Effects of Bund Crops and Insecticide Treatments on Arthropod Diversity and Insect Regulation in Tropical Agricultural Fields

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Abstract- **Ecological engineering using vegetable or flower strips is promoted as a potential pest management strategy in irrigated rice. Farmers in the Philippines often plant rice levees (bunds) with vegetables, particularly string beans (Vigna unguiculata Walpers) to supplement income, but without considering the potential for pest management. This study examines the effects of planted bunds on rice herbivores and their natural enemies. We compared arthropods in (a) rice fields that had string beans planted on bunds, (b) fields without string beans and without any insecticide applications, and (c) fields without string beans but with insecticide treatments (standard practice). Rice yield was similar across all treatments; however, the vegetation strips produced an extra 3.6Kg of fresh string bean pods per meter of bund. There were no apparent increases in major natural enemy groups in fields with string beans compared to fields with conventional bunds. Fields with insecticide treatments had higher damage from leaf folders (Lepidoptera: Pyralidae). The sprayed fields also had lower parasitism of planthopper eggs and fewer predatory dragonflies and damselflies (Odonata). Furthermore, the mortality of plant hopper (Delphacidae: Hemiptera) and stemborer (Pyralidae) eggs by parasitoids and predators was density-dependent only in the unsprayed fields (with and without string beans). Our results demonstrate that planting string beans on rice bunds improves the productivity of rice farms, but our ecological engineering system did not appreciably affect natural enemy or herbivore abundance; however, chemical insecticides adversely affected pest regulatory ecosystem functions leading to higher pest damage.**

Index Terms- **Ecological engineering, egg parasitoids, arthropod sampling, leafhoppers, Philippines, planthoppers, stemborers.**

INTRODUCTION

Ecological engineering for pest management has been proposed as a method to increase the abundance, diversity and function of natural enemies in agricultural habitats thereby enhancing the resilience and sustainability of farming systems. Already, successful ecological engineering systems using interspersion of crops with plants of functional significance for pest management have been developed and are increasingly implemented by farmers: For example, the planting of buckweed, Fagopyrum esculent Moench, as a cover crop in vineyards (Berndt et al. 2006) and Alyssum, Lobularia maritima (L) Desv., between rows of vegetables (Gillespie et al. 2011) are gaining popularity as a means to reduce herbivore damage by providing resources for predators and parasitoids. Since the beginning of the Green Revolution, a number of planthoppers (Delphacidae) and leafhoppers (Cicadellidae) have become problematic for rice farmers in Asia. Outbreaks of the brown plant hopper, Nilaparvata lugens (Stål), and the white backed plant hopper, Sogatella furcifera (Horváth), can occur over thousands of hectares and cause millions of dollars in losses to the rice sector (IRRI 2011). Outbreaks of these two planthoppers have increased markedly throughout Asia since about 2000 (Catindig et al. 2009; Cheng 2009). Furthermore, pest Lepidoptera such as stemborers and leaf folders (Pyralidae) have also increased in recent decades, partly due to the adoption of susceptible rice varieties and increased use of chemical fertilizers, but also due to a reduction in the abundance of natural enemies caused by excessive pesticide use (Bottrell and

Schoenly 2012; Horgan and Crisol 2013). Prompted by these trends, and based on reports of the role of natural enemies in regulating pests, a number of authors have recommended the use of flower and vegetation strips to restore natural enemy populations.

