frontiers in Environmental Science

ORIGINAL RESEARCH
published: 31 March 2016
doi: 10.3389/fenvs.2016.00022

Effects of Integrated Pest Management on Pest Damage and Yield Components in a Rice Agro-Ecosystem in the Barisal Region of Bangladesh

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OPEN ACCESS

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Specialty section:
This article was submitted to Agroecology and Land Use Systems, a section of the journal Frontiers in Environmental Science

Received: 16 November 2015
Accepted: 14 March 2016
Published: 31 March 2016

Citation:
Alam MZ, Crump AR, Haque MM, Islam MS, Hossain E, Hasan SB, Hasan SB and Hossain MS (2016) Effects of Integrated Pest Management on Pest Damage and Yield Components in a Rice Agro-Ecosystem in the Barisal Region of Bangladesh. Front. Environ. Sci. 4:22. doi: 10.3389/fenvs.2016.00022

Recently, recognition of negative environmental impacts associated with overuse of pesticides in the agricultural regions of Bangladesh has made it clear that unsustainable pest-control strategies must change. Integrated Pest Management (IPM) was developed for use as a tool in the production of healthy, sustainably grown food. A strategic approach to crop-pest control, IPM aims to minimize pest populations by combining environmentally friendly pest-control methods and economically viable farming practices. This study examined the impact of IPM on insect damage to crop-yield parameters in a rice agro-ecosystem. IPM methods tested were: (1) collection of egg masses; (2) sweeping (using a funnel shaped net to capture insects); (3) perching (installing a branch or pole which serves as a resting place for predatory birds); and (4) Economic Threshold Level (ETL) based insecticide application (The ETL is the point at which the value of the crop destroyed exceeds the cost of controlling the pest). We also examined the effects of prophylactic insecticide application and current management practices on rice yield. Rice-yield indicators included number of healthy tillers, number of hills, central leaf drying (Dead Heart), and grain-less panicles (White Head). For two consecutive years, the lowest percentages of Dead Heart (1.23 and 1.55) and White Head (2.06) were found in the IPM-treated plots. Further, the IPM-treated plots had higher yields (7.3–7.5 ton/ha) compared with the non-IPM treatments (6.28–7.02 ton/ha). The location of the plots appeared to be non-significant for all measured yield components. The effect of treatment on the percentage of Dead Heart, White Head, number of hills, and yield was statistically significant ($p \leq 0.05$). We concluded that IPM is an effective strategy for obtaining high rice yields in sustainable rice agro-ecosystems.

Keywords: rice, Dead Heart, White Head, Integrated Pest Management, pesticide, agro-ecosystem, environment

INTRODUCTION

Integrated Pest Management (IPM) is an effective, environmentally sound approach to pest management (Kabir and Rainis, 2015). It provides for the protection of beneficial insects, as well as prevention of secondary pest outbreaks, pest resurgence, and the spread of disease. IPM strategies aim to protect air, water, and soil resources while meeting specific production objectives (Mangan and Mangan, 1998; National Pesticides Information Center in USA, 2015[1]). IPM combines the use of a variety of pest-control methods in a way that facilitates biological control of pest insects in crops in order to improve economic, public-health, and environmental outcomes. Key components of effective IPM strategies are monitoring of pest populations, recognizing pest-resistant plant varieties, and modifying cultural, mechanical, chemical, and biological controls as needed to achieve production goals (Adams, 1996). Including farmers' traditional agricultural knowledge of insect behavior and life cycles is essential for developing a successful IPM plan (Petit et al., 2003; Roitberg, 2007; Vinatier et al., 2012), as is taking into account their current agricultural practices and experience in a given agro-ecosystem (Rahman, 2012; Craig, 2015).

The focus of IPM is to protect and encourage natural predators of pest insects (Naranjo et al., 2015). Understanding the life cycles and the interactions of pest insects and predators provides the basis for successful design and implementation of an IPM strategy. In addition to taking advantage of predator-prey interactions, IPM often includes the judicious use of pesticides. Organic food systems employ similar methods but limit the use of pesticides produced from "non-natural" or synthetic sources (U.S. Environmental Protection Agency [US-EPA], 2014[2]). Worldwide, chemical pesticides have played a vital role in providing an abundant and inexpensive food source (US-EPA, 2015[3]). Despite an increase in food production, however, the persistent overuse of chemicals has resulted in a number of adverse environmental impacts such as, outbreak of secondary pests, decreasing of beneficial insects and the accumulation of toxins in the food webs (Arora et al., 2014). Continued research and development of sustainable and effective agricultural-pest-management techniques is essential if farmers are going to successfully adopt environmentally friendly pest-management strategies (Pretty and Bharucha, 2015).

As a result of the world's unprecedented population growth, food-production systems are being pushed to maximum efficiency (International Institute for Environment and Development [IIED], 2015[4]). Among the widely cultivated food crops, cereals are recognized as an important component of food security. The Food and Agriculture Organization (FAO)[5] estimates that demand for food will more than double by the year 2050 (2009). To meet this demand, cereal-crop production in developing countries must increase by 40% (Eze and Echezona, 2012). Rice, one of those cereal crops, is a staple food source for more than fifty percent of the world's population (International Rice Research Institute [IRRI], 2006[6]). Rice crops either directly or indirectly sustain 3 billion people (Food and Agriculture Organization Stat. [FAOSTAT], 2012[7]). In 2010, 154 million hectares of rice was cultivated worldwide FAOSTAT, 2012. Asia comprised 137 million hectares, with 48 million hectares harvested in Southeast Asia (FAOSTAT, 2012). In Bangladesh 80 percent of agricultural land is dedicated to rice cultivation (Department of Agriculture Extension in Bangladesh [DAE], 2010[8]).

