Pest Management in Rice—Current Status and Future Prospects

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Achieving high rice yields is constrained by the losses caused by insect pests. With reduced land availability and increased demand for food production, rice cultivation is being intensified through higher fertilizer inputs and cropping. Such intensifications may in turn increase pest intensities and demand for more pesticides. Pesticide application by most of the rice farmers in Asia is influenced by misperceptions and overestimations of damages. Thus, great majority of Integrated Pest Management (IPM) programs in the tropics never took an “integrated” approach. This paper highlights the past, present pest management practices in rice and offers possible scope for an ecologically based IPM.

I. INTRODUCTION

Rice is the staple food for over half the world’s population. It provides 27% of dietary energy and 20% of dietary protein in the developing world. The crop is cultivated in at least 114, mostly developing countries and is the primary source of income and employment for more than 100 million households in Asia and Africa (FAO, 2004). China and India together account for more than half of world’s rice area and, along with Indonesia consume more than three-fourth of the global rice production (Hossain, 1997; MacLean et al., 2002). In recent years, concern over food security is increasingly sensed, more in developing countries where rice production did not match the increasing population. Focus sharpened as prices soared steep leading to widespread fear of hunger followed by riots and violence in 2008. Export of rice was curtailed or suspended by some of the Third World’s leading producers (Cotula et al. 2009). With reduced land availability and increased demand for enhanced production, attention is turning towards intensification through higher fertilizer inputs and cropping. Such efforts in turn increased pest intensities (Heong, 1996) and losses caused by pests remained an important constraint to achieving high rice yields (Waddington et al., 2010). Given that the world’s population is expected to reach nine billion by 2045 (US Census Bureau, 2009), the importance of reducing losses from pests gains greater focus. Only 18–20 species out of nearly 800 insect pest species recorded on rice, are major pests in tropical Asia. Of the several management options available, by and large, only pesticides still dominate and serve as the primary component.
The largest proportion of the world rice pesticide market is in insecticides. In 1993, an estimated US $1,114 million or 37% of the total was spent on insecticides for rice (Woodburn, 1993). Of this, a large portion was in Japan (34%), India (22%), China (11%), and Korea (10%), (Kiritani, 1979). It is apparent therefore that majority of Integrated Pest Management (IPM) programmes in Asia never took an “integrated” approach. This paper highlights the past and present pest management practices in rice and indicates possible scope for providing an ecologically based IPM.

II. EVOLUTION OF PEST MANAGEMENT IN RICE

Insect pest control remains a core problem for Asian rice farmers. Yield losses of 15 to 25% or more were attributed to “ravages due to pests” (Oerke et al., 1994). Crop losses due to pests remain at 30%, no different from 30 to 40 years ago. Yield loss variability was greater between fields than crops or sites and crop losses due to insect pests depending on location, are much lower than generally perceived, amounting to just over 10% on the average and rarely exceeding 20% (Waibel, 1986). Two or three crops a year, often overlapping of heavily fertilized monocultures of ‘Green Revolution’ (GR), and high yielding cultivars were considered a vulnerable pest breeding ground (Kiritani, 1979).

The GR was literally and metaphorically a technology packaged for mass consumption. The package usually included the seeds of high yielding varieties, inorganic fertilizers, insecticides and fungicides. In many countries, farmers were obliged to use all these inputs, including calendar-based insecticide application (van der Fliert, 1993). However, after around 30 years of application of insecticides, there is no good evidence to show that farmer’s yield has been increased due to this component (Settle et al., 1996). Insecticide application decimates natural enemies along with their food supply, leaving the field open for pest build up by secondary and resurgent pests like the brown planthopper (BPH), *Nilaparvata lugens* Stal (Kenmore et al., 1984) and green leaf hopper (GLH) *Nephotettix* spp. (Kiritani, 1988). Aside from causing pest out breaks, insecticide use is believed to have accelerated the adaptation of BPH to resistant varieties by favouring the survival and reproduction of virulent individuals (Gallagher et al., 1994). Furthermore, insecticides
have drastically altered the faunal composition in rice and polluted the environment ultimately resulting in pesticide residues in food and mother’s milk (Kiritani, 2000). Although the problem of insecticide-induced secondary pests (notably BPH) was recognized and attributed to the destruction of natural enemies, insecticides used according to economic threshold were considered a valuable complement to insect-resistant rice varieties and synchronized planting as the basis for IPM (Matteson, 2000).

