Program (Zandstra et al. 1981), were established to find out the reasons. Farmers in Central Luzon in particular transplanted 30-d-old seedlings when the recommendation calls for 20-d-old ones. They also applied higher N rates and higher seed rates than recommended (Fajardo et al. 2000). Researchers were puzzled as to why farmers were applying these inputs at higher than recommended levels given their expense as they also pay usurious interest rates. High N rates also have been associated with higher pest incidence (Litsinger 1994).

The objective of the Farming Systems Program was to increase cropping intensity in rice-based systems, thus farmers embraced early maturing rices in order to squeeze in one more crop per year (Morris et al. 1982). With a growing emphasis on increased cropping

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intensity in both irrigated and rainfed areas to feed Asia's burgeoning population, there is considerable demand for early maturing rices with growth durations around 100 d in order to increase productivity per day and to conserve irrigation water. Research has shown that such varieties are less able to tolerate pest damage and as a consequence suffer higher yield losses than if longer maturing rices are used (Litsinger et al. 1987). The mechanism of tolerance is compensation, the process by which plants respond positively to the effects of injury by stresses such as insect pests (Bardner and Fletcher 1974; Litsinger 2009).

The environment of most farmers' fields sustains more stresses than that of an experiment station where the recommendations were developed. We hypothesized that, as farmers develop their practices by trial and error (Goodell 1984), their management practices may be a product of the number of stresses that they face. In order to test this hypothesis, we established a research project at three Farming Systems Program on-farm sites to test the effect of three farmer practices on yield via their tolerance to one group of stresses, namely insect pests. A fourth variable examined was to compare varieties of differing crop maturity as to their tolerance to insect pest injury.

MATERIALS AND METHODS

Site Descriptions

Field trials were conducted in cooperation with farmers who offered portions of their fields in three sites within two major rice bowls in the Philippines. Different research teams that lived in local towns staffed each of the three sites located in areas of irrigated, transplanted, double-cropped rice. Farmer cooperation was assured as the local staff had established on-farm trials over a number of years with the same farmers. Zaragoza and Guimba are towns located in Nueva Ecija province in Central Luzon within the largest rice bowl. Zaragoza is located at the tail end of the 20,000 ha run-of-the-river Upper Pampanga River Irrigation System, whereas each electric pump in Guimba serviced only about 100 ha. Both sites are in a monsoon climate typified by a six-month rainy season and distinct dry season. Zaragoza suffers flooding in low-lying areas exacerbating zinc deficiency. Generally the clay soils are classified as excellent for rice. Koronadal, on the other hand, located in South Cotabato province in Mindanao Island, is under the influence of the equatorial Inter-Tropical Convergence Zone climate that lies near the equator outside of the monsoon belt where it has a longer rainy season and less distinct dry season. Irrigation is from the Marbel River, and as the volcanic soils are still fertile, less inorganic N is needed. Farm sizes averaged 1 ha in all three sites and farmers did not use any organic fertilizer.

General Crop Management and Experimental Design

Each field trial was established late in the season to maximize natural pest infestation in order to realize highest yield loss. Certified seed of each variety was obtained from IRRI to ensure quality. The high-yielding, semi-dwarf varieties tested (IR58, IR60, IR64, IR70, IR74) possessed genetic resistance (antibiosis rather than tolerance) to brown planthopper *Nilaparvata lugens* (Stål) and green leafhopper *Nephotettix virescens* (Distant) (Khush 1984). Agronomic practices were standardized to those most farmers followed except when the variable was one of the treatments. Thirty-d-old seedlings were transplanted from a wetbed within each field at 6-8 seedlings per hill. Spacing between hills was 20 x 20 cm in Zaragoza and Koronadal with 25 x 25 cm being employed in Guimba. Nitrogen was applied in two splits with 50% each application. The first paddy-water broadcast occurred 3 wks after transplanting with the balance 7 d before panicle initiation. Thirty kg P/ha was soil incorporated during field leveling prior to transplanting as N and P are the two most common nutrients that need replenishing. In zinc deficient areas of Zaragoza, 25 kg zinc oxide was applied in the seedbed per ha transplanted. A pre-emergence herbicide (butachlor) was used against grasses followed by hand weeding as needed. In the other trials with 50-100 m^2 plots (Tables 1-6), five yield cuts of 5 m^2 each were taken in a stratified grid. Yield components were taken by recording the number of panicles from a 1 m^2 sub-sample of each yield cut. The number of filled grains per panicle was recorded from a sample of 50 randomly selected panicles from each yield cut. In the trials where yield was taken per hill (Figures 1-3), the number of tillers per hill was recorded at the end of the reproductive stage. At harvest, panicles were cut, threshed by hand, and sun dried. One thousand-grain weight was taken from each yield cut using an electronic balance accurate to $\pm$ 0.1 g. An electronic moisture meter was used to adjust grain weight to 14% moisture for final yield determination in all trials.

All trials were conducted on farmers' fields in each of the research sites; except when indicated, all agronomic practices were under our management. Trials were set out in a randomized complete block design with replications either within one field, or more commonly, replication was across farms (each farmer served as a replication). In trials that compared varieties, the treatments were randomized in the layout. Shallow bunds were constructed around each plot in experiments testing different fertilizer regimes to prevent inter-plot movement.

Pests and Yield Loss Assessment

Pests that caused yield loss in the three sites included whorl maggot *Hydrellia philippina* Ferino, defoliating caterpillars (green hairy caterpillar *Rivula atimeta* [Swinhoe], green semi-looper *Naranga aenescens*

Moore), yellow and white stemborers (*Scirpophaga incertulas* (Walker) in Luzon and *S. innotata* (Walker) in Mindanao), and leaffolders (*Marasmia exigua* [Butler], *M. patnalis* Bradley, and *Cnaphalocrocis medinalis* [Guenée]), which collectively attack the three main crop growth stages as described by Yoshida (1981).

The insecticide-check method was employed in trials where yield loss was measured, which contrasted insecticide protected and unprotected treatments (Litsinger et al. 2005). Yield loss was calculated as the difference between a protected and an unprotected plot divided by the yield of the protected plot multiplied by 100. Frequent insecticide applications were scheduled to ensure as much as possible an insect pest-free treatment (Litsinger 2009). The number of applications was greater on longer maturing varieties, and it is to be made clear that this treatment is not a recommended practice for farmers but it is only a research tool to measure yield loss. Farmers spray many fewer times (Litsinger et al. 2009).

The first application was an immersion of seedling roots in 0.5 kg a.i. isofenophos seed dressing (SD) formulation/ha for 12 h before transplanting to control early season insect pests including the hard-to-control whorl maggot. This was followed by weekly foliar sprays of 0.75 kg a.i. monocrotophos EC/ha beginning 14 d after transplanting (DT) continuing over the rest of the vegetative stage. During the reproductive stage, a mixture of chlorpyrifos + BPMC (Brodan EC) was sprayed weekly at 0.75 kg a.i./ha. Ripening stage pests were controlled with three sprays of 0.75 kg a.i. monocrotophos EC/ha at milk, soft, and hard dough.

Crop Maturity and Yield Loss

A wet season experiment in Zaragoza compared two varieties differing in maturity on yield loss (Table 1). The very early maturing IR58 matures in 90 d, whereas IR74 matures in 125 d. Yield loss was determined by the insecticide check method, thus, the trial composed protected and unprotected treatments. Plot size was 100 m^2 in the randomized complete block design trial conducted with four replications in a single field. Seedlings of both varieties were transplanted on the same day. The fertilizer rate was 70-30-0 kg NPK/ha.

Nitrogen Rate and Yield Loss

Two trials were conducted in Guimba in individual farmers' fields over both a wet and dry season comparing the farmer's fertilizer practice with the recommended practice and an untreated control (Table 2). The untreated and researchers' practice were set out in a small block in a farmer's field. There were six replications per season in the randomized complete block design. In each 50-m^2 plot, the natural infestation of yellow stemborer was artificially augmented by placing 3 egg masses per m^2 9 wks after transplanting following the method described in Bandong and Litsinger (2005). The researchers' N level was 70 and 80 kg N/ha in the wet and dry seasons, respectively. The farmer's practice was 122 and 150 kg N/ha in the wet and dry seasons, respectively. IR64, maturing in 117 d, was the variety of choice by both researchers and farmers.