Two-hundred and sixty-six insect species have been identified in rice ecosystems (DAE, 2011[9]). Of these, 42 species are considered to be pests (Srivastava et al., 2004). Pest insects can be categorized as either minor or major pests. Different pest insects cause severe damage to rice crops at different growth stages. The degree of damage depends on the growing season and environmental conditions (Khaliq et al., 2014). One pest species, Yellow Stem Borer (YSB-*Scirpophaga incertulas;* Lepidoptera Crambidae), is considered to be a major rice pest (Chatterjee and Mondal, 2014). Rice plants damaged by this insect develop unhealthy tillers and hills, Dead Heart (central leaf drying), and White Head (grain-less panicles), all of which affect the overall yield (Satpathi et al., 2012). According to DAE (2011) YSB populations can be reduced through several IPM methods, including: light trapping (placing a light source inside a funnel-shaped trap), hand picking eggs from rice leaves (Leaves with egg masses are removed from plants by hand during tillering and booting stages), sweeping (using a funnel shaped net to capture insects), perching (installing a branch or pole which serves as a resting place for predatory birds), cultivation of insect resistant rice varieties, using bio-agents [releasing predator insects such as Long horned grasshopper *Conocephalus longipennis* (Haan)], applying Economic Threshold Level (ETL) based insecticides (The ETL is the point at which the value of the crop destroyed exceeds the cost of controlling the pest). Most rice farmers currently rely on heavy insecticide applications rather than IPM strategies for pest insect control (Mohiuddin et al., 2009).

We believe the wide-scale adoption of IPM in rice agro-ecosystems could provide a net benefit to farmers. The IPM program used in this study is from the "Farmer Field School" (FFS) model. Continuing farmer education and training play a vital role in advancing IPM practices, and this innovative

[1] National Pesticides Information Center in, U. S. A. (2015). Available online at: http://npic.orst.edu/envir/beneficial/index.html.

[2] USEPA (United States Environmental Protection Agency). (2014). Available online at: http://www.epa.gov/agriculture/tipm.html.

[3] USEPA (United States Environmental Protection Agency).(2015). *Agricultural Pesticides: Management Improvements Needed to Further Promote Integrated Pest Management*. Available online at: http://www.epa.gov/agriculture/tipm.html.

[4] IIED (International Institute for Environment and Development). (2015). *Can Small-Scale Farmers Feed the World ?* Available online at: http://www.iied.org/can-small-scale-farmers-feed-world.

[5] FAO (Food and Agriculture Organization). (2009). *How to Fee the World in 2050*. Available online at: http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf.

[6] IRRI (International Rice Research Institute). (2006). *Bringing Hope, Improving Lives: Strategic Plan 2007–2015*. Manila. 61.

[7] FAOSTAT (Food and Agriculture Organization Stat.). (2012). Available online at: www.faostat.fao.org/.

[8] DAE (Department of Agriculture Extension). (2010). Available online at: http://www.dae.gov.bd/.

[9] DAE (Department of Agriculture Extension). (2011). Available online at: http://www.dae.gov.bd/.

IPM-education program provides training for the identification of beneficial and pest insect species, as well as the recognition of associated impacts on crop yields (Craig, 2015).

For this study our IPM strategy consisted of egg-mass collection, perching, sweeping, and ETL-based insecticide application. Non-IPM treatments consisted of egg-mass collection, perching and sweeping without insecticide application, prophylactic insecticide application only, and current pest-management practices. We studied the effects of IPM and non-IPM strategies on rice-yield components. Our working hypothesis was that fields in which we used IPM strategies would have less crop damage and higher rice yields compared with fields treated with non-IPM strategies.

MATERIALS AND METHODS

Geographical Position and Experimental Site

We chose the Barisal region of Bangladesh for our study. Because of the diversity of rice grown and the consistently high yields, it is one of the most important regions for rice cultivation in Bangladesh. For several decades farmers in this region have been plagued by a number of pest-related issues. These include the emergence of new pest-insect biotypes, pesticide resistance, the absence of predatory insects, and yield reduction (DAE, 2010). Barisal is in southern Bangladesh, and encompasses an area of approximately 3000 square kilometers (**Figure 1**). Our field sites are located at 22°42′00″N 90°22′00″E22.7000°N, 90.3667°E in an agricultural area that comprises approximately 324.41 km^2 (BBS, 2011[10]).

In 2011 an inception meeting was organized with local farmers and the DAE at the DAE offices in Barisal Sadar, Bangladesh. The purpose of this meeting was to determine an appropriate experimental field site and target pest. It was decided that YSB (Yellow Stem Borer) would be designated as the major rice pest for this study. Site selection was based on uniformity of cropland, presence of major rice insects, cultivated rice varieties, transplanting season, and previous pest-management strategies.

Experimental Design

The experiment was conducted during November–March growing season of 2011-12 and 2012-13 at three locations in the Barisal region; (Sardarpara, Uttarsagardi, and Gaptala). At each location we had three replicate plots for each of the 4 treatments, resulting in 36 total plots. Each plot was 100 m^2 with 1.5 m buffer strips. Treatments were as follows; T_1: collection of egg masses, sweeping, and perching; T_2: collection of egg masses, sweeping, perching, and ETL-based insecticide application; T_3: application of prophylactic insecticides; and T_4: standard pest-control strategies currently employed by farmers in the Barisal region (**Table 1**).