Vegetation, including flowering weeds and grasses, on the raised earthen levees (called ' bunds') that surround rice fields has been shown to provide alternative prey for the natural enemies of rice pests at times when their principal food is scarce. For example Yu et al. (1996) indicated that wild grasses on rice bunds harbor several egg parasitoids including Oligosita sp. (Trichogrammatidae: Hymenoptera) and Anagrus sp. (Mymaridae: Hymenoptera); these developed in the eggs of planthoppers such as Toya spp. and Tagosodes pusanus (Distant), but are also important parasitoids of the rice pest N. lugens. In laboratory studies, Zhu et al. (2013a, 2013b) indicated that several flowering plants can improve the longevity and survival of egg parasitoids such as Anagrus sp. and predators such as Cyrtorhinus lividipennis (Miridae: Hemiptera). In a recent multi-country study by Gurr et al. (2016), planting rice bunds with flower and vegetable strips was associated with an increased abundance of predators and parasitoids of the principal rice pests in each country. Furthermore, Horgan et al. (2016b) reported that vegetable plots in rice fields increased bird activity and provided suitable perches for predators of apple snails, Pomacea canaliculata Lamarck, and caterpillars.

In recent years, several government and international programs have promoted the planting of flower strips on rice bunds as a pest management strategy (Lv et al. 2015; Westphal et al. 2015; Gurr et al. 2016 and references therein). Furthermore, many farmers, particularly land-scarce farmers, traditionally plant bunds with dry crops to gain from water and nutrient seepage into the bunds and to optimize space in their landholdings. Taro, Colocasia esculenta (L.) Schott., and string beans, Vigna unguiculata (L.) Walpers, are among the most commonly planted 'bund crops' in the Philippines (Foronda 2007). Superficially, these planted bunds approach ecological engineering designs for rice (Gurr et al. 2016); however, farmers do not generally adjust their insecticide applications in response to potential benefits from the planted bunds (personal communications with farmers in the Philippines). In the present study, we examine the potential for planting strips of string beans as a pest management approach for irrigated rice fields. In a study conducted at the field-scale, we compared the arthropod communities in fields that had unmanaged but periodically mowed bunds and fields prepared with string bean strips. We also included in the study a set of 'control', standard practice fields where standard rice pest management practices, including insecticide applications, were carried out. The fields were monitored for the diversity and abundance of rice herbivores and some of their key natural enemies using two commonly employed sampling techniques. Furthermore, the effects of habitat and crop management practices on rice crop damage and the regulation of plant hopper and stemborer eggs by natural enemies were examined. We present our results in the light of promoting dry crops on bunds during rice production and discuss how such systems might be improved.

MATERIALS AND METHODS

Study site:

The study was conducted at Rizal Agricultural Station (RAS; 14°34 N, 121°20S, 360 m asl) near the village of Cuyambay, Rizal Province, Philippines. The site, on the northern shores of Laguna de Bay, was located in a mountainous region on the western slopes of the Sierra Madre Mountains. The rice fields at the site were located in a deep valley surrounded by fruit groves and grasslands on lightly undulating hills with regenerating scrub and secondary forest on steeper slopes. The climate at Cuyambay is mild montane; the average temperature over the course of the study (July-December 2013) was 22.7°C and average daily rainfall was 12mm. Because of low rainfall during the dry season months (December-June), the site was best suited for a single wet-season, irrigated rice crop.

Experimental fields and vegetation strips:

The experiment and monitoring was conducted using 15 experimental fields. The fields varied in size and also varied slightly in altitude (3m from highest to lowest fields). Fields were randomly assigned to three categories:

a) Vegetation strips and no insecticide treatments (VS)

b) No-vegetation strips and no insecticide treatments (NI) and
c) Standard station practice (SP).

All fields were planted with rice variety Rc216. The fields with vegetation strips had string beans planted on the bunds and surrounding the entire field. The beans were first planted to PVC trays filled with paddy soil and transplanted to the bunds when the seedlings were beyond the 4-leaf stage, about 1 month prior to rice transplanting. Bamboo stakes were erected on the bunds to support the bean vines. All bunds, including those with vegetation strips, had spontaneous grass and weed growth that was periodically mowed.

