សំណាយផ្លេកនៃមមាចត្នោត និងការគ្រប់គ្រង

BROWN PLANTHOPPER OUTBREAKS AND MANAGEMENT

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អត្ថបទសង្ខេប

មូលហេតុ និងបញ្ហានៃការផ្ទុះឡើងរបស់ប្រជាករ មមាចត្នោតបានធ្វើការបកស្រាយនៅក្នុងអត្ថបទនេះ។ ការមានពងច្រើន និងភាពរស់រានមានកិរិតខ្ពស់ គឺជាកត្តាដែលអាចធ្វើអោយប្រជាករមមាចត្នោតអាចផ្ទុះបាន។ កត្តាទាំងពីរនេះគេបានដឹងថាបណ្តាលមកពីការប្រើប្រាស់ជីគីមី និងថ្នាំពុលសម្លាប់សត្វល្អិត។ ដូច្នេះហើយបានជាមានការសិក្សាអំពីឥទ្ធិពលនៃថ្នាំសម្លាប់សត្វល្អិត និងជីគីមីទៅលើកំណកំណើតពង និងកិរិតអាចរស់រានរបស់កូនមមាចនៅក្នុងលក្ខខណ្ឌស្រែកសិករ។ ម្យ៉ាងវិញទៀតពេលវេលាសំរាប់សាបសំណាបក៏អាចជាកត្តាមួយធ្វើអោយមមាចកកើតឡើងខ្លាំងដែរ។ យើងបានដឹងថាបន្ទុះប្រជាករមមាចនៅក្នុងប្រទេសកម្ពុជាបានកើតឡើងជាអន្លើៗ និងរកេតរកូតខ្លាំងណាស់។ បាតុភូតនេះអាចមានការទាក់ទងគ្នាទៅនិងពេលវេលានៃការសាបសំណាប និងការផ្លាស់ប្តូរទីលំនៅរបស់មមាចត្នោត។ ថ្នាលសំណាប ដែលសាបមុនគេខុសប្រក្រតី អាចផ្តល់ជាទីជំរកដល់មេមមាចពង ហើយពងមមាចដែលមាននៅក្នុងសំណាប នឹងញាស់ហើយបង្កជាកូន ពូនជាចៅច្រើនឡើងៗ ហើយដែលអាចឈានទៅរកបន្ទុះប្រជាករដោយដុំៗ។ ដូច្នេះហើយសន្ទូងដែលមានមមាចត្នោតដែលជាដើមហេតុនៃបន្ទុះប្រជាករ ត្រូវបានយកមកធ្វើការសិក្សា។ លើសពីនេះយើងបានដឹងថាបន្ទុះប្រជាករមមាចត្នោតនៅក្នុងតំបន់អាស៊ីត្រូពិច គឺបណ្តាលមកពីការករជាកូនពូនជាចៅ ពីពីរទៅ បីជំនាន់ហើយដែលមានការទាក់ទងទៅនឹងទំហំប្រជាករដំបូង គឺជាដើមហេតុនៃបន្ទុះនេះ។ ហើយដោយភាពផ្ទុះនៃប្រជាករ មមាចត្នោតនៅប្រទេសកម្ពុជាមានលក្ខណៈជាបណ្តុំរាយប៉ាយនោះបញ្ហាទាំងនេះ ត្រូវបានធ្វើការសិក្សា និងពិភាក្សានៅក្នុងអត្ថបទនេះដែរ។ លើសពីនេះការសិក្សាអំពីប្រសិទ្ធិភាពនៃសត្វល្អិត មានប្រយោជន៏ក្នុងការកំចាត់មមាចត្នោតក៏ត្រូវបានលើកយកមកពិភាក្សាដែរ។ និយាយជារួមកត្តាទាំងអម្បាមាណដែលបានរៀបរាប់កន្លងមកនេះ ត្រូវបានពិភាក្សា និងសំយោគដើម្បីឈានទៅរកសេចក្តីសន្និដ្ឋាន និងអនុសាសន៏មួយសំរាប់ការងារអនុវត្តន៏ និងស្រាវជ្រាវជាបន្តទៀត។