An additional trial was conducted in Zaragoza where four N rates (0, 30, 60, and 90 kg/ha) were established on IR74 in 50 m^2 plots in a farmer's field (**Figure 1**). Within each of the six replications of the randomized complete block design, 20 hills having 0-5 whiteheads/hill were randomly harvested and yield was taken per hill. A basal application of 30 kg P/ha was applied to the whole field. N dosages were split half basal and half 7 d before panicle initiation.

Interaction of Nitrogen Rate and Crop Maturity on Yield Loss

Two sets of trials were established that compared yield losses in early and medium maturing rice varieties with different rates of N. In both trials, N rates were split: half basal and half 7 d before panicle initiation. 30 kg P/ha was basally applied to all treatments. In both locations there were four replications per variety with individual farmers' fields as replicates in 100 m^2 plots contrasting insecticide protected and unprotected treatments. Varieties were randomly mixed in the complete block design.

The first trial in Zaragoza compared the very early maturing IR58 to the medium maturing IR70 (135 d) each at four N rates (0, 30, 60, and 90 kg/ha) (Table 3). The second trial, also in the dry season, was in Koronadal and compared IR60 (109 d) and IR74 with three N rates (0, 45, 90 kg/ha) (Table 4).

Influence of Seedling Density on Stemborer Damage Function

In the dry season in Zaragoza, four 200 m^2-plots of IR74, were each sown at different densities (3, 6, 12 seedlings/hill) in a farmer's field (**Figures 2-3**). At crop maturity, 50 hills each with 0-7 whiteheads were randomly selected per plot. The number of tillers was tallied and the yield measured for each hill. There were five replications for each of the eight whitehead densities.

Interaction of Seedling Density and Variety on Yield Loss

In the wet season crop in Koronadal, two varieties were compared (IR60 and IR74) at two densities: 3 and 9 seedlings per hill (Table 5). Both varieties were randomly placed in the complete block design with eight replications with a plot size of 50 m^2. The trial was conducted in a single field and the seedlings of all varieties were sown on the same day. The recommended seedling density was 3 per hill, whereas based on observations, farmers often use from 8-14 seedlings per hill. The objective was to determine possible differences in yield compensation in both varieties. N rate was 40 kg/ha, split half basal and half 7 d before panicle initiation. Rates were lower than in Luzon as the soil is more fertile. P was applied as a basal application at 30 kg/ha.

Interaction of Seedling Age and Variety on Yield Loss

A similar trial as above was carried out in Koronadal in the dry season crop with the same two varieties with and without insecticide protection but with two different seedling ages, 20 and 30 d old (Table 6). The recommendation is to transplant 20-d-old seedlings that encourage high tillering and rapid recovery from transplanting shock. Farmers often sow 30-d-old seedlings as they are larger and thus easier to pull from the soil. N rate was 40 kg/ha, split half basal and half 7 d before panicle initiation. P was basally applied at 30 kg/ha. The plot size was 50 m^2 with eight replications in a randomized complete block design. The trial was conducted in a single field.

Statistical Analysis

All statistical analyses were performed by SAS with $P < 0.05$ as the criterion for significance. Results were subjected to two-way ANOVA and regression analyses were performed where appropriate. Best fit among regression models was determined by Akaike's Information Criterion (AIC) (Burnham and Anderson 2002). AIC quantifies predictive power of candidate models (model performance) based on evaluation of the Kullback-Leibler distance between fitted models and the underlying data-generating mechanism. Compensation is indicated by a quadratic model rather than linear. The preferred and most parsimonious model would be the one with the minimum AIC value in each comparison. AIC not only rewards goodness of fit, but also includes a penalty that is an increasing function of the number of estimated parameters. This penalty discourages over-fitting. Treatment means were separated using the paired t-test for two variables or Least Significant Difference (LSD) test for more than two variables. Means are shown with standard errors of the mean (SEM) using a pooled estimate of error variance.

RESULTS

Crop Maturity and Yield Loss

In Zaragoza, yield loss from insect pest pressure was measured on two varieties differing by 35 d in maturity. In IR58, one of the earliest rice varieties, there was a significant 14.2% yield loss (0.72 t/ha) as determined by the insecticide check method, compared to an insignificant 4.0% loss (0.21 t/ha) in the longer maturing IR74 (Table 1). Yields were high for a wet season crop as measured in the protected plots, as normally cloudy weather at grain filling, common in a monsoon climate, restricts solar radiation and thus limits yield potential (Yoshida 1981). Yield loss came from the high populations of whorl maggot and defoliators during the vegetative stage combined with moderate levels of stemborer deadhearts. Stemborer damage continued to be high during the reproductive and ripening stages in the purposefully late plantings. Leaffolder also attained relatively high densities (7.5-9.2%) on the flag leaves. Even though there was considerable insect pest pressure, the longer maturing rice variety could entirely compensate from the damage, whereas the earlier maturing variety could not. Only when highly protected could the earlier maturing variety achieve an equivalent yield as the untreated plot in the longer maturing variety.

Yield components tell us how the yield was lost. Tillering rates were significantly lower (462 panicles/m^2) in the unprotected early variety compared to the other three treatments that registered 501-532 panicles/m^2. Lowest yield occurred in the untreated plot with IR58 that also recorded the fewest number of grains per panicle (13.1) compared to the other three plots (16.7-20.6). Thus low yield was related to lower tillering and reduced grain filling. There was no effect of 1000-seed weight between any treatments in any of the trials conducted in this study; therefore the data are not reported.

Nitrogen Rate and Yield Loss

Damage functions are regressions that show the relationship between pest density (x axis) and yield (y axis) and were compared over four N rates in a trial where hills were harvested ranging from 0-5 whiteheads/hill in Zaragoza. As expected, without stemborer infestation, yields were highest at 90 kg N/ha (26 g/hill) and lowest at 0 kg N/ha (21 g/hill), but were similar at an intermediate level (23 g/hill) for both the 30 and 60 kg N/ha rates (Figure 1). In both 60 ($P = 0.02$, $F = 7.93$, $df = 15$) and 90 ($P = 0.01$, $F = 8.61$, $df = 15$) kg N/ha rates, the best fitting regression models between increasing stemborer injury and yield were quadratic based on the lower AIC values (14.5 for linear and 7.6 for quadratic for 90 kg N and 9.8 for linear and 7.5 for quadratic for 60 kg N/ha, respectively). Compensation up to the 2-3 whiteheads/hill level was indicated due to the shape of the curve (Pedigo et al. 1986). With lower rates of 0 ($P = 0.04$, $F = 5.06$, $df = 15$) and 30 ($P = 0.03$, $F = 5.11$, $df = 15$) kg N/ha, the relationships were linear, indicating no compensation. This was supported by the AIC test as the value at 30 kg N/ha was 1.5 for the quadratic model and -3.7 for

Table 1. Comparison of two varieties differing in growth duration on their tolerance of yield loss from insect damage on irrigated transplanted rice, Zaragoza, Nueva Ecija, 1990 wet season [1]

Variety/Days to maturity	Insect Protection	Whorl maggot + defoliators (% damaged leaves 35 DT)	Stemborer: Deadhearts (%) 35 DT	Stemborer: Deadhearts (%) PI	Stemborer: Whiteheads (% 10 days before harvest)	Leaffolder (% damaged flag leaves)	Panicles (no. /m^2)	Filled grains (no./panicle)	Yield (t/ha)	Yield Loss [3] %	Yield Loss [3] t/ha	Yield Loss [3] P
IR58 90 days	Insecticide Protected [2]	3.8 ± 0.8 a	0.7 ± 0.2 a	0.2 ± 0.1 a	1.1 ± 0.4 a	0.7 ± 0.4 a	501 ± 34 b	17.2 ± 3.1 a	5.07 ± 0.34 a	14.2	0.72	<0.0001
	Untreated	20.4 ± 4.9 b	5.3 ± 0.4 a	7.2 ± 1.7 b	6.8 ± 0.3 b	9.2 ± 0.5 b	462 ± 26 a	13.1 ± 2.5 b	4.35 ± 0.27 b			
IR 74 125 days	Insecticide Protected [2]	5.4 ± 1.7 a	0.5 ± 0.4 a	1.6 ± 0.5 a	1.4 ± 0.2 a	1.0 ± 0.4 a	532 ± 37 b	20.6 ± 4.2 a	5.23 ± 0.55 a	4.0	0.21	ns
	Untreated	25.7 ± 5.3 b	6.3 ± 0.2 a	5.2 ± 0.7 a	7.5 ± 0.3 b	7.5 ± 0.3 b	520 ± 31 b	16.7 ± 3.6 a	5.02 ± 0.61 a			
	P	0.02	0.01	0.004	0.04	0.02	0.04	0.03	0.03			
	df	9	9	9	9	9	9	9	9			
	F	4.72	4.89	5.12	6.54	4.44	3.15	4.72	4.91			