Agronomic and IPM Methods

In order to maintain food security, the Bangladesh Rice Research Institute (BRRI) releases many rice cultivars to farmers. Two cultivars, BRRI Dhan 28 and BRRI Dhan 29, are popular in the Barisal region because of their yield performance. We selected BRRI Dhan 29 for our study.

Participating researchers used agronomic practices established by the Bangladesh Rice Research Institute (BRRI). These practices include: soil preparation with a motorized tiller; fertilizer application (250 g urea, 300 g Muriate of Potash (MOP) and 400 g Triple Super Phosphate (TSP)/Decimal or 40 m^2); irrigation; and hand weeding. Nursery-raised rice seedlings were transplanted in the experimental plots with 20 cm × 20 cm spacing. Our study examined common IPM strategies employed in rice agro-ecosystems including egg-mass collection, perching, sweeping, and ETL-based insecticide application. The ETL For YSB, the ETL can be defined as the presence of 2 egg masses or 1–2 moths per m^2, and 5 percent Dead Heart between planting and early tillering. Ten percent of Dead Heart, or 1 moth, or 2 egg masses per m^2 at mid tillering stage also indicates ETL. Between panicle initiation and booting stage, 2 egg masses or 1 moth per m^2 can be considered ETL (Prakash et al., 2014). Timing, frequency, application rate, and insecticide concentration for each treated field are described in **Table 1**.

Description of Pest Control Methods

YSB egg masses are multilayered, densely covered with hairs, and they are usually found on the leaves of rice plants. Leaves with egg masses were removed from plants by hand during tillering and booting stages during field visits in daylight hours. During weekly visits to the field sites, approximately 10 min were spent on egg-mass collection. Time dedicated to collecting egg masses was dependent on the presence and number of observed egg masses.

A sweep net is a funnel-shaped net attached to a long handle that can be swept through the foliage of the rice plants. The net is used to capture adult insects and to "scoop up" larvae and eggs. Sweeping is accomplished by quickly moving the net from side in a shallow figure eight pattern. A person practicing this method walks through the rice field while forcefully sweeping the net through the rice leaves. Sweeping continues for some distance (1–2 passes) before the net is emptied. This technique can be used to determine whether a sufficient number of pest insects are present to justify an ETL-based insecticide application. Sweeping is typically done before flowering. During weekly visits to the field site, approximately 10 min were spent sweeping each plot that required sweeping (based on the number of flying insects observed).

Perching is a treatment in which bamboo poles with branches, or perches, are placed in rice fields. These perches serve as nesting structures for predatory birds. Standard spacing for perching poles is 10 m × 10 m. We installed perching poles in each plot on a horizontal axis with an east–west orientation to lessen damage from prevailing winds. This placement also increased perch visibility for predatory birds. We installed one perch in each plot when perching was a component of the IPM treatment.

Data Collection

At each location we recorded the total number of hills (rice plants) per 10 m^2 and the average number of healthy tillers

[10] BBS (Bangladesh Bureau of Statistics Region Census). (2011). Available online at: http://www.bbs.gov.bd/home.aspx.

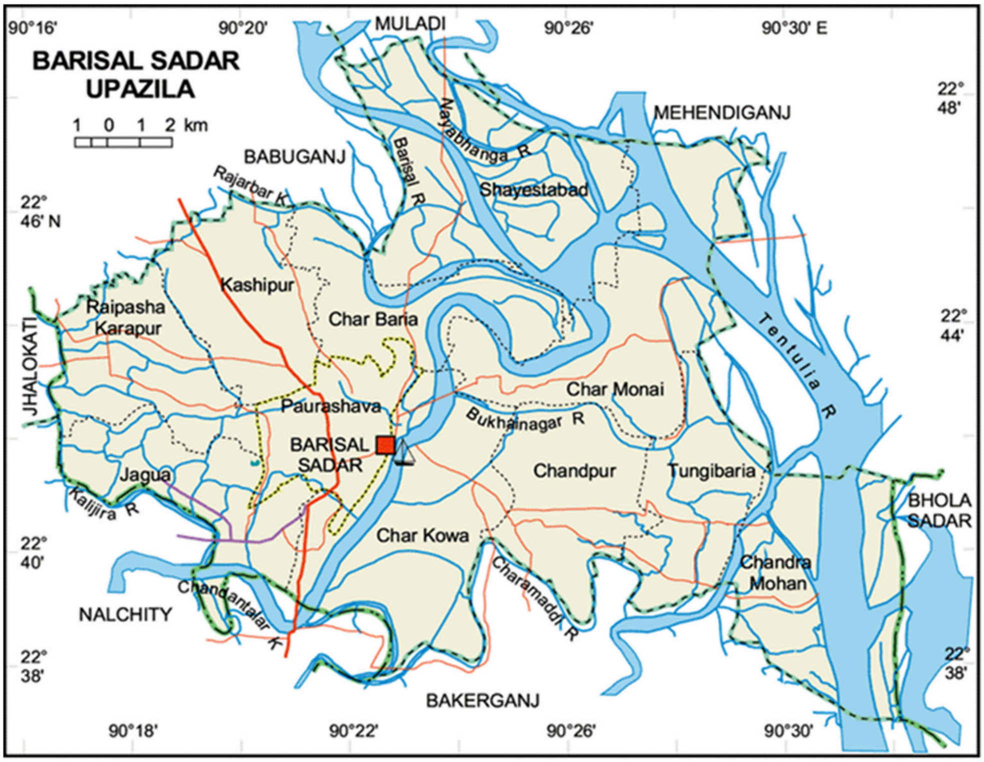

FIGURE 1 | Study area.