ABSTRACT

The causes and problems of BPH outbreaks are discussed in this paper; increased fecundity and survival are factors that can lead to outbreaks of brown planthopper populations. These two factors are believed to be influenced by the use of chemical fertilizers and insecticides. Therefore the effects of chemical fertilizers and insecticides on fecundity and survival of BPH under Cambodian field conditions were studied. The effect of fertilizer on BPH oöcyte (egg) production was examined. Timing of seedbed establishment as a cause of brown planthopper outbreaks is one of the most possible factors. Outbreaks of brown planthopper in Cambodia are very localized and appear to be random. This phenomenon may be related to the time of seedbed establishment and colonization by migrating or dispersing BPH; rice seedbeds that are established early may provide a suitable host for BPH to colonize and subsequently to be transplanted into fields initiating localized outbreaks. Transplanted rice seedlings as a source of initial BPH infestation is examined. Outbreaks of brown planthopper in tropical Asia are generally related to population build up over two or three generations. The size of the initial population in a field may enable BPH populations to reach outbreaks levels. As outbreaks of BPH in Cambodia appear random and localized, it was thought these spot outbreaks might be from seedlings infested with BPH eggs. Cambodian rice fields have abundant natural enemies and these play an important role in reducing BPH population density. Field experiments on the relationship between BPH establishment and their natural enemies are presented. Overall synthesis of my findings, where the different strands of this work are brought together by focusing on the effects of host plant nutrition, cultivar reaction, timing of crop establishment and predation effects on the growth of populations of BPH. This leads to the final conclusions and recommendations for further research.

KEYWORDS:

Brown planthopper, outbreak, fertilizer, cultivar, fecundity, egg production, seed bed, & insecticide.

1. INTRODUCTION

Outbreaks occur when the population of a species increases in abundance rapidly over a relatively short period of time (Berryman 1987). As Berryman (1987) points out populations increase when the "environment" becomes more favourable for the reproduction and/or survival of the species and individuals aggregate into an area. In tropical Asia outbreaks of BPH have been wide spread since the introduction of new high yielding cultivars, chemical fertilizer and pesticides. Since BPH can devastate rice fields during an outbreak, this delphacid has the potential to cause tremendous economic losses. The Cambodian government began documenting pest outbreaks in 1991. There has been a BPH outbreak every year in Cambodia since then. Outbreaks of BPH in the Cambodian rice agro-ecosystem appear to be localized and patchy within a field (Preap et al. 2001a).

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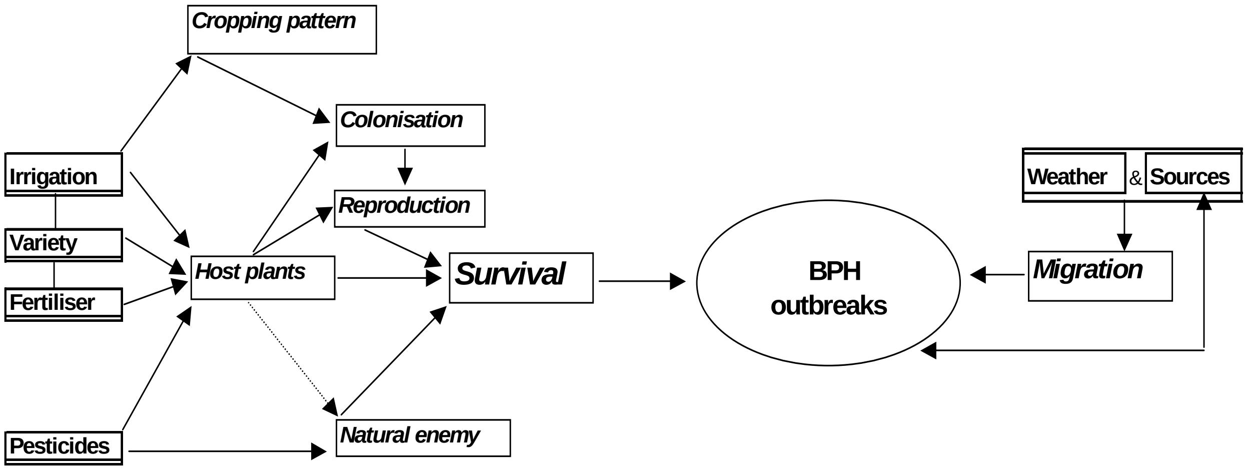
Fig.1 Summary of factors related to BPH population outbreaks (Denno 1994, Gallagher et al. 1994, Preap et al. 2001a & b, 2002a &



Most BPH outbreaks in Cambodia have been localized, and on a small scale. These localized outbreaks are thought to be related to several factors, that alone or together influence adult colonization, reproduction and survival of nymphs and adults. These factors are related to host plant quality and natural enemies and will depend on farming practices such as: pesticide application, fertilizer use, host plant cultivar, irrigation, and cropping pattern (Fig 1).