[1] Average of four replications on farmer's fields in 100 m2 plots. In a column, means ± SE followed by a different letter are significantly different ($P \le 0.05$) by LSD test
PI = panicle initiation stage. Plots sown to each variety were transplanted on the same date in a randomized complete block design.
[2] Vegetative stage - 0.5 kg ai isofenophos seed dressing (SD) root soak/ha and 0.75 kg ai monocrotophos EC/ha weekly beginning 15 days after transplanting (DT); reproductive stage 0.75 kg ai chloropyrifos + BPMC EC/ha, weekly from 35 DT; ripening stage - 0.75 kg ai monocroptophos EC/ha milk, soft, and hard dough stages
[3] Yield loss is the difference in yield between insecticide protected and untreated treatments

linear. AT 0 kg N/ha the AIC value was 5.7 for quadratic and -13.3 for linear. For both rates the lower AIC values indicated best fit.

In two trials in Guimba, conducted in consecutive seasons, stemborer incidence was artificially augmented by placing egg masses in field plots under three fertility regimes to measure the effect of N rate on stemborer incidence and yield. As the level of N increased from 0-122 kg/ha in the wet season, so did whitehead incidence (4.2-9.8%) but also yield 4.16-5.56 t/ha, both significantly (Table 2). The researchers' practice of 70 kg N/ha attained an intermediate yield level (4.98 t/ha), significantly higher than the untreated but significantly less than the highest N level. Yield increase occurred despite the higher stemborer pressure from both increased panicle density (from 387-538 panicles/m^2) and filled grains per panicle (from 14.7-24.3 grains/panicle). Both of these yield components led to the increased production at the highest N rate despite the increased whitehead density.

In the dry season crop, both the intermediate and high N level of 80 and 120 kg/ha significantly out-yielded the 0 kg/ha treatment 5.16-5.22 t/ha compared to 3.70 t/ha. Whitehead incidence increased from 2.1-5.6% with increasing N, but panicle density also increased from 414-581/m^2, as did the number of filled grains per panicle from a low of 12.4 to a high of 22.6. In only the dry season trial did the researchers' N practice yield similarly to the farmers' much higher N level.

Interaction of Nitrogen Rate and Crop Maturity on Yield Loss

In a dry season trial in Zaragoza, yield loss from insect pest pressure was compared over two varieties of different maturities and four N rates (Table 3). Moderate damage levels were exhibited by the combined feeding of whorl maggot and defoliators that increased in both varieties with N rates: 15.9-27.4% in IR58 and 13.4-29.6% in IR70. The late planting also ensured relatively high infestation levels for stemborer both in the reproductive (deadhearts) and ripening (whiteheads) stages. Deadhearts showed a positive response with N rates in the longer maturing IR70 (4.3-7.7%) whereas there was no significant increase in IR58. Whiteheads, however, significantly increased with N rates in both varieties (6.3-9.1% in IR58 and 5.5-10.1% in IR70).

Overall, yields at each level of N were higher with IR70 than at IR58, despite the fact that yields progressively rose in both varieties with increasing N rates (Table 3). IR58 resulted in significant yield losses (ranging from 18-23%) at all four N levels. With IR70, there were only significant losses at the two lowest N rates (0 and 30 kg/ha). At 60 and 90 kg/ha, losses were < 3%. Even at 0 kg N/ha, however, loss was only 9%. Under insecticide protection, IR70

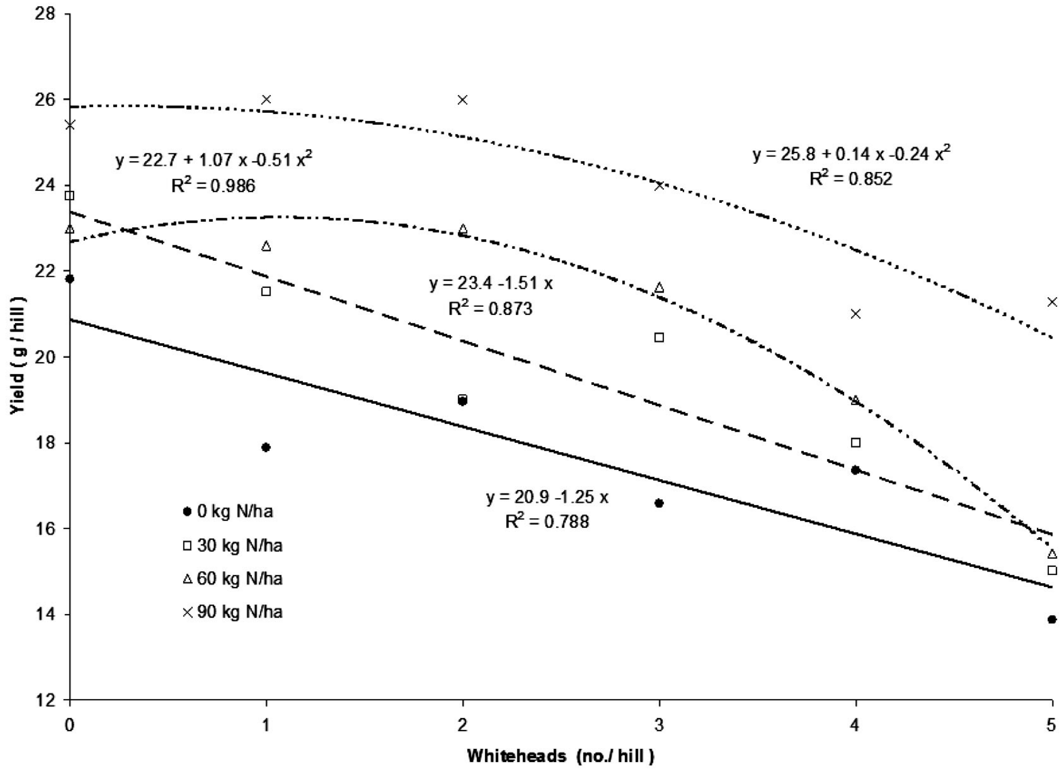

Figure 1. Stemborer damage functions as influenced by four rates of nitrogen fertilizer on IR74 irrigated rice, Zaragoza, Nueva Ecija, 1989 dry season.

Table 2. Effect of nitrogen fertilizer rates on crop yield and stemborer incidence on irrigated IR64 transplanted rice, Guimba, Nueva Ecija, 1991 wet season and 1992 dry season.