TABLE 1 | Description of all field treatments.

Treatments	Details
T_1	Collection of egg masses, sweeping and perching. Egg mass collection and sweeping were done on 7 day intervals.
T_2	Collection of egg masses, sweeping, perching and Economic Threshold Level (ETL) based insecticide application. Collection of egg masses, sweeping, and perching activities were the same as T_1. The application rate of Cartap (Suntap 50SP) insecticides was 1.4 kg/ha (0.14 g/m^2). Insecticide concentration was 0.46 mg/m^2. Insecticide was applied during tillering and booting stage of rice plants. Insecticide was applied on afternoons when the forecast called for low wind speeds.
T_3	Prophylactic insecticide application. We considered ETL at early tillering, mid-tillering, and booting stages of rice plants. During these stages we applied Cartap insecticide a total of three times with an application rate of 0.14 g/m^2. Insecticide concentration was 0.46 mg/m^2. Insecticide was applied on afternoons when the forecast called for low wind speeds.
T_4	Farmer's current practices. Pest control practices consisted of allowing farmers to apply pesticides according to their understanding of appropriate pest management practices. No consideration was given to ETL based insecticide application, egg mass collection, sweeping, insect and plant life stages, or environmental contamination. Insecticide application rate was 1.5 kg/ha (0.15 g/m^2). The concentration of Carrtap insecticide was 0.5 mg/m^2 at early, mid and late tillering and booting stages of rice plants. They did not follow weather forecasts to minimize wind drift.

(each rice plant has approximately 20–30 tillers) during tillering and flowering stages. Measurements were taken from 20 plants that were randomly selected from diagonal transects in each plot. Percentage of Dead Heart during the vegetative stage and White Head through panicle-initiation stage were recorded from each plot. Rice yield (ton/ha) was determined post-harvest (**Tables 2**,**7**).

Data Collection: Environmental Impacts

We interviewed three groups of people who had been living near each field site in 2013. Each group was comprised of 15 people at each location. Several questions were discussed with interviewees, such as the status of IPM in their rice fields and their understanding of major threats to the environment. During the course of the discussion, we noted that several people brought up their experiences with negative environmental impacts that are associated with overuse and/or inappropriate pesticide applications. Information pertaining to environmental degradation was also garnered through discussions with DAE personnel in Bangladesh (Supplementary Material).

TABLE 2 | Effect of location on tillers, hills, dead heart, white head, and yield of rice crops in 2011-12.

Location	Healthy tiller—tillering	Healthy tiller-flowering	Percent of Dead Heart	Percent of White Head	Total no of Hills/10 m^2	Average Yield (ton /ha)
Sarderpara	1.36 (23.16)	1.35 (22.58)	1.32 (1.83)	1.51 (2.32)	2.37 (240.50)	6.89
Uttarsagardi	1.36 (23.33)	1.36 (23.16)	1.37 (1.91)	1.59 (2.56)	2.39 (247.66)	6.95
Gabtala	1.37 (23.66)	1.36 (23.00)	1.40 (2.01)	1.49 (2.25)	2.37 (240.66)	6.89
SE	0.840 (0.450)	0.452 (0.230)	0.233 (0.608)	0.316 (0.971)	0.96 (5.00)	0.115

Values outside parenthesis are the transformed mean values. Numbers in parenthesis are the actual means.

TABLE 3 | Effect of treatment on tillers, hills, dead heart, white head and yield in 2011-12.

Treatments	Healthy tiller—tillering	Healthy tiller-flowering	Percent of Dead Heart	Percent of White Head	Total no of Hills/10 m^2	Average Yield (ton /ha)
T1	1.36 (23.22)	1.34 (22.33)b	1.53 (2.37)a	1.60 (2.60)a	2.41 (258.00)a	7.02b
T2	1.37 (24.00)	1.37 (23.66)a	1.10 (1.23)c	1.42 (2.04)c	2.40 (253.33)a	7.50a
T3	1.34 (22.33)	1.36 (23.00)ab	1.22 (1.52)b	1.56 (2.44)b	2.35 (228.66)b	6.28c
T4	1.37 (24.00)	1.35 (22.66)b	1.59 (2.56)a	1.55 (2.43)b	2.36 (231.77)b	6.83b
SE	0.970 (0.520)	0.522 (0.266)	0.269 (1.25)	0.365 (0.11)	0.11 (5.77)	0.133

Values outside parenthesis are the transformed mean values. Numbers in parenthesis are the actual means. Letters indicate significant differences between treatments on yield components.

Statistical Analysis

The experiment was laid out as a Randomized Complete Block Design (RCBD). Growing seasons were analyzed separately. Location and treatment were considered as independent variables. Dependent variables were: the number of hills, number of tillers at tillering and flowering stages, the percent of Dead Heart and White Head, and crop yields. Data was analyzed using ANOVA with a fixed-effect model to evaluate significant differences ($p \leq 0.05$) between location, treatment, and statistical interactions of treatment and location on yield components for the 2011-12 and 2012-13 growing seasons. Pairwise comparisons were made using Duncan's Multiple Range Test (DMRT) (Crop Stat 7.2, International Rice Research Institute [IRRI], Philippines; M-STAT, Michigan State University (MSU), USA). Count data was log transformed and calculated percentages were square-root transformed. Residuals were normally distributed.