Compared to other countries in the region, for example Vietnam (Pham 2001, 2002) and Thailand (Setboonsarng 1993, Vongsilabutr 2001), Cambodia suffers relatively little crop loss to BPH outbreaks. Compared to Vietnam, high yielding cultivars are not widely grown in Cambodia (only 13% of the total rice land), but highly BPH-susceptible traditional cultivars, such as *Eth Chhmoush*, are planted by local farmers. Some Cambodian farmers use a high rate of fertilizer, but extensive outbreaks are very rare. What are the key factors that keep BPH outbreaks in Cambodia to a minimum? In this works I will discuss the factors that contribute to the BPH population changes in the rice agro ecosystem in Cambodia.

2. Materials and methods

The effects of chemical fertilizers and insecticides on fecundity and survival of BPH under Cambodian field conditions experiments were conducted in farmer fields in Samrong district, Takeo province and in CARDI's fields, Phnom Penh in wet season 1999. The effect of fertilizer on BPH oöcyte (egg) production was examined under glass house condition in 1999; I used two rice varieties (IR72 & *Eth Chhmoush*) and two fertilizer rates (low & high) to test the egg production. Egg productions from each female were counted under binocular and compound microscopes. In wet season 2000, I conducted an experiment to examine the effect of timing of seedbed establishment on brown planthopper outbreaks in farmer fields in Samrong district and CARDI's fields. Seed beds were established in four times: very early, early, normal, and late, compared to the normal time of local farmer practices.

To check the influence of initial number of BPH on transplanted rice seedlings as a source BPH population build up and outbreak, I conducted and experiment at the same time and at the same fields of Samrong and CARDI.

Further more, Cambodian rice fields have abundant natural enemies and these play an important role in reducing BPH population density. Thus, field experiments on the relationship between BPH establishment and their natural enemies are presented.

3. Effect of plant nutrition and insecticide treatments on *BPH production and survival*

Host plant nutrition is thought to influence host plant selection, subsequent insect performance (development, survival, growth) and the consequent population growth and dynamics (Waloff 1980, Denno & Roderick 1990). If brown planthoppers develop on nitrogen-rich host plants more nymphs survive to become larger and more fecund adults (Denno & Roderick 1990, Preap *et al*. 2001a).

Host plant quality influences BPH development. BPH that develop on susceptible plants produced more eggs and nymph survival was much higher than on a resistant cultivar (Table 1). Susceptible plants if treated with a high rate of fertilizer achieve higher yields but also a higher density of BPH, and some times these may reach outbreaks level. In general, what is good for the plant is good for the pest (Jahn *et al*. 2001). In irrigated rice fields, herbivores, predators, and parasitoids increase in abundance with increasing levels of nitrogen fertilizer use (De Kraker *et al.* 2000, Preap *et al.* 2001a).

Many insect species exhibit higher growth rates and decreased development times when their host plant is fertilized with high nitrogen levels (Tabashnik 1982, Fisher & Fiedler 2000, fig.2). Many pests are associated with heavy fertilizer application (Chelliah & Subramanian 1972, Reissig *et al.* 1986). The use of a resistant cultivar can alleviate this pest problem. In Southeast Asia outbreaks of BPH have declined in frequency and scale, as framers started to plant resistant cultivars such as IR26 and IR36 (Way & Heong 1994). My results indicated that BPH developing on a resistant cultivar had a smaller body, were less fecund and had poorer survival than on a susceptible cultivar (Table 1). Denno & Roderick (1990) suggested that a low level of BPH population occurred on resistant cultivars because of chemical compounds. Yoshihara *et al*. (1979, 1980) and Sogawa (1982) indicated that a decarboxilated derivative of aromatic amino acids and oxalic acid are inhibitors BPH feeding. Minor plant nutrients, such as silicon can increase the resistance of rice plants to planthoppers (Chang *et al.* 2001).

Fig.2 Brown planthopper colony, nymphs & adults

The repercussions can be quite serious when we make drastic changes in the agro-ecosystem without understanding the consequences. In the mid-1980s BPH outbreaks in Indonesia were induced through insecticide applications (Kenmore *et al.* 1985, Kenmore 1996).