Nitrogen Treatment	N(kg/ha)	Whiteheads (%)	Panicles (no./m^2)	Filled grains (no./panicle)	Yield (t/ha)
Wet season 2/					
Untreated	0	4.2 ± 1.2 c	387 ± 8.7 b	14.7 ± 3.6 b	4.16 ± 0.19 c
Researchers' practice	70	6.1 ± 0.5 b	426 ± 17.9 ab	17.3 ± 5.2 b	4.98 ± 0.15 b
Farmer's practice	122	9.8 ± 0.5 a	538 ± 18.1 a	24.3 ± 4.8 a	5.56 ± 0.18 a
P		0.03	0.04	0.03	0.0002
F		2.35	3.60	4.38	7.76
df		10	10	10	10
Dry season 3/					
Untreated	0	2.1 ± 0.6 b	414 ± 19.2 c	12.4 ± 3.8 b	3.70 ± 0.16 b
Researchers' practice	80	5.8 ± 1.1 a	516 ± 7.9 b	22.6 ± 5.0 a	5.16 ± 0.18 a
Farmer's practice	150	5.6 ± 0.9 a	581 ± 11.9 a	21.1 ± 6.2 a	5.22 ± 0.27 a
P		0.04	0.04	0.04	0.0002
F		4.20	4.57	4.05	7.76
df		10	10	10	10

1/ Trials replicated six times in 50 m2 plots conducted on one farmer's field each season and stemborer incidence was artificially augmented by placing egg masses in the plots.
With each trial in a column, means ± SE followed by a different letter are significantly different ($P \leq 0.05$) by LSD test.
2/ Researchers' N level was split equally between a basal application and one 7 days before panicle initiation, while the farmer's was split equally at 2 and 5 weeks after transplanting (WAT)
3/ Researchers' N level was split equally between a basal application and one 7 days before panicle initiation, while the farmer's was split 37 kg/ha 4 WAT, 70 kg/ha 5 WAT, and 43 kg/ha 7 WAT.

Table 3. Interaction between two varieties differing in maturity and N rates on yield loss of irrigated transplanted rice, Zaragoza, Nueva Ecija, 1991 dry season. [1]

Variety/Days to maturity	N kg / ha [2]	Whorl maggot + defoliators (% damaged leaves 35 DT)	Stemborer		Insecticide protected [3]			Untreated			Yield loss (A-B)		
			Deadhearts (% at PI)	Whiteheads (% 10 days before harvest)	Panicles (no. /m^2)	Filled grains (no. /panicle)	Yield(t/ha) (A)	Panicles (no. /m^2)	Filled grains (no. /panicle)	Yield (t/ha) (B)	%	t/ha	P
IR58 90 days	0	15.9 ± 3.5 b	3.2 ± 0.1 b	6.3 ± 2.7 b	355 ± 10.8 b	13.8 ± 4.5 b	4.5 ± 0.72 d	381 ± 9.5 b	11.3 ± 4.3 b	3.13 ± 0.42 d	22.7	0.92	< 0.0001
	30	18.4 ± 3.6 b	2.8 ± 21.8 b	5.6 ± 3.4 b	477 ± 13.9 b	14.1 ± 3.6 b	4.38 ± 0.51 cd	422 ± 8.8 b	14.7 ± 3.6 ab	3.45 ± 0.25 cd	21.2	0.93	< 0.0001
	60	23.7 ± 6.2 ab	4.5 ± 2.1 b	7.4 ± 3.2 ab	486 ± 17.9 ab	15.5 ± 6.7 b	4.64 ± 0.27 b	416 ± 11.9 b	12.9 ± 6.6 b	3.78 ± 0.43 c	18.5	0.86	< 0.0001
	90	27.4 ± 6.8 a	5.5 ± 3.0 ab	9.1 ± 4.4 a	521 ± 16.6 ab	17.6 ± 5.2 ab	5.08 ± 0.79 b	475 ± 15.5 ab	14.8 ± 6.0 ab	4.19 ± 0.29 bc	17.5	0.89	< 0.0001
IR70 135 days	0	13.4 ± 4.1 b	4.3 ± 2.1 b	5.5 ± 2.9 b	499 ± 21.5 ab	15.2 ± 6.4 b	4.57 ± 0.51 bc	424 ± 13.5 b	13.6 ± 5.8 b	4.18 ± 0.21 bc	8.5	0.39	0.004
	30	16.7 ± 3.9 b	5.3 ± 3.3 ab	6.7 ± 3.4 ab	511 ± 17.9 ab	14.7 ± 6.8 b	4.74 ± 0.48 b	478 ± 17.9 ab	17.0 ± 7.1 ab	4.38 ± 0.48 b	7.6	0.36	0.02
	60	20.9 ± 5.2 ab	6.2 ± 3.0 ab	8.4 ± 4.0 ab	552 ± 19.5 a	19.3 ± 5.2 a	5.41 ± 0.38 a	527 ± 15.9 a	19.0 ± 5.5 a	5.27 ± 0.29 a	2.6	0.14	ns
	90	29.6 ± 7.3 a	7.7 ± 4.1 a	10.1 ± 3.8 a	560 ± 22.3 a	21.3 ± 5.3 a	5.65 ± 0.41 a	560 ± 17.8 a	20.0 ± 6.1 a	5.53 ± 0.31 a	2.1	0.12	ns
	P	0.02	0.01	0.03	0.01	0.03	< 0.0001	0.006	0.004	< 0.0001			
	df	21	21	21	21	21	21	21	21	21			
	F	4.26	4.89	3.67	4.54	3.67	5.77	5.01	4.99	5.43			

[1]/ Average of four replications on farmer's fields in 100 m^2 plots. In a column, means ± SE followed by a different letter are significantly different ($P \leq 0.05$) by LSD test
PI = panicle initiation stage. 100 m2 plots sown to each variety were transplanted on the same date in a randomized complete block design.
[2]/ Applied as urea in two splits of equal rates - the first basally (soil incorporated before transplanting) and the second 7 days before panicle initiation, 30 kg P/ha was applied basally to all treatments days before panicle initiation , 30 kg P/ha was applied basally to all treatments.
[3]/ See Table 1 for insecticides used

showed a significant level of compensation regarding panicle density (424-560 panicles/m^2 in IR70) between 0 and 90 kg N/ha as well as with the number of grains per panicle (15.2-21.3). Both of these yield components in IR58 showed no significant change with regard to N rate. In the untreated condition, there was no significant increase in either yield component in IR58 with increased N, whereas both components increased in IR70 indicating compensation. Panicle density significantly increased from 424-560 panicles/m^2 and grains per panicle significantly increased from 13.6-20.2 grains/panicle in IR70.

In a similar trial in Koronadal with a different pair of varieties, there was a significant increase in whiteheads (4.2-9.5%) and leaffolder damaged flag leaves (8.6-18.8%) in IR58 as the N rate increased from 0-90 kg/ha (Table 4). With the medium maturing IR74, whorl maggot/defoliators increased from 11.6-19.9% damaged leaves, whereas leaffolders increased from 7.7-20.5% damaged flag leaves. The early maturing IR60 registered significant yield losses (9.4-15.0%) at the three N rates. With the longer maturing IR74, significant loss (9.4%) only occurred without applied N. No losses were recorded at 45 and 90 kg N/ha on the 125-d variety. At each level of N, yield was higher in the longer than shorter maturing variety without insecticide protection. Yield compensation only occurred at the two highest N levels in only IR74. Panicle density in IR58 significantly increased from 410-516 panicles/m^2 and filled grains from 13.0-17.1 grains/panicle with increasing N. Yield components likewise increased with N rate in IR74: panicle density from 478-563 panicles/m^2 and filled grains from 13.3-21.8 grains/panicles. Thus compensation occurred as a result of both higher tiller densities and more filled grains.

Influence of Seedling Density on Stemborer Damage Function

Stemborer damage functions were compared in a Zaragoza dry season crop at three different densities: 3, 6, and 12 seedlings per hill. The regression equations for the two highest densities, 6 ($P < 0.001$, $F = 31.22$, df = 23) and 12 ($P = 0.0001$, $F = 27.70$, df = 23) seedlings per hill, followed the quadratic model with increasing stemborer whitehead densities from 0-7 per hill on IR74 indicating compensation occurred (Figure 2). For six seedlings the AIC values for linear and quadratic regression models were -2.2 and -8.0, respectively, thus the quadratic was indicated. Those for twelve seedlings were 9.7 for linear and 5.4 for quadratic, again favoring the quadratic model. At the lowest density of 3 seedlings per hill, the regression was linear ($P = 0.003$, $F = 11.56$, df = 23) indicating no compensation. The AIC values for linear and quadratic models were -0.1 and 5.4, respectively, thus the linear is model is indicated. At the two highest seedling densities, compensation occurred up to 2 whiteheads/hill (about 11%

Table 4. Interaction between two varieties differing in maturity and two N rates on yield loss of irrigated transplanted rice, Koronadal, South Cotabato, 1991 wet season