Though, globally rice IPM was evolved through sustained efforts of several entomologists, its adoption has not attained the desired level, due to varied reasons. The strong influence of agrochemical manufacturers and distributors in thwarting the holistic adoption of IPM is one of the primary reasons for its slow implementation (Murray, 1994; Brader, 1982). IPM has always encompassed a broad range of practices and is ecologically based (Morales, 2004). The earlier studies were restricted or were based on single or a complex of the pests and their natural enemies in rice. A holistic approach of rice ecosystem was either never considered important or ignored. Consequently, there were periodical insect outbreaks, the reasons for which are to be investigated in depth (Litsinger, 2009).

III. WHY RICE INSECTS ARE PESTS – BREAKING SOME MYTHS

i. Traditional varieties are more pest resistant than modern rices:

It was believed that modern rices such as IR8 were intrinsically more pest susceptible than traditional rices and outbreaks resulted from the wide scale planting of a single susceptible variety. But studies showed that it was not true that modern rices lacked pest resistance as IR8 was resistant to green leafhopper (Heinrichs et al., 1985). Most traditional varieties were later found to be equally susceptible to all common rice insect pests and very few have been resistant donors. Outbreaks were the result of multiple rice cropping and the use of insecticides (Loevinsohn et al., 1993). As traditional rices were only grown as an annual crop, they gave the impression of being resistant due to the lengthy dry season fallow, not genetic resistance.
ii. Insect pests were not controlled on modern rice varieties

The damage seen in modern varieties is so great that yields would be less than those of traditional varieties. This led to the myth that insecticides were therefore ‘required’ for high yields. But this is not supported by evidence. When modern rices are grown in irrigated culture side by side with traditional ones both without insecticide or fertilizer, yields of the modern rices are significantly higher (Litsinger, 2008).

iii. New pest resistant modern rices by being planted uniformly over broad areas increased risk of development of highly virulent insect biotypes

This was the belief at the beginning of the GR (Gallagher et al., 1994) when only a few new varieties were available. IR36 is the typical example and is still widely planted in Asia. It was only natural that farmers wanted to plant the best variety available. Now a days many local modern rices have been developed by national programmes and farmers sow a wider range of varieties. In addition, farmers regularly change varieties as a measure to prevent such problems. For instance, in the Cauvery delta, Tamil Nadu farmers have adopted the use of CR 1009 replacing earlier varieties to prevent gall midge, Orseolia oryzae outbreaks during the past few years.

iv. Nitrogen fertilizer contributes too many of the pest outbreaks and thus should be used minimally:

It is true that nitrogen increases pest fecundity and survival leading to higher pest incidence (Litsinger, 1994) but this belief does not take into account crop compensation which enhances the crop’s ability to tolerate damage. The researchers who perpetrated this myth did not integrate yield data into their conclusions, as despite higher pest incidence, one finds yields are also higher and this is what matters to the farmer. If nitrogen is used judiciously by splitting applications 3–4 times per crop, the effect on pest buildup is moderated (Litsinger, 2009).

v. Pest outbreaks appeared due to changes in the microclimate or weather:

It is true that close spacing increased BPH outbreaks that could be attributed to the higher humidity for increased egg survival (Dyck et al., 1979), but research has shown that the primary
Factors spawning outbreaks have been insecticide usage, increase in rice area, and multiple cropping (Loevinsohn et al., 1993). Climate and weather factors are only secondary factors but they can become important from time to time and be responsible along with primary factors in certain insect outbreaks. For example yellow stem borer, *Scirpophaga incertulas* suffers high mortality when the day temperature and humidity reach >34°C and RH< 70%, as at >30°C oviposition ceases, and strong winds disrupt dispersal (Catling and Islam, 1999). Similar weather events negatively affect natural enemies which then unleash rapid population increases that can lead to epidemics (Mochida et al., 1987).