RESULTS

Number of Tillers during Tillering and Flowering Stages

Field location was not significant at tillering or flowering stages for the 2011-12 or 2012-13 growing season (**Tables 2**, **5**). In the 2011-12 growing season the number of healthy tillers at flowering was statistically similar for T_1,T_3,and T_4 treatments. During this growing season, the number of healthy tillers in T_2 was significantly different ($p \leq 0.05$; **Table 3**). In 2012-13 the number of healthy tillers at tillering was similar in the T_1, T_2, and T_4 treated plots, with fewer tillers observed in the T_3 plots (**Table 6**). At flowering the number of healthy tillers in the T_2 treated plots was higher than the T_1,T_3, and T_4 treatments (**Table 6**). There was not a statistical interaction between treatment and field location (**Tables 4**, **7**).

Number of Hills

The effect of field location on the average number of hills/10 m^2 was not significant for the 2011-12 or 2012-13 growing season (**Tables 2**, **5**). For both growing seasons, the number of hills was statistically different ($p \leq 0.05$) between the T_1/T_3 and the T_2 /T_4treatments. In 2011-12 the average number of hills /10 m^2 for the T_1, T_2, T_3, and T_4 treatments was 258, 253, 228, and 231, respectively. Similarly, in 2012-13, the average number of hills was 248, 257, 226, and 224 for T_1, T_2, T_3, and T_4, respectively (**Tables 3**, **6**). The interaction of treatment and field location was not statistically significant (**Tables 4**, **7**).

Dead Heart

The effect of location on Dead Heart percentages was not significant for either growing season (**Tables 2**, **5**). The relationship between the percentage of Dead Heart and treatment was significant ($p \leq 0.05$) for both growing seasons (**Tables 3**, **6**). During both growing seasons, the lowest percentages of Dead Heart (1.23 and 1.55) were found in the T_2treatments, and the highest were observed in the T_4 plots (2.56 and 2.77; **Tables 3**, **6**). For both growing seasons, the percentage of Dead Heart was statistically similar in the T_1 and T_4 plots. The T_1-treated plot was statistically significant ($p \leq 0.05$) compared with the T_2 and T_3treatments in 2011-12 (**Table 3**). In the 2012-13 growing season, Dead Heart percentages were statistically different between T_2 and T_1 treated plots, as well as the T_3 and T_4 treated plots (**Table 6**). The interaction between treatment and location for Dead Heart was statistically significant ($p \leq 0.05$) for both growing seasons. The interaction between T_1 at Sarderpara was significant when compared with T_1 at Gabtala in 2011-12. Similarly, the interaction of treatment and location for T_3 at Sarderpara was significantly different when compared with T_3 at Gabtala in 2012-13 (**Tables 4**, **7**).

TABLE 4 | Interation effect of location and treatment on tillers, hills, dead heart, white head and yield of rice crops in 2011-12.

Treatment	Healthy tiller -tillering stage			Healthy tiller- flowering Stage		
	Sarderpara	Uttarsagardi	Gabtala	Sarderpara	Uttarsagardi	Gabtala
T1	1.35 (23.00)	1.36 (23.00)	1.37 (23.66)	1.34 (22.33)	1.34 (22.33)	1.34 (22.33)
T2	1.35 (22.66)	1.39(24.66)	1.38 (24.66)	1.34 (22.33)	1.39 (24.66)	1.37 (24.00)
T3	1.34 (22.33)	1.35(22.66)	1.34 (22.00)	1.36 (23.00)	1.36 (23.00)	1.36 (23.00)
T4	1.39 (24.66)	1.36(23.00)	1.38 (24.33)	1.35 (22.66)	1.35 (22.66)	1.35 (22.66)
SE		0.168 (0.900)			0.904 (0.461)	
CV		2.1 (6.7)			1.2 (3.5)	
Treatment	**Percent of Dead Heart**			**Percent of White Head**		
	Sarderpara	**Uttarsagardi**	**Gabtala**	**Sarderpara**	**Uttarsagardi**	**Gabtala**
T1	1.49 (2.25)b	1.52 (2.33)ab	1.59 (2.53)a	1.60 (2.58)	1.65 (2.73)	1.57 (2.50)
T2	1.01 (1.03)cd	1.10 (1.23)cd	1.18 (1.43)c	1.40 (2.00)	1.46 (2.16)	1.39 (1.96)
T3	1.10 (1.22)cd	1.32 (1.76)c	1.25 (1.56)c	1.52 (2.33)	1.63 (2.66)	1.52 (2.33)
T4	1.68 (2.83)a	1.52 (2.33)ab	1.59 (2.53)a	1.53 (2.38)	1.64 (2.70)	1.48 (2.21)
SE		0.466 (0.121)			0.633 (0.194)	
CV		5.9 (11)			7.1 (14.1)	
Treatment	**Total no of Hills /10 m^2area**			**Average Yield (ton/ha)**		
	Sarderpara	**Uttarsagardi**	**Gabtala**	**Sarderpara**	**Uttarsagardi**	**Gabtala**
T1	2.41 (261.33)	2.40 (251.33)	2.41 (261.33)	6.96	6.96	7.13
T2	2.38 (243.33)	2.40 (256.66)	2.41 (260.00)	7.46	7.56	7.49
T3	2.33 (218.00)	2.39 (250.00)	2.33 (218.00)	6.19	6.37	6.30
T4	2.37 (239.33)	2.36 (232.66)	2.34 (223.33)	6.97	6.90	6.64
SE		0.193 (10.00)			0.230	
CV		1.4 (7.1)			5.8	

Values outside parenthesis are the transformed mean values. Numbers in parenthesis are the actual means. Letters indicate significant differences for the interaction of location and treatment on yield components.