Standard practices for wet season rice production were followed at the site. The rice was initially sown to raised seedbeds before manual transplanting in August. Fertilizer was applied at three stages of the rice crop: first as a basal treatment, again during active tillering, and at the time of panicle initiation. The fields were continually flooded with water supplied from a local river and stored in a concrete reservoir. Water was drained from all fields at preharvest. Insecticides were used only at the SP fields as a standard station practice using 4 insecticide applications: 2 applications of Selecron 500 EC (profenofos – organophosphate) and 2 applications of Decis (deltametrin – pyrethroid) at two week intervals beginning at 20 days after transplanting (DAT). The bean plants were manually watered and tended throughout the rice growing season. No pesticides and no fertilizers were applied to the vegetable strips during the experiment. String beans were harvested as fruits matured. All fields were hand-weeded.

MONITORING OF RICE AND VEGETABLE CROPS

The growth and development of the rice crop and vegetation strips was monitored at 30 DAT and again at 60 DAT: Three rice hills per field were randomly sampled (pulled from the mud with roots) from each field. Hills were examined noting the crop stage, number of tillers, and any apparent insect or disease damage. The hills were individually dried in a forced-draught oven at 60°C until a stable weight was attained and then weighed on a precision balance. The string beans were measured (height) and flowers, buds and fruits counted at three randomly selected 1m lengths of bund per field. At harvest, 5 rice areas of 1×1m were randomly sampled for yield at each field. Vegetable yield (wet weight of string bean pods) was recorded at the time the ripe pods were collected.

ARTHROPOD SAMPLING

The rice and bunds at each field were sampled for arthropods at 30 DAT and 60 DAT using two sampling methods. Sweep netting was conducted in each experimental field (N = 5) using standard entomological sweep nets (diameter = 40cm) and with 10 sweeps across the height of the rice crop, at the height of grasses and weeds on the conventional bunds, and at the height of grasses and weeds on the bunds with vegetation strips (this included the lower growing leaves and stems of the bean plants). For the second method a blow-vac suction apparatus was used (Domingo and Schoenly 1998). To enable sampling, a transparent acetate cage (100×60×60cm, H×L×W) was first quickly placed over the vegetation to be sampled (either rice plants or bund vegetation) and covered with a fine mesh cloth to prevent any flying insects from escaping. All arthropods inside the cage were then sucked through the blow-vac into glass vials; these included aquatic organisms that inhabit the flood waters in the rice fields. Each experimental field (N = 5) was sampled once with the blow-vac apparatus at 30 DAT and 60 DAT. All samples (sweepnet and blow-vac) were stored in 90% ethanol and all pest species and recognized natural enemies were identified. Rice pests and natural enemies were determined according to Heinrichs (1994) and Pathak and Khan (1994).

HERBIVORE REGULATION

The potential for regulation of two pest species (N. lugens and the yellow stemborer, Scirpophaga incertulas [Walker]) by egg predators and parasitoids was monitored at 30 DAT. To monitor parasitism of plant hopper eggs, we prepared rice plants (Rc 216) with different densities of N. lugens eggs. Rice plants were transplanted to #3 pots (9.5×12.5cm, H×D) in soil collected from paddy fields with similar fertilizer levels but without any pesticide treatments. The plants had been sown together with rice plants in the paddy fields and were transplanted to the pots at the same time as transplanting in the field. The plants were covered with acetate cages of 40×12cm (H×D) that fitted neatly into the pots. The cages had a mesh top and mesh windows. Gravid female N. lugens were taken from a colony maintained at the International Rice Research Institute (IRRI) and placed on the plants at densities of 1, 3 and 9 females per plant. The planthoppers were allowed to feed and lay eggs for 24 hours after which time they were removed and the plants transported to the field. The plants were set out in each experimental field as a block (with eggs from 1, 3, and 9 females; N = 5) during the early morning and were collected 72 hours later. Plants were returned to the laboratory and the eggs and parasitoids allowed develop for a further 10 days in large glass tubes (25×3cm, H×D) with moistened filter paper. After 10 days, the tubes were examined for parasitoids and the plants dissected to determine the number and fate of unhatched eggs.