**vi. BPH epidemics have been caused by the stimulation of their reproductive capacities by direct exposure to low insecticide dosages:**

While it is true that greenhouse trials showed that exposure to sublethal dosages of insecticides does stimulate increased fecundity in BPH, the magnitude of the effect is not enough to explain the large field populations that developed within the span of a few months (Chelliah et al., 1980). Extensive research has demonstrated that killing of natural enemies by insecticides is by far the most important mechanism (Heinrichs et al., 1982).

**vii. Yield loss and economic threshold levels:**

Among the pest groups, insects cause the most losses. In Japan, where farmers utilize maximum crop protection measures, loss from insect pests is less than 2% annually while in India it is 36% (Cramer, 1967). The literature abounds with phrases such as ‘most destructive pest’, ‘serious pest’, ‘heavy crop losses’ and ‘major losses annually’ rather than precise figures.

Estimates of crop losses caused by insect pests are generally based on educated guesses or on a small number of experiments in limited locations and therefore are not reliable and objective (Cohen et al., 1998). For instance, Pathak and Dyck (1973) reported almost 50% yield loss, measured by the insecticide check method on the IRRI Farm from 1964 to 1971. However the fields were planted with susceptible varieties in order to test insecticides and thus were not representative of farmers’ conditions. These high losses were widely circulated that led to the perception that to grow rice one needed to apply several rounds of insecticide applications for...
high yields. Studies later showed that the situation was different with varied rice varieties (Gallagher et al., 1994). Cramer’s (1967) often quoted losses were also taken from insecticide trials, many of which were conducted on research stations and timed when the highest pest populations occur.

Cohen et al. (1998) reviewed the rice crop loss assessment literature over a period of three decades for diseases and insect pests to determine the representativeness of existing data so as to evaluate how it could be extrapolated region wide. The study focused on five criteria: (1) rice production in tropical Asia, (2) measuring yield loss, (3) descriptions of experimental and sampling designs provided, (4) techniques used for measuring loss described, and (5) quantitative information on loss provided. Reports were compiled according to rice ecosystem with data from trials conducted for more than one year, in more than one location, and field level plot size. Only a few reports met these criteria as most

reports were in irrigated rice conducted in one location, in one season, and in plots<100m². They concluded that it is difficult to extrapolate such results for even the irrigated rice ecosystem in Asia.

Yield losses have been found to be highly variable by rice culture, location, season, and field. In the same field, farmers experience wide variability between crops and years. Such variations are also exhibited between farmers, fields in the same location, with out much variation in cultural practices. Part of the reason for the season to season variability is the propensity of farmers to change management practices, variability in initial insect populations and weather.

Economic threshold levels (ETLs) recommended by researches and extension workers are invariably not adopted by farmers. The literacy level of the farmers and their reluctance to step into the field and assess by adopting systematic methodology are the reasons for the failure. At field level, farmers make the decision on pest control on their own assessment, by virtual judgement. The price factor of rice grain and the expenditure on pesticides and their application are mentally assessed by them to make a decision on pest control intervention. In practice, ETLs are used more for surveillance, than for farmers’ pest control decision making.

In all the myths mentioned above, the assumptions were centered on modern rice varieties (irrespective of their resistance levels to insects) which were cultivated with
indiscriminate pesticide use leading to insect out breaks. Chemical control finds the last place in the list of IPM tactics, as the philosophy in IPM is to minimize insecticide usage and spare natural enemies by prioritizing other components. Despite a growing body of scientific and empirical evidence showing that insecticides were a mistaken and counter-productive input for rice, the fact remains that insecticides are still the dominant control tactic (Settle et al., 1996) and inevitable too, under pest outbreaks.

Current approach in irrigated tropical rice ecosystem and corresponding recommendations for insect pest management needs a radical revision of previous ideas regarding losses due to insect pests and their management practices that includes decision on economic threshold levels, cultural practices, use of agrochemicals, use of resistant cultivars, biological control, etc (Table 1).