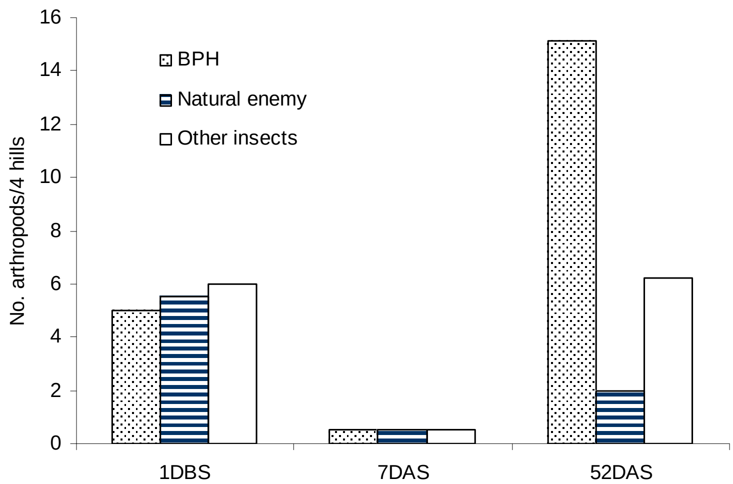
Natural enemies were killed faster than the target pest and BPH population became resurgent and reached outbreak level. Gallagher *et al.* (1994), Way & Heong (1994) and Settle *et al.* (1996) consider that the action of natural enemy is fundamental to sustainable brown planthopper management. The recovery of natural enemies after pesticide application was very poor compared to other insect, particularly BPH. A week after being sprayed almost all the population of natural enemies, other insects and BPH were killed. But 52 days after being sprayed the population of other insect and BPH had recovered better than natural enemies (Fig. 3).

My results in field cage experiments indicated that each *A. inustus* or *P. pseudoannulata*; which are very abundant in Cambodian rice field ecosystem (Preap *et al.* 2001a & b); can kill up to 97% of BPH in 15 days after spiders were introduced into the cage with a ratio of spider to BPH of 1:24 to 1:57 (Preap *et al.* 2001b).

Table1. Body length, fecundity, eggs laid and nymph survival of brown planthopper (+/- se) on resistant and susceptible cultivars treated with low and high fertilizer rates.

Host plant variety	***Resistant* (IR 72)**		***Susceptible (Eth Chhmoush)***	
Fertiliser rate	Low	High	Low	High
Body length (mm)	3.74±0.02	3.86±0.01	3.85±0.01	4.34±0.02
Oocytes production (no./female)	101±7	158±8	123±7	338±6
Eggs laid (no. per female)	46±2.3	66±2.5	55±2	72±2
Survival of nymphs (%)	19±1	35±3	28±3	53±4

Fig.3. The population dynamics of natural enemies, BPH and other insects in plots treated with insecticide.



4. COLONIZATION AND INITIAL POPULATION SIZE: ARE THESE THE KEY FACTORS FOR LOCALIZED POPULATION OUTBREAKS

The combined effects of high levels of colonization and improved performance on nitrogen-rich host plants often result in rapid population growth and larger population size.

After apparently randomly landing into fields BPH macropterous tend to choose high fertilized-plants (Preap *et al.* 2001a). They tend to move from plant to plant and selected more nutritious plants (susceptible cultivar, high-fertilized) on which to feed and, oviposit. Such plants accumulate locally higher densities. Subsequent populations will be higher; nymphs have a higher survival rate and adults are more fecund (Sogawa 1970, Denno 1985).

The BPH population build up depends on the number of insects initially infesting the crop and the crop stage infested. When the crop was planted with seedlings that had been exposed to BPH at a seedling to adult BPH ratio of 27:1 to 108:1, BPH built up to high numbers and the crop was killed. The higher the numbers of infesting insects the sooner plants were killed, and high-fertilized plants were killed faster than low fertilizer plants (Table 2). Even crops planted with seedlings exposed at the lowest BPH density tested, 216 seedlings to 1 BPH, were seriously affected when the BPH population increased to a high level at 72 days after transplanting. When colonization started late with a few insects (one per hill 22 days after transplanting) on low fertilized plants BPH did not increase to a high level and subsequently did not affect plant yield. However high fertilizer application is favorable for the BPH population increase and these plants were seriously affected (Table 2).