To monitor mortality of stemborer eggs, adult female moths were collected from rice fields in the Laguna area around IRRI. The moths were maintained in large acetate cages with 30 day old rice plants for 24 hours and allowed to oviposit on the rice plants. Egg masses were collected from the cage by cutting the leaf tissue behind the masses. These were transferred to the field site when the rice was 60 DAT and attached to rice plants in the experimental fields using double-sided sticky tape. The egg masses were set-out in each field in blocks at densities of 1, 2, 3, 4, and 5 egg masses per rice hill. Because of insufficient numbers of collected egg masses, blocks were replicated in only two fields per treatment (VS, NI and SP: N = 2). Egg masses were set out in the early morning and were collected 72 hours later. The masses were held in individual glass vials until the parasitoids or stemborer larvae emerged. Egg masses were then examined for unhatched eggs and any signs of predation. A number of egg masses were attacked by fungus in the laboratory and were excluded from the study.

DATA ANALYSES

Rice herbivores were assigned to one of eight groups because of low captures during the study. Leafhopper species were grouped as vectors of tungro virus. The planthoppers N. lugens and S. furcifera were examined separately as relatively large numbers were captured during the study. Similarly, natural enemies were grouped into nine groups. The effects of treatment (VS, NI, or SP), habitat (bund or rice field), sampling method (blow-vac or sweepnet) and their interactions on herbivores and predators were examined using univariate repeated general linear models (GLM) for each group, with samples repeated at 30 and 60 DAT. Repeated measures GLM were also used to examine rice growth parameters and insect damage during the study. Parasitism of plant hopper eggs by the main parasitoid species was analyzed using multivariate GLM. Mortality of stemborer eggs and rice yield were examined using univariate GLM. Regression analyses were used to assess density dependence of egg mortality. Data residuals were plotted following all analyses and were normal and homogeneous following relevant transformations. Data transformations are indicated with the results. Analyses were conducted using IBM SPSS Statistic 22.

RESULTS

Rice herbivores and insect damage:

Twenty six herbivore species (sample size = 2021 individuals) regarded as rice ‘pests’ were recorded during the experiment. Planthoppers (N. lugens and S. furcifera) and leafhoppers were the most abundant herbivores. We found no differences in N. lugens abundance according to crop stage (30 or 60 DAT), treatment (VS, NI, or SP) or habitat (bund or rice field); furthermore, captures were not different between sampling methods. There was a significant treatment × habitat interaction because of larger numbers of N. lugens in rice than on the bunds for the NI treatment, but not for VS or SP, and a significant crop stage × treatment × method interaction because more N. lugens were captured in the NI treatment using the blow-vac at 30 DAT. Sogatella furcifera occurred predominantly on rice plants (habitat), but there was also a crop stage × habitat interaction because more individuals occurred in the rice than on the bunds at 30 DAT than at 60 DAT sampling.

Leafhoppers occurred predominantly in the rice crop (habitat) and at 60 DAT. There was a crop stage × method interaction with more leafhoppers occurring in sweepnet samples at 60 DAT but no difference between the two methods at 30 DAT; there was also a habitat × method interaction because more leafhoppers were captured on rice when using the sweepnet, but the difference was not apparent when using the blow-vac method.

All other rice herbivores were more abundant in sweepnet samples. Leaf miners were more abundant at 60 DAT, with differences only apparent from sweepnet samples (crop stage × method interaction). Grasshoppers were more abundant on rice plants than on bund vegetation; however, there were significant treatment × method and treatment × method × habitat interactions because more were found on bunds of VS and NI fields from sweepnet samples. Adult moths were more abundant at 30 DAT based on sweepnet samples, but not blow-vac samples (crop stage × method interaction) and caterpillars were more common on rice plants than on bund vegetation based on sweepnet samples (habitat × method interaction). Furthermore, seed bugs were more abundant at 60 DAT, but only based on sweepnet samples (crop stage × method interaction).