TABLE 5 | Effect of location on tillers, hills, dead heart, white head and yield of rice crops in 2012-13.

Location	Healthy tiller—tillering	Healthy tiller-flowering	Percent of Dead Heart	Percent of White Head	Total no of Hills/10m^2	Average Yield (ton /ha)
Sarderpara	1.37 (23.58)	1.34 (22.33)	1.47 (2.25)	1.62 (2.66)	2.37 (239.50)	6.79
Uttarsagardi	1.36 (23.08)	1.36 (23.16)	1.47 (2.20)	1.61 (2.62)	2.38 (241.58)	6.82
Gabtala	1.35 (23.00)	1.36 (23.33)	1.52 (2.34)	1.53 (2.36)	2.37 (236.41)	6.74
SE	0.89 (0.463)	0.93 (0.496)	0.311 (0.981)	0.320 (0.982)	0.78 (4.07)	0.113

Values outside parenthesis are the transformed mean values. Numbers in parenthesis are the actual means.

White Head

The effect of location on White Head was not significant for either growing season (**Tables 2**, **5**). Treatment was significant ($p \leq 0.05$) over both growing seasons (**Tables 3**, **6**). For both growing seasons, the percentage of White Head (2.06 and 2.04) was significantly lower for the T_2 treatments compared with the other treatments (2.43–2.94). In 2011-12 the percentages of White Head were similar between T_3 and T_4 and was significantly higher for the T_1 treatment (**Table 3**). This similar result was also observed for the 2012-13 growing season (**Table 6**). The interaction of treatment and location for White Head was not significant (**Tables 4**, **7**).

Yield

For both growing seasons, the effect of location on rice yields was non-significant (**Tables 2**, **5**). The effect of treatment on yield was statistically significant ($p \leq 0.05$) for both growing seasons (**Tables 3**, **6**). For the 2011-2012 growing season, rice

TABLE 6 | Effect of treatment on tillers, hills, dead heart, white head and yield of rice crops in 2012-13.

Treatments	Healthy tiller—tillering	Healthy tiller-flowering	Percent of Dead Heart	Percent of White Head	Total no of Hills/10 m^2	Average Yield (ton /ha)
T1	1.36 (23.33)a	1.34 (22.33)b	1.61 (2.62)a	1.71 (2.94)a	2.39 (248.11)a	6.89b
T2	1.38 (24.55)a	1.39 (24.77)a	1.24 (1.55)b	1.43 (2.06)c	2.41 (257.77)a	7.32a
T3	1.33 (21.55)b	1.34 (22.22)b	1.44 (2.11)b	1.62 (2.64)a	2.35 (226.44)b	6.37cb
T4	1.36 (23.44)a	1.35 (22.44)b	1.66 (2.77)a	1.59 (2.55)ab	2.35 (224.33)b	6.56b
SE	0.103 (0.535)	0.107 (0.573)	0.359 (0.113)	0.369 (0.113)	0.901 (4.70)	0.131

Values outside parenthesis are the transformed mean values. Numbers in parenthesis are the actual means. Letters indicate significant differences between treatments on yield components.

yields were 7.02, 7.50, 6.28, and 6.83 ton/ha in the T_1, T_2, T_3, and T_4 treated plots, respectively. For the same plots in the 2012-2013 season, rice yields were found to be 6.89, 7.32, 6.37, and 6.56 ton/ha, respectively (**Tables 3**, **6**). Statistically higher yields (7.3–7.5 ton/ha) were found in the T_2-treated plots compared with T_1, T_3, and T_4 treated plots (6.28–7.02 ton/ha, respectively) during both growing seasons (**Tables 3**, **6**). The interaction of treatment and location was non-significant (**Tables 4**, **7**).

Negative Impacts

We found that farmers were overly reliant on Cartap insecticides for controlling pest insects in rice agro-ecosystems. According to interviews with community members who work and reside near the study area, as well as DAE personnel, major threats have arisen from the persistent overuse of pesticides. These threats include; lower populations of beneficial insects, outbreaks of secondary pests, high production cost-benefit ratio, noxious odors, rice-yield reduction, and an increased risk of health problems (Supplementary Material).

DISCUSSION

Rice has been cultivated by humans for 5000 years. Through those millennia farmers developed increasingly efficient systems of coping with environmental factors, including pest insects that threatened yields. When modern pesticides became available, they were marketed to farmers as a panacea for eradicating pests, saving labor, and increasing yields. Pesticides, however, came with a cost: environmental degradation and decreased crop resilience. To mitigate some of these negative impacts, IPM was developed as a pest-management strategy designed to blend traditional, knowledge-based pest-control methods and judicious use of pesticides. The goal is to improve yields, increase crop resilience, and end damage to environmental systems associated with overuse of pesticides.