Initial population density on seedlings may be a key factor leading to subsequent population increase and local outbreaks and these outbreaks are closely related to the plant quality, crop stage of infestation and natural enemies. The density of the initial population depends on BPH sources, weather (particularly wind systems that influences BPH migration from longer distance) and the target host plants (crop stage and time of crop establishment).

Some areas (Takeo province) are "outbreak prone" because BPH sources are relatively abundant (thousands of hectares of rice crop are grown in the dry season and generally develop to the maturing stage by the beginning of the wet season crop). When seedbeds were established very early, which coincides with when BPH migrates from the source crops, seedbeds trapped relatively high numbers of macropters and these formed a high initial colony and subsequently increased to outbreak level, especially on high-fertilised crops (Preap *et al.* 2002a).

In some areas BPH sources are very limited (e.g. CARDI). Even seedbeds established very early had very low initial colonization and no subsequent population increase. With very low incidence at the early stages of a rice crop BPH populations are very stable at a low density during season for both traditional and modern cultivars. For crops that started with a relatively high colonization the population of BPH increased to a high level at the 3rd or 4th generation when the crop reached the reproductive stage (modern high yielding cultivar) and maximum tillering for a traditional cultivar.

Table 2. BPH infestation at different crop stages and the impact of population increase. The crop damage score of 9 indicates very high BPH density and all plants were killed, score of 7 is BPH in high density and almost all plants were killed, and score of 3 is some BPH were observed and plants were slightly affected

Low fertiliser rate

No. adults infested per hill	***Crop stage of infestation***	***At highest BPH density***	
		Crop damage score	DAT when achieved
8	Seedling	9	32 DAT
4	Seedling	9	32 DAT
2	Seedling	9	43 DAT
1	Seedling	3	72 DAT
1	22 days after transplanting	3	72 DAT

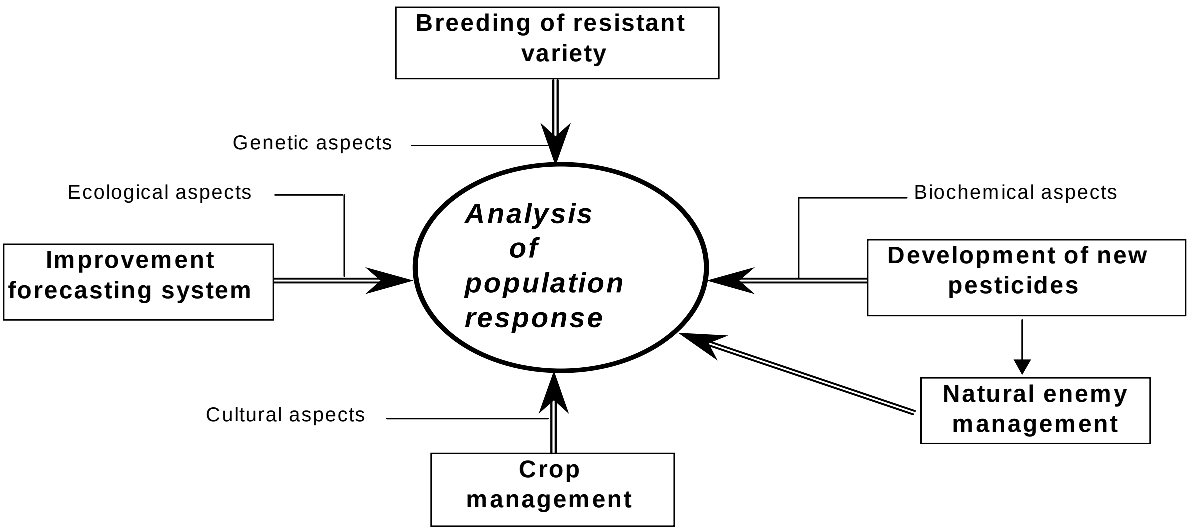
High fertiliser rate

No. adults infested per hill	***Crop stage at infestation***	***At highest BPH status***	
		Crop score	Crop stage
8	Seedling	9	7 DAT
4	Seedling	9	22 DAT
2	Seedling	9	43 DAT
1	Seedling	7	72 DAT
1	22 days after transplanting	7	72 DAT

5. APPROACHES AND RECOMMENDATION FOR BPH MANAGEMENT

A long-term strategy for BPH management for both temperate and tropical Asia will rely on: crop management (cultural aspects), breeding of new resistant cultivars (genetic aspects), development of new pesticides (biochemical aspects), natural enemy management thought proper use of insecticide and improved forecasting systems to better time management intervention (ecological aspects) (Fig. 3).