					Insecticide protected			Untreated			Yield loss (A-B)		
Variety/days to maturity	N kg / ha 2/	Whorl maggot + defoliators (% damaged leaves 35 DT)	Whiteheads (% 10 days before harvest)	Leaffolder (% damaged flag leaves)	Panicles (no. /m^2)	Filled grains (no. /panicle)	Yield (t/ha) (A)	Panicles (no. /m^2)	Filled grains (no. /panicle)	Yield (t/ha) (B)	%	t/ha	P
IR 60 109 days	0	15.8 ± 4.6 ab	4.5 ± 2.7 b	8.6 ± 3.1 c	475 ± 12.5 ab	14.6 ± 5.8 b	4.53 ± 0.35 c	410 ± 9.9 c	13.0 ± 7.8 c	3.85 ± 0.10 d	15.0	0.68	0.02
	45	20.4 ± 5.6 a	6.8 ± 3.3 ab	12.4 ± 5.3 b	533 ± 15.5 a	18.9 ± 7.3 a	5.24 ± 0.60 b	466 ± 16.1 b	14.6 ± 5.2 bc	4.63 ± 0.38 c	11.6	0.61	< 0.0001
	90	22.6 ± 7.6 a	9.2 ± 2.9 a	18.8 ± 4.8 a	536 ± 18.8 a	16.1 ± 6.0 ab	5.75 ± 0.48 a	516 ± 22.2 b	17.1 ± 5.8 b	5.21 ± 0.59 a	9.4	0.54	0.02
IR 74 125 days	0	11.6 ± 4.7 b	4.0 ± 3.2 ab	7.7 ± 2.9 c	488 ± 21.3 ab	15.0 ± 4.8 b	4.78 ± 0.21 c	478 ± 14.4 b	13.3 ± 5.3 c	4.35 ± 0.19 c	9.0	0.43	0.03
	45	14.7 ± 7.3 ab	8.6 ± 3.5 a	14.0 ± 6.2 b	543 ± 22.3 a	17.7 ± 4.8 ab	5.20 ± 0.43 b	490 ± 14.7 b	20.6 ± 6.1 a	5.64 ± 0.35 a	-8.7	-0.45	ns
	90	19.9 ± 4.9 a	10.1 ± 5.5 a	20.5 ± 5.5 a	537 ± 24.3 a	19.3 ± 5.2 a	5.66 ± 0.56 a	563 ± 28.9 a	21.8 ± 8.5 a	5.76 ± 0.52 a	-1.7	-0.1	ns
	P	0.003	0.002	0.006	0.03	0.04	0.001	0.02	0.003	< 0.0001			
	df	15	15	15	15	15	15	15	15	15			
	F	4.32	3.99	3.78	4.31	3.97	5.68	4.63	3.89	5.02			

1/ Average of four replications on farmer's fields in 100 m^2 plots. In a column, means ± SE followed by a different letter are significantly different (P ≤ 0.05) by LSD test
PI = panicle initiation stage. 100 m2 plots sown to each variety were transplanted on the same date in a randomized complete block design.
2/ Applied as urea in two splits of half basally (incorporated in the soil before transplanting) and half 7 days before panicle initiation, 30 kg P/ha was applied basally to all treatments
3/ See Table 1 for insecticides used

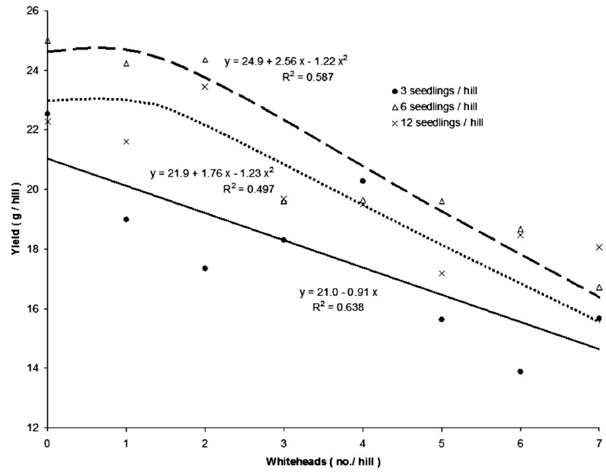

Figure 2. Stemborer damage functions as influenced by three seeding rates on IR74 irrigated rice, Zaragoza, Nueva Ecija, 1989 dry season.

whiteheads), but thereafter declined in a linear fashion. At three seedlings per hill, no compensation was noted as yields began declining at 1 whitehead/hill (about 8% whiteheads). At the end of the scale, five whiteheads/hill translates to 33% whiteheads. Overall yield was significantly highest (P = 0.03, F = 4.80, df = 23) at 6 seedlings/hill, more than 3 or 12 seedlings/hill.

Regression analysis of the same dataset showed significant increase in tiller density with increasing whitehead pressure in all three seeding rates (Figure 3). There was a significant difference in total numbers of tillers based on seedling density with the lowest at 17.5 ± 0.21 with 3 seedlings/hill followed by 21.2 ± 0.46 with 6 seedlings, and 23.1 ± 0.40 with 12 seedlings (P < 0.0001, F = 56.44, df = 23). Significant linear regressions of each of the treatments showed an increasing number of tillers with higher whitehead damage levels. The statistics were: (P = 0.01, F = 12.02, df = 7), (P = 0.01, F = 11.67, df = 7), and (P = 0.003, F = 22.92, df = 7) for 3, 6, and 12 seedlings/hill, respectively. The slopes were steeper at the 6 and 12 seedlings/hill, showing greater compensation.

Interaction of Seedling Density and Variety on Yield Loss

In the Koronadal wet season crop, yield loss from insect pest pressure at two plant densities, 3 and 9 seedlings/hill, was compared in two varieties of differing maturation. Insect pest densities were insignificantly affected by seedling density (Table 5). The vegetative stage registered relatively high damage levels from whorl maggot/defoliators (14.7-21.9% damaged leaves), while deadhearts ranged from 4.6-8.0%. Whiteheads ranged from 7.7-9.0%, which is a moderate infestation level. When protected with insecticide, there was no difference in yield between both varieties at either seedling density.

Table 5. Interaction between two varieties differing in maturity and two seedling densities on yield loss of irrigated transplanted rice, Koronadal, South Cotabato, 1991 wet season [1]/

Variety/days to maturity	No. seedlings/hill [2]/	Whorl maggot + defoliators (% damaged leaves 35 DT)	Stemborer: Deadhearts (% at 35 DT)	Stemborer: Whiteheads (% 10 days before harvest)	Insecticide protected [3]/: Panicles (no. /m^2)	Insecticide protected: Filled grains (no. /panicle)	Insecticide protected: Yield (t/ha) (A)	Untreated: Panicles (no. /m^2)	Untreated: Filled grains (no. /panicle)	Untreated: Yield (t/ha) (B)	Yield loss (A-B): %	Yield loss (A-B): t/ha	Yield loss (A-B): P
IR 60 109 days	3	14.7 ± 3.8 a	7.2 ± 3.2 a	9.9 ± 3.2 a	566 ± 24.5 a	16.5 ± 74.9 a	5.99 ± 0.66 a	475 ± 32.2 b	15.0 ± 4.8 a	4.80 ± 0.45 c	19.9	1.19	< 0.0001
	9	19.3 ± 5.0 a	5.0 ± 1.8 a	8.6 ± 5.3 a	552 ± 19.5 a	15.4 ± 3.1 a	5.41 ± 0.98 a	523 ± 32.4 ab	16.3 ± 6.8 a	5.05 ± 0.51 b	6.7	0.36	ns
IR 74 125 days	3	21.9 ± 5.8 a	4.6 ± 2.1 a	7.5 ± 4.1 b	505 ± 26.8 a	16.3 ± 5.6 a	5.52 ± 0.48 a	567 ± 29.0 a	15.8 ± 7.4 a	5.78 ± 0.31 a	-4.7	-0.26	ns
	9	18.6 ± 4.6 a	8.3 ± 4.3 a	6.9 ± 2.9 a	537 ± 24.3 a	15.1 ± 4.6 a	5.74 ± 0.33 a	552 ± 31.5 a	17.2 ± 6.5 a	5.73 ± 0.39 a	0	-0.1	ns
	P	ns	ns	ns	ns	ns	ns	ns	ns	< 0.0001			
	df	21	21	21	21	21	21	21	21	21			
	F	2.21	2.01	1.46	1.56	1.99	2.53	3.71	2.09	4.78			