IV. CULTURAL METHODS:

Crop husbandry practices that have a dual purpose of crop production and protection form the cultural methods. These practices were developed by the farmers through observation and trial and error. The insect control component of these practices, learnt through generations is not practiced and carried forward by the present day farmers. Cultural, mechanical and physical methods of control are often complementary. The practices that have been followed such as hand picking, roguing, trap cropping, mixed cropping and barrier crops are found to be beneficial (Litsinger, 1994) except a few practices which are discussed below.

i. Age of seedlings: Yields of modern cultivars decline dramatically when older seedlings are planted but traditional cultivars by and large are not affected by seedling age. In both cases, effects of seedling age on pest suppression are inconsistent. Now with the popularization of System of Rice Intensification technique, the effect of planting 14-day old seedling on rice insects needs to be studied.

ii. Synchronous planting vs. Asynchronous planting: The promotion of synchronous planting as a means of controlling pests is often cited in the literature (eg. Loevinsohn et al., 1993) and is one of the IPM tactics in vogue in many areas. The assumption is that non-synchronous planting patterns
promote pest problems because they give the rice pests a constant source of food. That analysis, however, is based solely on a plant-herbivore model, and does not take into consideration natural enemies and alternative prey. Examination of patterns of the BPH outbreaks in Northwest Java from 1986 to 1991 (Sawada et al., 1991) revealed that the rice BPH outbreaks are more prevalent and more serious in the synchronously planted areas than in the non synchronous planted ('staggered') areas nearby. These differences were attributed to high levels of pest mortality caused by the natural enemies in the staggered areas.

Similar results were found in Malaysia (Wada and Salleh, 1992) and Indonesia (Settle et al., 1996) also. Thus, in contrast to earlier advocacy of large-scale, synchronized planting with long fallow period for controlling pests, ecologists are now recommending continuous, staggered planting that keeps natural enemies in mature rice within easy immigration distance of new crops (Ives and Settle, 1997; Schoenly et al., 1998). In many locations, due to large scale migration of agricultural labourers to urban areas, labour scarcity during planting season is experienced. Evidently, this results in planting through an extended period. This social change is good for IPM. In addition, to ‘bridge’ the natural enemies across long, dry fallow periods, planting of dry season crops, such as soybeans or green manure or promoting the conservation of straw mulch piles are also recommended (Settle et al., 1996). Natural enemies like spiders have been shown to colonize in rice straw bundles that are placed in the field during rice harvest (Ooi and Shepard, 1994).

iii. Water management: Water management practices such as draining (whorl maggots, yellow stemborer and caseworms), flooding (armyworms, grasshoppers, white grubs, root aphids, termites), and alternate flooding and draining (planthoppers, black bug, gall midges and many stem borers) have been practiced by the farmers for many years. But the recent water management technology to conserve water has seriously affected this time tested tactics. For the conversion of ill drained wet rice fields to well drained wet land, traditional earthen ditches have been replaced by U shaped concrete ditches and distributive channels have been separated from drainage channels. This “environment formative technology” (development of infrastructure for rice cultivation) has effectively reduced the habitat diversity of many organisms and limited their
movement throughout the rice water system. As a result, two insect species, five bird species, one species of fish and one amphibian and three plant species are listed on the red data book as endangered species inhabiting rice fields in Japan (Hidaka, 1988).

iv. Weed management: Grassy weeds serve as hosts for most rice pests both in and outside the rice fields. Regular weeding is often advocated for managing the rice pests. But current production trends together with likely economic developments including shortage of labour force, suggest a continued increase in the use of herbicides for weed control in rice (Pingali and Roger, 1995). Crop plants are typically tolerant of selective herbicides and are not killed, but their physiology is often temporarily altered. Such physiological changes can make the crops more or less suitable for arthropods. An example of improving host plant suitability comes from a report stating that several herbicides made the rice plant more susceptible to and had stimulating effects on BPH.