Fig. 3. Long term approaches for BPH management



Understanding the impact of these factors on BPH population dynamics will enable us to improve BPH management in the long term.

5.1 CROP MANAGEMENT

Using resistant cultivars, fertilizer, seedbed management and other cultural practices all contribute to pest control and crop harvest.

Georghiou (1972) suggested that cultural control methods could reduce insect populations. Cultural control methods are the modification of certain farm operations to make the environment unfavorable for the development and multiplication of the insect pest but favorable for crop production. Cultural control of rice pests incorporates crop production methods. Farmers use cultural control consciously or unconsciously to improve yield by reducing pest number (Reissig *et al.* 1986). Proper land preparation can provide a good crop and minimise use of herbicides. Herbicide application, such as butachlor, quinchlorac or betazone, increased the feeding rate of BPH and may also lead to high population (Wu *et al.* 2002).

The current recommendations for nutrient and pest management are woefully inadequate for predicting edaphic effects on multiple pests and different cultivars (Jahn *et al.* 2001). For example, applying N to promote recovery following stem borer and defoliator damage (Peng 1993, Litsinger 1994) and to increase grain yield may lead to higher planthopper incidence (Cook & Denno 1994, Preap *et al.* 2001a). To date, the application of the science of pest management-nutrient interactions in rice is a simple recommendation to split nitrogen applications, plow straw into the soil to increase silicon uptake or apply K during planthopper outbreaks (Jahn *et al.* 2001).

To avoid a high density of macropters at the seedling stage in "outbreak prone areas" the timing of seedbed establishment needs to be considered. If seedlings are infested with a relatively high number of BPH (see above discussions) then localised outbreaks may occur. For example, at Takeo, Cambodia ("an outbreak prone area") seedbeds must not be established very early because these seedbeds act like a trap for catching BPH macropterous adults migrating from older dry season crops. These BPH are then transplanted into the crop and this population may subsequently increase to a high level. The need for seedbed field monitoring with yellow pan traps would help growers to make a management decision. Control by using insecticides at the seedling stage should be used if seedbeds are infested with a relatively high number of macropters (yellow pan trap catch more than 2 adults per trap per day). This decision can deal with the right target with minimum risk to the environment. Small scale use of insecticides at the seedling stage in seedbeds will not lead to a huge reduction of natural enemies, as would occur after transplanting, is economical and most farmers can afford it.

Using cultural practices such as plant spacing, weeding, cropping pattern (synchronous planting or crop rotation), fertilizer and irrigation management, in pest control may prevent buildup of BPH populations. Farmers can reduce the pest population by flooding the field or plowing under the stubble after harvest. Using these methods, farmers are able to reduce the number of larvae and pupae of rice stem borer for instance (Reissig *et al.* 1986). Cultural control techniques should be compatible with other control methods and with the needs of the crop. Cultural methods must be cost effective although their results may not be immediate or as spectacular as insecticide use (Oka 1979).

Clark *et al.* (1974) pointed out that cultural methods are the priority in controlling pest attack; they are dependable, economical, ecologically sound, and nonpolluting. Some cultural methods are already used to combat brown planthopper. Rice is the only suitable host for BPH. On alternate hosts, this insect can survive but does not multiply well (Mochida & Dyck 1977). Consequently, during a fallow period, the insect population will be much reduced. The population phenology of the pest will be disrupted when the rice crop is rotated with other crops or there is a fallow between two rice seasons (Oka 1979).

Cultural control methods are not broadly satisfying because the same practice may be good for decreasing one pest but not for another (Reissig *et al*. 1986). For example farmers drain the field to control case worm, *Nymphula depunctalis* Guenée, but the yield will decrease if there is insufficient water supply. Oil applied onto the water surface and shaking the plants (Kenmore *et al.* 1984) can kill BPH but has negative effects on the plants-physiology. Rotation crop should be non-hosts for the insects otherwise rotation may increase pest population.