[1]/ Average of eight replications in a randomized complete block design with a plot size of 50 m^2. In a column, means ± SE followed by a different letter are significantly different ($P \leq 0.05$) by LSD test
[2]/ 20 x 20 cm spacing between hills on a square, inorganic fertilizer applied at 40-30-0 kg NPK/ha
[3]/ See Table 1 for insecticides used

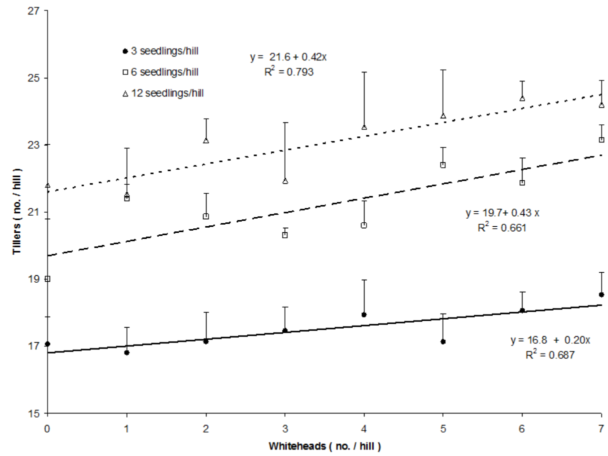

Figure 3. Effect of stemborer damage on rice tillering as affected by three seeding rates on IR74 irrigated rice, Zaragoza, Nueva Ecija, 1989 dry season.

However without protection, the longer maturing variety out-yielded (5.73-5.78 t/ha) the shorter one (4.80-5.05 t/ha) with the lower plant density registering significantly lower. In terms of yield loss, the early variety IR60 recorded a 19.9% loss at the lower plant density, whereas loss was insignificant (6.7%) at the 9 seedlings/hill. With a longer maturing variety IR74, neither seedling density resulted in a significant yield loss.

With insecticide protection, the two yield components showed no effect of seedling density for either variety. IR60 ranged from 552-556 panicles/m^2, while grains per panicle ranged from 15.4-16.5. IR74 ranged from 505-537 panicles/m^2 and grains per panicle from 15.1-16.3. Without insecticide, however, IR60 registered a significantly lower panicle density at the lower seedling rate 475 panicles/m^2 compared to 523 panicles/m^2 at 9 seedlings per hill. But with IR74, there was no difference in panicle density (552-567 panicles/m^2) and grains per panicle (15.8-17.2 grains/panicle) when unprotected. The lower yield in IR60 at 3 seedlings/hill was attributed to a lower tiller density.

Interaction of Seedling Age and Variety on Yield Loss

In Koronadal, a final trial compared the yield loss from insect pest damage in two varieties differing in maturity, each sown with different seedling ages, 20- and 30-d-old. Insect pest infestation was moderate, and was not affected by seedling age (Table 6). Whorl maggot/defoliators ranged from 10.3-15.9% damaged leaves, while stemborer deadhearts in the reproductive stage ranged from 4.8-6.4%. Whiteheads were relatively moderate ranging from 5.8-9.0%. In the insecticide protected plots, highest yield (5.02 t/ha) occurred in the longer maturing IR74 at the younger seedling age while lower yield was in the early maturing IR60 sown with older seedlings (4.08 t/ha). A

Table 6. Interaction between two varieties differing in maturity and two seedling ages at transplanting with and without insecticide protection on irrigated double crop rice, Koronadal, South Cotabato, 1992 dry season [1]

Variety/days to maturity	seedlings (age (d) [2])	Whorl maggot + defoliators (% damaged leaves 35 DT)	Stemborer: Deadhearts (% at 35 DT)	Stemborer: Whiteheads (% 10 days before harvest)	Insecticide protected [3]: Panicles (no. /m^2)	Insecticide protected [3]: Filled grains (no. /panicle)	Insecticide protected [3]: Yield (t/ha) (A)	Untreated: Panicles (no. /m^2)	Untreated: Filled grains (no. /panicle)	Untreated: Yield (t/ha) (B)	Yield loss (A-B): %	Yield loss (A-B): t/ha	Yield loss (A-B): P
IR 60 109 days	20	10.3 ± 2.8 a	5.3 ± 3.9 a	5.8 ± 2.2 a	523 ± 19.7 a	14.7 ± 5.1 a	4.45 ± 0.37 b	488 ± 14.7 a	13.8 ± 6.3 a	4.20 ± 0.41 b	5.6	0.25	ns
	30	15.9 ± 3.7 a	6.4 ± 3.3 a	7.3 ± 2.9 a	485 ± 23.4 a	16.3 ± 8.3 a	4.08 ± 0.42 c	402 ± 7.4 b	14.4 ± 4.2 a	3.37 ± 0.38 c	17.4	0.71	< 0.0001
IR 74 125 days	20	14.24 ± 3.0 a	5.5 ± 3.8 a	9.0 ± 3.2 a	544 ± 23.4 a	16.9 ± 5.8 a	5.02 ± 0.37 a	501 ± 28.5 a	15.7 ± 4.9 a	4.87 ± 0.22 a	3.0	0.15	ns
	30	16.2 ± 4.6 a	4.8 ± 3.4 a	7.9 ± 3.5 a	476 ± 28.4 a	15.9 ± 5.2 a	4.67 ± 0.29 ab	445 ± 13.0 a	13.9 ± 4.7 a	4.55 ± 0.41 ab	2.6	0.12	ns
	P	ns	ns	ns	ns	ns	ns	ns	ns	< 0.01			
	df	21	21	21	21	21	21	21	21	21			
	F	2.25	2.01	1.46	1.99	2.23	4.05	5.43	2.05	5.55			

[1] Average of 8 replications per trial by variety with 50 m^2 plots in a random complete block design. Within each variety, means ± SE followed by a different letter are significantly different ($P \leq 0.05$) by LSD test
[2] Sowing of the wetbed seedling nurseries was staggered so that transplanting was carried out on the same day for both seedling ages. Inorganic fertilizer at 40-30-0 kg NPK/ha
[3] See Table 1 for insecticides used

similar outcome occurred in the unprotected treatments with IR74 sown with 20-d-old seedlings registering 4.87 t/ha while IR60 sown with 30-d-old seedlings yielded only 3.37 t/ha. The highest yield loss (17.4%) was recorded in the IR60 transplanted with older seedlings (30 d), whereas a non-significant loss (5.6%) occurred on 20-d-old seedlings. With IR74 there was an insignificant loss (2.6-3.0%) recorded with either seedling age.

Under insecticide protection there was no significant difference among the two yield components for both varieties. Panicle density for IR60 ranged from 485-523 panicles/m^2 and the number of grains per panicle ranged from 14.7-16.3. Panicle density with IR74 ranged from 476-544 panicles/m^2 and the number of grains per panicle ranged from 15.9-16.9. Without insecticide protection, however, the 30-d-old seedling treatment registered a significantly lower panicle density (402 compared to 488 panicles/m^2). The number of grains per panicle was not significantly different (13.8 versus 14.4). With IR74, however, there were no significant differences between panicle density (445-501 panicles/m^2) and the number of grains per panicle (13.9-15.7 grains/panicle). Therefore the lower yield was attributed to lower tillering and not filled grain density.

DISCUSSION

Bardner and Fletcher (1974) noted that, based on trial and error, farmers learned to manipulate planting dates, sowing rates, and other husbandry practices to minimize the effects of expected pest infestation on yield. Filipino farmers appear to be no different. Probably in both cases, however, the farmers would explain they changed their practices because they increased yield rather than because of decreased impact of insect pests. Our study centered on adjusting the levels of four cultural practices in transplanted rice husbandry to determine whether yield compensation occurred. The data showed, in the three different locations where the study took place, that two of these measures (higher N rates and higher seedling densities) strengthened the modern, high-yielding rice varieties' ability to offset losses from insect pest damage. The two other variables (longer maturing varieties and younger seedlings), while not adopted by the majority of farmers, also resulted in significant yield loss compensation. We discuss each of these four cultural variables.