Water, land preparation, seeding and weed control are interrelated. Good land preparation is an effective and economical way of keeping down weed infestation in annual crops. Frequently, it is recommended that area-wide weed control is a requirement for successful insect control. Weeds can directly serve as food sources or provide other ecosystem resources for herbivorous arthropods, and indirectly serve carnivorous (beneficial) arthropods by providing food and shelter to their prey. Weeds can serve as alternative hosts for pest and beneficial arthropods when their preferred crop host is absent. Weeds can serve as a source of increased diversity in agroecosystems. Increased diversity has been the rationale for enhancing biological control of arthropod pests through habitat management (Norris and Kogan, 2004). However, competitive nutrient foraging by rice plants and weeds eventually drive the farmers to maintain the field weed-free, with least concerns over habitat management to support beneficial arthropods.

v. Nutrient management: Fertilizer use in irrigated rice ecosystems was very low prior to the GR and during the first decade after the adoption of modern rice varieties. The average chemical fertilizer usage in irrigated rice in India is around 170 Kg/ha of NPK compared to only 32 Kg/ha in rainfed rice. Fertilizer subsidy offered by government to encourage high rice productivity has made the farmers to rely more on inorganic fertilizers than organic manures. Organics require
land, labour and other inputs for their production and application and the effective price of
nutrients from this source has been found to be the higher than that from inorganic sources (Pingali
and Roger, 1995).

Enhanced fertilization in rice fields results in high rice productivity. However, it causes
changes in the chemical composition of the rice plant. The most remarkable change by the heavy
application of nitrogenous fertilizer is the increase of nitrogenous compounds, and consequent
decline in C: N ratio. Nitrogen accelerates plant physiological processes and the production of
greater amounts volatile chemical attracting more pests which locate their hosts by odour.
Phosphorus tends to increase abundance of stem borers but to a lesser degree than nitrogen.
Phosphorus is important to root development allowing the crop to tolerate root weevils (Tirumala
Rao, 1952). Potassium however suppresses most of the insect pests. Though phosphorus and
potassium are beneficial in rice pest management, due to high pricing, farmers are reluctant to
use these two important nutrient sources. The effects of well fertilized plants on insect are greater
insect survival, increased tolerance to stresses (pesticides, cold), large body size (greater
fecundity), increased feeding rate (more damage) and faster growth (more generations per crop).

Farmers in rainfed environments have traditionally relied on organic sources such as farm
yard manure, compost, straw and green manure crops for maintaining soil fertility. A close
integration of livestock with cropping and low opportunity costs of land and labour in traditional
rainfed systems has made the use of organic source of nutrients economically viable. Agronomic
evidence indicates that organic fertilizer improves soil characteristics and could result in additional
gain. Possible long-term adverse effects of inorganic fertilizers on soil properties and environment
could be ameliorated by judicious combination of inorganic and organic sources. These long-term
and environmental benefits are not priced in the market. Currently available information on this is
very limited. Further research on quantifying long term benefits under farmers’ condition in a
range of environment is warranted. (Pingali and Roger, 1995).
V. USE OF RESISTANT CULTIVARS:

The potential utility of resistant cultivars to insects, either alone or in combination with other IPM tactics, by and large, remains unexploited in rice. Despite the availability of thousands of resistance sources against insects, host plant resistance studies have not made any significant impact on rice crop production in our country except in a few locations. The reasons attributed are failure of entomologists and plant breeders to complete their task after identifying the insect resistant germplasm, failure of farmers to accept and use insect resistant cultivars; tendency to separate crop production and crop protection, and failure to produce adequate information about the pests and resistant cultivars (Teetes, 1985). We should always realize that farmers would always accept an insect-resistant variety only when it is high yielding with quality grains.

The occurrence of insect biotypes is a major constraint to breeding and utilization of resistant varieties. Till date five biotypes have been identified in *N. lugens*. However, the concept of biotypes is questioned on the grounds of stability and the usefulness of the term. Even if the nagging problem of selection and spread of prolific insect biotypes persists, host plant resistance will continue to be an essential feature of varietal improvement programmes at both national and international levels. Varieties with relatively more stable resistance should be developed to slow down the process of biotype development.

i. Marker assisted breeding in rice: The naturally occurring resistance to insects should be exploited in the development of resistant cultivars. The classical genetic analysis and the recent molecular marker technology resulted in the detection of several major genes in cultivated and wild rice accessions associated with BPH resistance (Zhang, 2007). Moreover, the occurrence of quantitative resistance to BPH in rice was unequivocally established based on the quantitative trait loci (QTL) mapping (Alam and Cohen, 1998). Combining classical genetic analysis and engaging the recent molecular marker technology will facilitate easy identification of DNA markers closely linked to the gene(s) of interest. These markers are expected to speedup the process of selection in the breeding process. The marker assisted selection (MAS) is being exploited in many resistance breeding programmes for major genes. However, MAS for quantitative resistance is still
in the preliminary stage and this is because of the poor understanding on the complexity of resistance.