When properly implemented, a pest-management strategy enriches ecosystem services and provides a sustainable food source for a range of beneficial insects (Hillocks and Cooper, 2012). Healthy rice agro-ecosystems support a diverse insect community by maintaining a complex food web (Redfern et al., 2015). The insects participating in this food web can help maintain ecosystem function as long as predator species (insects and others) continue to flourish (Allara et al., 2012). Two hundred and sixty-six insect species have been documented in rice agro-ecosystems (DAE, 2011). Predator insect species account for 64.74% of all insects, with the remainder classified as pest species (Lou et al., 2013). Since pesticides have become available, the number of predator species and populations within surviving predator species have declined. Current non-IPM pest-management strategies often involve over application of pesticides (**Table 1**), which has, in turn, resulted in decreased populations of beneficial insects and increased pest damage to a number of critical crop-yield components (Abrol, 2013). In this study, rice yield was typically higher in the IPM-treated plots as compared with plots treated with pesticides only (**Tables 3**, **6**).

Rice tillers, hills, leaves, panicles, and grains are the most important yield components of rice crops. Reduction in the number of tillers, drying of central leaves (Dead Heart), and damage to the panicles (White Head) are indications of stem-borer infestation often visible in rice fields (Paul, 2007). When stem-borer damage becomes apparent, farmers often apply inappropriately large quantities of pesticides (**Table 1**). IPM and pesticide-only control methods both have a significant effect on rice-yield indicators. We found the incidence of Dead Heart and White Head were lower than 5% in the IPM treated plots (**Tables 2**, **6**), which, in fact, is lower than established critical limits (5%). Egg masses were 2/m^2 or 1 moth/ m^2 from mid-tillering to booting stage.

As part of the IPM treatment, we applied ETL-based insecticides strategically, which minimized the pest population in IPM-treated plots. As a result rice yield was 7.5 ton/ha in the IPM-treated plots. These yields were significantly higher than the other treatments (**Table 3**). Singh et al. (2014) conducted similar research on the effectiveness of IPM for YSB in rice- and wheat-cropping systems. They found similar incidence of Dead Heart and White Head (<5%) in their IPM treatments. Other studies have shown that a well-designed IPM program can control pest insects in an ecological manner (Bux et al., 2013; Ehi-Eromosele et al., 2013). By reducing the incidence of Dead Heart and White Head in YSB-infested rice fields, IPM improves rice yields (Bux et al., 2013). It has also been demonstrated by DAE (2011) that IPM approaches minimize pest damage while maximizing yields and improving overall environmental quality (U.S-EPA, 2015).

According to Abrol (2013), IPM strategies that use appropriate ETL-based insecticide applications can be an effective method for managing pest insects. Rodrigo et al. (2013) demonstrated that appropriate pesticides used at application rates compatible with IPM strategies are beneficial for the control of rice pests

TABLE 7 | Interation effect of location and treatement on tillers, hills, dead heart, white head and yield of rice crops in 2012-13.

Treatment	Healthy tiller -tillering stage			Healthy tiller- flowering Stage		
	Sarderpara	Uttarsagardi	Gabtala	Sarderpara	Uttarsagardi	Gabtala
T1	1.37 (24.00)	1.34 (22.33)	1.37 (23.66)	1.34 (22.00)	1.35 (22.66)	1.34 (22.33)
T2	1.37 (24.00)	1.39 (25.00)	1.39 (24.66)	1.36 (23.33)	1.40 (25.66)	1.40 (25.33)
T3	1.34 (22.00)	1.34 (22.00)	1.31 (20.66)	1.33 (21.66)	1.33 (21.66)	1.36 (23.33)
T4	1.38 (24.33)	1.36 (23.00)	1.35 (23.00)	1.34 (22.66)	1.35 (22.66)	1.34 (22.33)
SE		0.179 (0.927)			0.186 (0.993)	
CV		2.3 (6.9)			2.4 (7.5)	
Treatment	**Percent of Dead Heart**			**Persent of White Head**		
	Sarderpara	**Uttarsagardi**	**Gabtala**	**Sarderpara**	**Uttarsagardi**	**Gabtala**
T1	1.72 (3.00)a	1.52 (2.33)ab	1.59 (2.53)a	1.77 (3.16)	1.70 (2.90)	1.66 (2.76)
T2	1.15 (1.33)bc	1.28 (1.66)b	1.28 (1.66)b	1.46 (2.16)	1.43 (2.06)	1.39 (1.96)
T3	1.28 (1.66)b	1.46 (2.16)b	1.57 (2.50)a	1.66 (2.76)	1.68 (2.83)	1.52 (2.33)
T4	1.72 (3.00)a	1.63 (2.66)a	1.63 (2.66)a	1.59 (2.56)	1.64 (2.70)	1.54 (2.38)
SE		0.622 (0.196)		0.64 (0.196)		
CV		7.2 (15)		7.0 (13.3)		
Treatment	**Total no of Hills /10 m^2area**			**Average Yield (ton/ha)**		
	Sarderpara	**Uttarsagardi**	**Gabtala**	**Sarderpara**	**Uttarsagardi**	**Gabtala**
T1	2.41 (258.33)	2.38 (244.66)	2.38 (241.33)	6.87	6.83	7.97
T2	2.42 (263.33)	2.40 (253.33)	2.40 (256.66)	7.33	7.50	7.13
T3	2.34 (224.66)	2.36 (233.33)	2.34 (221.33)	6.37	6.40	6.33
T4	2.32 (211.66)	2.37 (235.00)	2.35 (226.33)	6.60	6.56	6.53
SE		0.152 (8.14)			0.227	
CV		1.1 (5.9)			5.8	

Values outside parenthesis are the transformed mean values. Numbers in parenthesis are the actual means. Letters indicate significant differences for the interaction of location and treatment on yield components.

during germination, vegetative stage, and flowering stage. In our study insecticides were applied at the tillering and booting stages in the IPM-treated plots (T_2) across all locations (**Table 1**). We found that higher than recommended rates of Cartap (0.15 g/m^2, recommended 0.14 g/m^2) were frequently applied in farmers' fields (**Table 1**). To mirror conventional practices, our study included treatments with three and four insecticide applications (T_3 and T_4, **Table 1**). We determined that IPM-treated plots (T_2) provided significantly higher yields and that conventional practices might have a negative impact on rice production. This result agrees with earlier studies, which found that pest-management systems that fail to use IPM strategies have lower average rice yields (Sattar et al., 2004; Alam, 2013).