Crop Maturity

Early maturing varieties gained popularity as they save on irrigation water, allow more crops to be grown per year, and generally reduce pest buildup by supporting fewer pest generations. The extensive plant- and leafhopper outbreaks and associated plant diseases on modern rices have been explained as being caused by greater apparency of rice in the landscape through double and triple cropping and a combination of heavy insecticide usage that caused pest resurgence via selective mortality of natural enemies (Gallagher et al. 1994). Loevinsohn et al. (1988) showed that, as the increase of rice insect populations is exponential, reducing crop apparency by organizing farmers to synchronously sow early maturing varieties can significantly reduce insect populations by creating a longer host-free fallow (Litsinger 2008). Van der Goot (1925), in his classic study of the white stemborer in Java, noted exponential buildup of up to seven generations on the long maturing, traditional varieties that often led to crop destruction on a large scale as egg parasitoids were unable to keep pace with host densities. In contrast, only 2-3 stemborer generations can develop on IR58.

Five experiments in this study compared early and late maturing varieties on yield loss (Tables 1, 3-6). In all of these trials, a consistent relationship of greater insect pest loss with earlier crop maturity was evident, even when maturity differed by only 16 d (IR60 versus IR74). The widest difference was between IR58 and IR70, some 45 d. An earlier summary paper that compared many trials over a range of locations, crop cultures, and varieties noted the relationship of maturity with yield loss was linear (Litsinger et al. 1987).

Where maturity was the sole variable and where there was insect pest pressure, a significantly sparser panicle density and a lower percentage of filled grains occurred in the early maturing compared to the longer maturing varieties (Table 1). Plant physiologists have noted that early-duration varieties with their reduced vegetative period require highly favorable growing conditions and management in order to achieve high yields (Yoshida 1981). When sub-optimal environmental conditions prevail, such as from insect pest injury, the crop does not produce sufficient leaf area to support an adequate panicle density or sufficiently high percentage of filled grains to achieve high yields. Plant physiologists also concluded that the highest yields are from varieties that mature in 130-140 d (Yoshida 1981). Longer maturing varieties, one would think, would allow for even higher yields. While it is true that longer growth duration is preferred where yield stability is a goal, yield potential is sacrificed due to excessive vegetative growth and proneness to lodging (Kupkanchanakul and Vergara 1999).

We noted that high yields are possible using early maturing varieties, but they have less scope for compensation against insect pest damage. A physiological limitation of early maturing varieties is the reduced vegetative stage that limits tillering. In order to overcome this limitation, closer spacing is suggested (DeDatta 1981). But our trials were conducted at very dense plantings (20 cm x 20 cm between hills of 8-14 tillers per hill). Determining the optimal maturity period for a variety that would both lessen pest build up as well as augment the crop's ability to compensate calls for a compromise. The results of our trials suggest that medium maturing varieties would be the optimal choice.

Nitrogen Fertilizer

Numerous studies have shown that rice stemborers, planthoppers, and leaffolders dramatically increase with additional applied N (de Kraker et al. 2000, Jahn et al. 2007). With stemborers, tillers also become more susceptible to penetration by first instar larvae as high N causes rapid stem elongation thereby diluting the density of protective silica bodies within rice stem tissue (Bandong and Litsinger 2005). Other effects are increased feeding, augmented fecundity, and greater survivorship (Litsinger 1994).

We noted increases in insect pest abundance with higher N rates for whorl maggot/defoliators, stemborers, and leaffolders (Tables 2-4). Counter intuitively, despite the increased pest abundance and damage, well-fertilized crops in our trials attained higher yields than plots with lower applied N. This same result was noted for dryland rice where a more fertilized crop resulted in greater white grub larval densities, as plants produced roots faster than grub consumption (MacLean et al. 2003). The same strategy is employed by nematologists (Prot et al. 1994). In Table 2 and Figure 3, higher tillering was noticed with increasing stemborer damage that was the result of the combination of increased N usage and reaction to stemborer damage. Ishikura (1967) documented that rice plants injured by stemborers tillered more as a compensatory reaction. The same effect has also been noted with rice gall midge *Orseolia oryzae* (Wood-Mason) (Reddy 1967). Such secondary tillers, however, bear few grains, thus plant energy resources used to make them are basically wasted.

In the rice plant, N application increases average leaf size, number of leaves per shoot, number of shoots per hill, number of grains per panicle, and percentage of filled grains (DeDatta 1981). In our study (Tables 2-4), low N rates led to sparser panicle density and lower percentage of filled grains in the unprotected plots as undernourished plants were less able to compensate. The effective minimal rate to stimulate compensation in Zaragoza was 60-90 kg N/ha (Figure 1) for the wet and dry seasons. In Guimba, there was a significant yield benefit from applying the highest rate in the wet season but not in the dry season (Table 2). Farmers were therefore justified in terms of yield in applying 122 kg N/ha in the wet season, but they run the risk of stimulating plant pathogens such as blast (*Pyricularia oryzae* Cav.) and bacterial blight (*Xanthomonas oryzae* pv. *oryzae* [Ishiyama] Swings et al.) (Ou 1972).

Modern semi-dwarf varieties are all high tillering, a trait derived from the indica race (DeDatta 1981). The tillering rate increases linearly with increasing leaf N content of up to 5% from photosynthetic activity (DeDatta 1981). High tillering capacity gives the crop greater ability to compensate from missing hills that may be caused by poor stand establishment or from pest damage (DeDatta 1981). Applications of N in later growth stages also favor compensation from leaffolder and stemborer damage by delaying leaf senescence (Peng et al. 1996). A second top dressing with additional N to aid in plant recovery from stemborer injury has been a recommended practice in parts of India (Rubia et al. 1996).

Filipino farmers recognize that rice is in a vulnerable condition after N application as they describe tillers as 'being soft' and therefore susceptible to pests (Bandong et al. 2002). Their response is to apply a prophylactic insecticide treatment at the time of the first top dressing of N as protection. The effect of increasing N rates on decreasing yield loss was noted in two field trials in this study when in combination with longer maturing varieties: a 135-d variety in Table 3 and a 125-d variety in Table 4. Therefore this study suggests that the farmers' insecticide application linked to fertilizer use is unnecessary, particularly if farmers are growing medium or long maturing rices.

Plant Density

There was no incentive for farmers growing traditional, low tillering rices to achieve closer spacing as the varieties could not respond to better management (DeDatta 1981). Modern high yielding rices, however, have the capacity to tiller profusely leading to a closed canopy to maximize interception of incident radiation with a result of high yields (Yoshida 1981). Tiller number per unit area in a field is largely a function of plant density. In Figure 3 we see that sowing higher numbers of seedlings per hill resulted in higher tiller densities. Tiller number is positively or negatively correlated with grain yield depending on the rice variety and crop environment (DeDatta 1981). At closer spacing, the yield per plant is low, but this is compensated for by a greater number of plants per unit area. At distances > 35 cm between plants, yields of most varieties are reduced because plant population per unit area is reduced and increased tillering cannot compensate. Sowing higher densities overcomes the problem of low tiller density per area that results from random planting if the farmer does not adopt two-directional row sowing.

Optimum spacing of any variety depends on soil fertility level, varietal characteristics, and prevailing weather, thus there is no single spacing practice best for all varieties (DeDatta 1981). When sown too densely, inter-plant mutual shading causes tillers to die, wasting scarce plant energy. Spaced too widely, even using high tillering rices, means that much of the yield will not be borne by the higher-yielding primary tillers (Yoshida 1981). Many of the same factors that were related to N application also are true of plant density. In Table 5, however, we noted the lowest tiller density in unprotected plots occurred when early maturing rice was sown at a low seedling density while the density of filled grains per panicle was unaffected.