Selective phenotypic screening for the components of resistance viz. antibiotic, antixenosis, or tolerance and identifying specific QTLs is another approach to go for breeding for durable resistance to insect pests. There are scenarios under which antibiotic or antixenosis might also be durable because of limited effects on pest fitness, e.g. the case of an antixenotic cultivar in a landscape where equally preferred host species are readily available to the pest population. From the available literature it is evident that the success of breeding for durable resistance to insects in rice depends on the understanding on the complexity of resistance. Though several major genes and QTLs are mapped for BPH resistance in rice, the success of exploiting them in rice breeding is not adequate except in two cases: developing introgression lines with brown planthopper resistance using marker assisted breeding (Jairin et al., 2009) and characterizing a gene for BPH resistance based on QTL analysis (Du et al., 2009).

ii. Transgenic rice for insect resistance: Rice transformation with a Bt-gene (Fujimoto et al., 1993) was first targeted against the yellow stem borer (YSB) (Scirpophaga incertulas), the striped stem borer (Chilo suppressalis) and leaf folders (Cnaphalocrocis medinalis). Many studies and evaluations of Bt rice have been conducted in both laboratory and field (Wuu¨nn et al., 1996; Chen et al., 2005). All the results consistently confirmed that Bt rice is highly effective against rice borers and leaf folders, which are the two major classes of rice lepidopteran pests that cause severe yield loss in all rice-growing countries.

Another insecticidal gene tried for developing transgenic rice for insect resistance is snowdrop lectin gene or Galanthus nivalis agglutinin (GNA) gene (Powell et al., 1993). Transgenic rice plants expressing GNA had various levels of resistance to all the major sap-sucking insects tested, including BPH, GLH and WBPH. (Foissac et al., 2000; Nagadhara et al., 2003). However, success of GNA rice to control sap-sucking insects is not comparable to that of Bt rice to lepidopteran insects. Transgenic rice expressing another mannose-binding lectin from garlic leaf...
(Allium sativum agglutinin from leaf, ASAL) also exhibited enhanced level of resistance to BPH and GLH. Moreover, expressing ASAL in transgenic rice plants significantly reduced the infection incidence of rice tungro diseases, which is a prevalent viral disease in many rice producing areas of Southeast Asia, caused by co-infection of GLH-vectored rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) (Saha et al., 2006, Sengupta et al., 2010). However, genetically modified rice with insect resistance genes is not popular like transgenic cotton with Bt gene and the consequences of transgenic rice in cropping system are not yet known. Despite the large volume of empirical data proving it success, the persistent stories of “Failure of Bt cotton in India” is also being reported (Herring, 2009). The apprehensions expressed about the adoption of GM technology in rice would likely to be repeated as in cotton. The likelihood of one or more GM genotypes becoming the dominant cultivars leading to reduction of crop diversity in farmers’ fields is also a possibility. Reduction in traditional crop diversity has in the past been associated with the large scale adoption of high yielding varieties during GR (Karihaloo and Kumar, 2009). Rice being a food crop, safety of transgenic rice grains for human consumption and the straw to cattle are to be thoroughly studied over an extended period before release of such varieties/hybrids for cultivation.

VI. BIOLOGICAL CONTROL:

Classical biological control programmes in general have failed to control native insect pests in rice. However, successful suppression of exotic pests like Chilo suppressalis (Walker) in Hawaii and Marasmia exigua (Butler) in Fiji with introduced parasitoids has been recorded (Sweezy, 1931; Hinckley 1963). Synchronized release of large number of natural arthropod enemies in an inundation programmes will be expensive in rice.