Abundance of predators and parasitoids:

A total of 1241 recognized natural enemies of rice herbivores representing 94 species were recorded during sampling. Overall, treatment (SV, NI or SP) rarely affected predator abundance. The blow-vac and sweepnets differed in their trapping efficiency: More predatory bugs, aquatic bugs, egg parasitoids, crickets and dragonflies/damselflies were recorded from blow-vac samples, more large parasitoids and predatory flies were recorded from sweepnets. There were no differences in the numbers of spiders or ladybeetles from the two sampling methods; however, more Atypena formosana (Oi) and Pardosa psuedoannulata (Boesenberg et Strand) were captured using blow-vac sampling, whereas more Tetragnatha javana Okuma were captured using sweepnets. The mirid predator Cyrtorhinus lividipennis Reuter was more commonly captured using the blow-vac.

Regulation of plant hopper eggs:

Three egg parasitoids attacked exposed N. lugens eggs in the fields. These were Oligosita sp., Anagrus sp. and Gonatocerus sp. Treatment had no effect on the relative proportions of eggs parasitized by each species (Wilk's $\lambda = 0.374$, $F_{8, 16} = 1.272$, $P = 0.323$). Treatment affected the mortality of eggs by Anagrus sp. ($F_{2, 11} = 3.997$, $P = 0.050$), but not by Oligocita ($F_{2, 11} = 0.749$, $P = 0.495$) or Gonatocerus sp. ($F_{2, 11} = 1.043$, $P = 0.0.385$). Fewer eggs were parasitized by Anagrus sp. in the insecticide sprayed fields. Oligosita sp. responded to egg density (per plant) in the VS fields and NI fields, but not in the SP fields Parasitism by Anagrus sp. and Gonatocerus sp. was not density dependent during the experiment.

Regulation of stemborer eggs:

Few parasitoids emerged from the stemborer egg masses during the study. Telenomus rowani (Gahan) (Scelionidae: Hymenoptera) emerged only from a single egg mass However, many of the egg masses showed signs of predation or were otherwise dead (failed to hatch). There was no difference in the mortality of eggs among the treatments ($F_{2, 3} = 0.481$, $P = 0.659$). Egg mortality was density dependent in the fields without insecticides (vegetation strips and no insecticide), although there was a positive trend between egg mass density and egg mortality in the insecticide-treated fields, this was not significant mainly because of lower mortality of eggs at high densities of egg masses.

Rice health and yield:

Rice plants sampled at 30 and 60 DAT had damage from whorl maggot (Hydrellia philippina Ferino), caseworms (Nymphula depunctalis [Guenée] [Pyralidae]), leaf folders (Pyralidae), leaf chewing insects and leaf miners. The numbers of leaves attacked by each (except whorl maggot) increased between 30 and 60 DAT. There was no difference in damage from any insect between pest management treatments; however, leaf folder damage increased significantly between 30 and 60 DAT in insecticide-treated fields, producing a significant crop stage × treatment interaction. The rice crops under each treatment were similar in plant height and weight and the final yields were similar. The fields with vegetation strips produced about 3.6Kg of string beans per meter of bund over the growing season.

DISCUSSION

String beans are one of the main crops grown by farmers on rice bunds: Beans in general are popular among rice farmers because they have high germination success, are relatively robust compared to other dry crops, and their seeds and pods can be stored for some time before being sold at local markets or consumed at home (Barzman and Das 2000; Foronda 2007). In the present study, string beans grew well on the rice bunds and produced over 3.6Kg of fresh pods per meter of bund length as an extra income from the fields. We found little evidence to support the use of string beans in vegetative strips as an ecological engineering approach to pest management; however, we did find some promising trends (e.g., lower leafhopper and white-backed plant hopper abundance in fields with bean strips) to suggest that the system we used could be adapted to enhance potential benefits. Furthermore, it was clear from our results that the insecticide treatments in this study had several negative effects for pest management and that growing beans on bunds may be a method by which farmers could be incentivized to avoid insecticides.