With the exception of stemborers and gall midge, insect pest damage generally reduces tillering, which is an argument to increase plant density to favor crop compensation. Apparently this is what Filipino farmers have learned by trial and error and why they use higher seeding rates than recommended. Those who hire transplanting gangs know that seedling densities will be high, e.g., a mean of 8-14 seedlings/hill in Central Luzon (Fajardo et al. 2000). Gangs transplant quickly and often carelessly, since they are paid by the job, not by the hour. It is quicker to grab a bunch of seedlings than to peel off just 3-4 as recommended. The agronomists that developed the recommendations for seedling density per hill did so in research station fields that were well managed and essentially insect-pest damage free, a condition few farmers can achieve. Seed is relatively inexpensive so the technology of overseeding is widely accepted by farmers, more so on direct seeded rice. However, our data show that a seedling density between 6-9 tillers per hill is most advantageous to obtain optimal yield and compensation. Above 9 seedlings per hill, inter-plant competition becomes intense resulting in yield decline.

Transplanted Seedling Age

Agronomic trials have shown highest tillering capacity and therefore highest yield comes from transplanting 20-d-old seedlings (DeDatta 1981). Studies showed there is an incremental loss in tillering and yield potential for each additional day of delay. Despite the scientific evidence to the contrary, most farmers do not transplant young seedlings. Because young seedlings are thinner, transplanters complain that they are too difficult to handle. Farmers state that pulling young seedlings from their seedbeds, where the roots hold fast, results in plants being torn in half. 30-d-old seedlings are sturdier and can tolerate pulling. But older seedlings recover more slowly from 'transplanting shock', especially if they suffer from excessive root injury during pulling.

Injury to roots limits tillering, promotes stunting, prolongs maturity, and usually reduces grain yield (DeDatta 1981). Rice soils are usually high in clay content and seedbeds at research stations such as IRRI often are heavily tilled giving a consistency of a slurry, while the soils of farmers are plowed and harrowed only twice producing a hard soil. Thus, farmers wait for seedlings to grow larger so they do not rip in half. Our trial in Koronadal, however, showed a distinct yield advantage when transplanting early maturing varieties with 20-d-old seedlings (Table 6). In the unprotected treatment, panicle density was significantly lower with 30-d-old seedlings combined with an early maturing variety. With medium maturing rice, older seedlings fared just as well as younger ones, as the treated and untreated yields of IR74 were statistically equal.

Implications for Pest Management

The first principle of Integrated Pest Management (IPM) for irrigated rice advocated in Farmer Field School training programs is for farmers to 'grow a good crop' by providing the best agronomic management (Matteson, 2000). The implication was that, following this principle would bolster the crop's tolerance against pest damage. Our results support this IPM principle. Filipino farmers have been heavy adopters of modern rice technologies (IRRI 1985), readily embracing varieties of all maturity types and they continually seek the latest ones (Litsinger et al. 2009). Farmers sow varieties of differing maturities in separate fields within a season as a risk avoidance strategy. Tall varieties are located in low-lying areas prone to flooding. Medium maturing rices, including the new true hybrids, are the most popular currently and can achieve sufficient compensation from insect pest loss, more so if combined with other cultural practices that favor compensation. We have shown that longer-maturing rices normally produce higher yields, but as Asia faces a future of irrigation-water scarcity (Gleick 2009), farmers will be forced to sow earlier maturing rices. Guimba farmers, for example, eagerly adopted IR58 because it required fewer irrigations. Our study shows that if farmers select earlier maturing rices then there is a capacity for greater losses to occur from insect pests. On the other hand, early maturing rices allow a greater rice-free fallow which reduces pest buildup, however, those same varietal types probably allowed white stemborer to survive an irrigated, double-rice cropping system (Litsinger et al. 2006). These are trade offs that pest managers must deal with.

This study presents evidence showing why farmers' crop density practices are in variance with national recommendations. Our trials revealed that, if the crop is stressed, such as by insect injury, highest optimal plant densities lie between 6-9 seedlings per hill, not 2-3 as recommended (DeDatta 1981). Also our results showed optimal N rates are about 60-122 kg/ha for the wet season and 60-90 kg/ha in the dry season. Farmers typically apply from 120-150 kg N/ha (Fajardo et al. 2000). In the wet season trial in Guimba (Table 2), it is believed that 122 kg N/ha was higher than optimally needed as IRRI agronomists have done extensive trials in Nueva Ecija and concluded that the optimal N rate is around 90 kg N/ha (DeDatta 1981). Farmers, however, do not perform trials testing different levels of inputs as agronomists do to discover the optimal level for each input and as they achieve high yields with very high N rates, they perpetuate the practice.

For both of these cultural practices, many farmers sow seed and apply N at higher rates than recommended. But as farmers learned that higher rates of these two variables gave higher yields, and with a 'more must be better' attitude, they use levels that jeopardize yield by applying >90 kg N/ha and sowing >9 seedlings/hill. The relationship between plant density or N levels and yield follows a sigmoid function that shows higher input rates actually depress yield (DeDatta 1981). Farmers, because they sow at high densities with early maturing rices probably are achieving higher yields with N rates above 100 kg/ha. Further research should be conducted to test these combinations further.

The age of seedlings for transplanting, however, represents a different situation, as the farmers' practice is not optimal. Farmers rarely transplant young seedlings in Nueva Ecija, although *dapog* culture that employs 10- to 14-d-old seedlings is popular in some locations (DeDatta 1981). We learned the reasons why farmers transplant much older seedlings. But as a result, when seedling roots are severely torn, recovery from 'transplanting shock' takes several weeks (DeDatta 1981). During the recovery period, the injured seedlings are not able to sufficiently compensate from other stresses such as early season pest damage. This has probably contributed to the high yield losses measured in our trials as we followed the farmers' practice of 30-d-old seedlings. Some farmers apply urea to seedbeds so the roots will stay shallow making seedlings easier to pull (Bandong et al. 2002), but this has not meant that they transplant younger seedlings. We recommend that farmers add compost during land preparation of the seedbed to make the clay soil a lighter texture that will reduce root injury during uprooting. Farmers could learn from the system of rice intensification (SRI) scheme of rice culture that is gaining popularity (Stoop et al. 2002). We believe one of the reasons why higher yields occur with SRI is the great care taken to prevent root injury and thus transplanting shock. Recommendations call for 10- to 14-day-old seedlings to be gently uplifted from the seedbed with a trowel to maintain the lump of soil around the roots and then carefully transplanted in a well-tilled field. This practice, although highly labor intensive, leaves the young root systems in tact, eliminating transplanting shock.

This study shows the benefit of testing farmers' practices and compares them with national recommendations. Farming systems research was developed to do just that by being more open minded to the contributions farmers can make in rice technology development (Zandstra et al. 1981). Farmers develop their practices more holistically from trial and error while most researchers use reductionist methods testing one variable at a time holding the others constant (Litsinger et al. 2009). Researchers in turn should validate their recommendations on farmers' fields and encourage feedback from farmers. As we can see from the results, the optimal set of practices is a compromise between both approaches.

Results presented herein call into question the results of yield loss trials and research that determined action thresholds. Results of such trials need to be framed in the context of the cultural practices that were employed in the research trials that were conducted. In future yield loss studies, the cultural practices should be documented and the losses seen in that context. For example, researchers question whether whorl maggot causes economic loss (Litsinger 2009), but as we saw in this study that whorl maggot could be a pest if a certain set of cultural practices were followed and not a pest if the practices differed.

CONCLUSION

This study has revealed four cultural practices that can be employed by farmers as preventative measures to enhance crop tolerance to chronic insect pest damage. These practices are dual-purpose as they engender high yields even in the absence of insect pest pressure. All four of these practices are compatible with one another. Therefore based on our results, we recommend farmers adopt as many of the four cultural insect control practices as possible, each at its optimal level, as a preventative strategy to mitigate loss. Action thresholds should be adjusted accordingly, so that farmers will not apply insecticides against infestation levels that the crop can tolerate.

It should also be noted that the results of this research applies to modern rices and not to traditional rices. As noted in this study, the ability to tiller profusely in response to good crop management gives modern rices a higher capacity to tolerate pest injury. This capacity represents a great deterrent against the chronic pests prevalent in most wetland rice fields and strikes a favorable balance with the genetic resistance in modern rices that deter epidemic pests. Both of these deterrents should greatly reduce the need to use insecticides, sparing natural enemies that will allow even greater pest suppression.

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