Pest-control strategies that include appropriate pesticide use have consistently been shown to increase rice production (Arora et al., 2014; Muck, 2015). Jacobsen and Hjelmso (2014) report that heavy pesticide use often has a higher cost-to-yield ratio than IPM methods. Our IPM-treated plots had lower pesticide costs than non-IPM treatments. Net economic losses for non-IPM techniques have been documented in an annual revenue report (Consultative Group for International Agricultural Research[11] [CGIAR]), 2010; Farrar et al., 2015). Measures of productivity and sustainability are frequently higher in IPM-managed farms than non-IPM farms (Côte et al., 2009; Ortiz et al., 2009; Sharma et al., 2015). These studies conclude that IPM techniques are yield efficient, environmentally friendly, and can be the foundation of sustainable cropping systems (Hall et al., 2013). An over-reliance on pesticides has proven to be unsustainable, less cost effective, and less efficient for pest control (Berg and Tam, 2012; Rasmussen et al., 2012; Alam, 2013; Rodrigo et al., 2013).

Farmers often over-apply pesticides or spray at inappropriate times because they lack knowledge of the negative impacts associated with these practices (Jepson et al., 2014). Contributing to this is a lack of understanding about how insect life cycles correspond to the life stages of rice plants and at what stages pesticides are most effective. Additional education and training is

[11] CGIAR (Consultative Group for International Agricultural Research). (2010). *Integrated Pest Management and Crop Health—Bringing Together Sustainable Agro-Ecosystems and People's Health*. Ibadan: White Paper. SP-IPM Secretariat, International Institute of Tropical Agriculture (IITA). 17.

needed to better inform farmers of responsible pest-management techniques and appropriate pesticide-application techniques (Parveen, 2010). Increasing the number of IPM-trained farmers will result in smaller quantities of pesticides being released into rice agro-ecosystems, increased rice yield, and improved human health and environmental quality (WHO, 2010[12]; Berg and Tam, 2012; Andersson et al., 2014; Nerilo et al., 2014; Sharma et al., 2015).

In the search for higher yields, the excessive use of pesticides might be the catalyst for current and future ecological crises. Potential problems include pesticide resistance, resurgence of insect pests, pesticide poisoning, environmental toxicity, elimination of predator species, negative outcomes for other non-target organisms, disruption in the food web, increased prevalence of pesticide residues in food, and reduced rice yields (Aktar et al., 2009; Sharma et al., 2015). These problems could be avoided by implementation of well-designed IPM strategies (Mohd Fuad et al., 2012; Srinivasan, 2012; Sharma et al., 2015). Despite several IPM techniques specifically designed for rice production, however, adoption remains low because of the perception that "chemical-free" strategies are less effective than heavy insecticide application.

CONCLUSIONS

IPM practices can be used for effective pest control in rice agro-ecosystems. The principle advantage of this technique is that rice yields increase as the resilience of the cropping system increases. Our study demonstrates that a well-designed IPM strategy can have a positive effect on yield components. In our study, rice variety BRRI Dhan 29 yielded 7.3–7.5 ton/ha in the IPM-treated plots. According to BRRI[13] (2015), the cultivar BRRI Dhan 29 is capable of yields from 6 to 8 ton/ha in Bangladesh agro-climatic zones. Despite the demonstrated advantages, adoption of IPM strategies might not happen quickly. It will be necessary to educate farmers about the environmental impacts associated with improper pesticide use and the consequences of those impacts on human communities and future food production. Further, in developing appropriate IPM strategies, it will be necessary to examine current pest-management practices and build on farmers' current and traditional knowledge. Additional research is needed to develop an understanding of farmers' traditional pest-management knowledge base, identify insect-resistant rice varieties, analyze the patterns of pesticide use, investigate constraints to controlling rice pests, examine farmers' awareness of environmental pollution caused by pesticide applications, and explore additional alternatives to pesticide use.

[12]WHO (World Health Organization). (2010). *Preventive Disease through Healthy Environments.* Available online at: http://www.who.int/ipcs/features/hazardous_pesticides.pdf.

[13]BRRI (Bangladesh Rice Research Institute). (2015). Available online at: http://www.brri.gov.bd/.

AUTHOR CONTRIBUTIONS

MA served as research team leader and was responsible for the study design, data collection, analysis and interpretation, and manuscript preparation. AC helped with manuscript preparation, edited the manuscript, and provided feedback on study design and data analysis. MH contributed to data analysis and interpretation. MI optimized the BRRI recommended agronomic practices utilized in this study. EH provided labor, hospitality, and administrative support. SaBH was responsible for data collection, tabulation, and provided an economic analysis of the yield data. ShBH helped with data collection. MH provided administrative assistance, aided in data collection, and provided information on relevant public health issues.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fenvs.2016.00022

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.