There is a rich complex of natural enemies in tropical Asia (Yasumatusu and Torii, 1968; Chui, 1979; Wongsiri et al., 1981; van Vreden and Ahmedzabidi, 1986). These arthropod natural enemies have existed in this environment for thousands of years and have contributed to keep the pest species below damaging levels. Most rice farmers apply their first insecticide spray 40 days after crop establishment (Heong et al., 1995) aimed to control early season foliage feeding insect
pests (van Vreden Berg et al., 1988). Using food web data and arthropod time-series records from one irrigated field, Cohen et al. (1994) found that insecticides disorganized and destabilized the population and community dynamics of arthropod species in rice agro-ecosystems. The successful management of the BPH problem in Indonesia and elsewhere was based largely on the reduction of insecticide usage in rice fields to conserve indigenous natural enemies (Kenmore et al., 1984; Heinrichs and Mochida, 1984; Way and Heong, 1994; Settle et al., 1996). Among the ecological conclusions that have emerged from whole-community studies of rice-invertebrate faunas under pesticide-free conditions are that detritivores and plankton feeders (springtails, midge and mosquito larvae) dominate early crop periods. Their food is the decomposing stubble and roots from the previous crop as well as algal blooms. They provide sustenance for early season generalist predators dominated by spiders.

Although there are literally dozens of species of natural enemies in the field at any given time, their number steadily increases with crop age as they colonize from areas outside of each field after land preparation. To make full use of this natural resource, farmers need to learn to recognize the beneficial effect of the wide array of natural enemies in rice fields and undertake efforts to conserve them (Settle et al., 1996). It is unfortunate that although indigenous bio control agents form the core of pest management, little value is ascribed to them by most rice farmers, extension workers or many researchers and the quantitative information about these natural enemies is generally lacking.

VII. ROLE OF NON-RICE HABITATS:

Diverse non-rice habitats in the rice ecosystem may serve as source of natural enemies. Undoubtedly non rice habitats may occasionally serve as source of localized invasion of polyphagous pests such as armyworms and locusts. However, most important pests are specific or narrowly oligophagous pests for rice, while numerous predators are polyphagous feeding on a variety of food. Non rice habitats must surely be considered or recognized as potentially very important particularly for off season continuity of some natural enemies. For instance, parasitoids, taxonomically identical with those attacking rice grasshoppers, commonly parasitize non rice
hoppers species on wild hosts during lean periods. The very early arriving predator *Cyrtorhinus lividipennis* Reuter (Hemiptera: Miridae) can also survive in the off season as an egg predator of insects on wild plants (Way and Heong, 1994). Many species of arthropods with diverse types of life cycles occupy different habitats within the paddy agroecosystem. *Sympetrum* dragonflies emerge from paddy fields and stay in coppiced woodlots to mature sexually before returning to paddy fields to oviposit. The eggs hatch in the following spring when irrigation water becomes available. Newly emerged adults of the water scorpion, *Ranatra chinensis* move from paddy fields to irrigation ponds for overwintering. Oviposition takes place in paddy fields in the next spring. The biodiversity of the paddy agroecosystem therefore depends not only on the paddy fields themselves but also on water channels, irrigation ponds, levees, surrounding fallow fields, neighboring farmlands, secondary forests, wetlands, rivers, and remote hibernating areas (Kiritani, 2000).

At the moment, field data on the potential role of the non-rice habitats and bunds are conspicuously lacking. This ecosystem approach to pest management opens up new research opportunities that can lead to development of innovative pest management strategies, especially the limits of many pest species lie beyond the regional boundaries.

**CONCLUSION:**

The pest management practices affect the entire community of the animals in the system, and understanding the changes in the community structure is of paramount importance. Reviewing what has happened in the rice fields during the past half century, the concept of a balanced ecosystem to prevent pest outbreaks need to be envisaged at. Stable resistance and tolerance to insect pests continue to be a valuable complement to natural controls. It is essential to adopt IPM strategies and tactics that are compatible with conservation. The conservation and enhancement of natural control is a key research area. There is much scope for designing rice systems, rotation crops, and landscapes that feed and shelter natural enemies and facilitate their access to newly planted rice. A better understanding of why and when pest outbreaks are triggered is necessary for creating ecologically sound control strategies, and for planning the
improvement of present levels of natural control (Matteson, 2000). Scientists must ensure that new technology promotes, rather than endangers the ecological balance in rice crop that protects rice from insect problems most of the time.
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