Vegetation strips and the natural enemies of rice pests:

The bean plants that grew on our bunds became tall and structurally diverse, which we predicted could promote the abundance and diversity of certain spiders (Uetz 1991) and other natural enemies. Furthermore, bean plants produce flowers that are attractive to bees and other pollinators and could potentially sustain parasitoids or predators. However, the results from the present study gave no evidence of the strips promoting populations of predators or parasitoids: Fields with planted bunds had similar abundances and diversity of natural enemies compared to unsprayed fields and regulation of plant hopper and stemborer eggs was similar between the unsprayed fields with and without vegetables on the bunds. Only predatory flies were more abundant on bunds, but this was a general trend among the unsprayed fields. This suggests that predatory flies – much like the pest dipterans – used the bund vegetation as a resting site or refuge irrespective of bund management (i.e., with or without vegetation strips). Other predator and parasitoid groups were either unaffected by habitat (bund or open field) or treatment (vegetable strips or conventional bunds), or were more abundant in the open field.

The effects of insecticide treatments:

In the present study, the net effect of spraying rice fields with insecticides was clearly negative. We did not advise the crop managers at the site on application methods, application times or chemical products; but allowed them to conduct their usual, standard practice. In the sprayed fields, we noted a significant increase in leaf folder damage to rice plants, higher densities of planthoppers and leafhoppers at 60 DAT, a concomitant increase in some predatory species (i.e., C. lividipennis), a decline in the abundance of donates, and no effect on resulting rice yield. Insecticides reduced the densities of Anagrus sp and reduced egg parasitism by this species and possibly by Gonatocerus sp. also. Furthermore, even though the densities of Oligosita sp. appeared unaffected by insecticide use , the efficiency of the parasitoid was reduced – this was noted as a lack of response to egg density in insecticide sprayed fields. A similar effect was noted with the mortality of stemborer eggs.

Several studies have reported similar increases in pest damage after insecticide applications to rice. This can be the result of physiological responses to pesticides that induce greater feeding and increased reproductive output. Insecticides may also increase pest densities by eliminating natural enemies. In the present study, the chemical insecticides likely reduced the efficiency of natural enemy responses to spatial variations in herbivore density, but did not appreciably affect natural enemy densities. In previous studies at IRRI, we noted deltametrin (Decis) to also increase leaf folder and stemborer damage to rice (unpublished data). These results indicate that the impact of ecological engineering and other environmentally friendly pest management interventions that include reduced pesticide inputs cannot be adequately determined if they are compared to standard practices that use pesticides: To evaluate the true effect of ecological engineering, or indeed to evaluate any pesticide-free pest management intervention, fields are better compared against unsprayed controls. If we factor in the increased costs of using insecticides, the obvious health risks to insecticide applicators as well as local communities and the contamination of ground waters and soil, then the option to use insecticides proved to be a poor choice at our field site.

CONCLUSION

Rice lends itself well to ecological engineering using habitat manipulations such as flower and vegetation strips. This is because irrigated rice is predominantly grown in small paddy fields surrounded by bunds. Although the principal aim of farmers when planting crops on bunds is for supplementary food production, the choice of bund crops could determine the abundance, diversity and efficiency of natural enemy populations. Although we did not see marked effects of planting bunds with string beans in the present study, we did note slightly lower incidences of white-backed planthoppers and leafhoppers. These observations suggest that improvements to rice bund management (i.e., using different bund crops, or combining bund crops with biocontrol agents) could reduce pest densities in rice fields and promote natural enemy abundance and diversity. The clearest result from this study was, however, the negative effect of the insecticide treatments on pest management. Although the insecticides used in the study did not appreciably deplete natural enemy abundance, they clearly affected predator and parasitoid efficiency. Our results indicate that future production systems that reduce or eliminate pesticides and adapt habitat to support natural pest regulation hold promise for Asian rice farmers and represent a potentially significant step toward sustainable rice production systems.

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