Synchronous planting and creation of a rice crop free period can greatly reduce pest abundance. Pests disperse from field to field and they can maintain high population levels and cause great yield losses in a farm community where planting times of neighboring fields are staggered beyond an interval of 3 to 4 weeks (Reissig *et al.* 1986). Preap *et al*. (2002a & 2002b) found that rice seedbeds established three weeks earlier than normal can lead to a serious yield reduction due to the high level of BPH landing into the seedbeds, especially in beds treated with high rates of nitrogen fertilizer.

5.2 Breeding of resistant cultivars

Controlling BPH with resistant cultivars and insecticides is often not adequate (Oka 1979). IR26 and other rice cultivars with the same gene for resistance to BPH were reported to be hopper burned in two widely separated small areas in the Philippines (IRRI 1975). Soon after introduction of the resistant cultivars insecticides were used to control rice pests and caused severe outbreaks of brown planthopper.

Brown planthopper-cultivars are one of the major products of rice pest control research and can go far towards reducing the farmer problems (Matteson *et al.* 1994). A resistant cultivar can slow down the population increase through lowered fecundity, and poorer survival (Preap *et al.* 2001a, 2002b). Tolerance to damage is also possible.

Cultivars containing the *Bph1 or Bph2* gene were initially highly successful in controlling BPH (Cohen *et al.* 1997). In Southeast Asia, BPH outbreaks declined in frequency and scale after the planting of these cultivars (Way & Heong 1994). Releasing resistant cultivars by the International Rice Research Institute (IRRI), began with IR26 in 1973, and provided effective but often only short-term control of BPH. After overuse of insecticides, massive outbreaks occurred in some areas planted with resistant cultivars (Reissig *et al.* 1982a & b). For example, the cultivar *Cisadane* containing *Bph2* was very popular in central Java, but became susceptible to *N. lugens* after the fields were intensively treated with insecticides (Kamandulu & Bahagiawati 1990). Planting resistant cultivars would be one method to help keep rice production safe from BPH attacks, but would not help in the long-term if insecticides are widely used and the resistance gene overcome (Gallagher *et al.* 1994, Setboonsarng 1993, Vongsilabutr 2001).

The ‘breakdown’ of resistance genes was accelerated by over use of insecticides and the planting of large areas to near monocultures of some cultivars, such as IR26 (containing Bph1) and IR36 (containing Bph2) (Gallagher et al. 1994, Cohen et al. 1997). Diversifying the use of rice cultivars in rice production would slow down the break down of resistance genes and outbreaks could be minimised. For example, in Cambodia there are more than 3,450 local rice cultivars (Sahai et al. 1992, Javier et al. 1999) and outbreaks of brown planthopper are very rare and on a small scale (even in susceptible cultivars).

5.3 New pesticides

The negative impact of pesticides on rice production increased when outbreaks of brown planthopper occurred in many countries in Southeast Asia (Kenmore *et al.* 1985). The outbreaks of this insect pest were caused by indiscriminate overuse of insecticides (Kenmore *et al*. 1985, Cohen *et al*. 1997). Development of resistance to various insecticides has been reported (IRRI 1970, 1975, Heinrichs 1994, Nagata 1982, 1999, Nagata *et al.* 2001). Insecticides do not kill BPH eggs, but do kill natural enemies (Reissig *et al.* 1982b) and BPH recovered faster than the natural enemy population (Settle *et al.* 1996, Preap *et al*. 2001a, Fig. 2).

However there are pesticides to control the egg stage of this pest. Suzuki *et al.* (1996) and Yamasaki *et al.* (1999) discovered that *S. furcifera* eggs laid in leaf sheaths and mid ribs of leaf blades suffer considerable mortality. The egg mortality reached 77% when a watery lesion is formed (Suzuki *et al*. 1996). Benzyl benzoate, which was extracted from the watery oviposition lesion, exhibited ovicidal activity against *S. furcifera* at concentrations of 6.4 ppm or more (Suzuki 2002). Thus this new compound would be an effective replacement for those products that cannot kill the egg stage. However this compound should widely be tested on the other planthopper species such as BPH.

5.4 Sustainable management and improvement of forecasting systems

BPH is one of the most serious insect pests in rice growing countries in Asia both in the sub-tropics and temperate regions. This phenomenon may be due to inappropriate management strategies and the lack of a reliable forecasting system in some countries of Asia. The latter in part reflects a lack of information and understanding of BPH population dynamics. One cannot solve the BPH problem alone without a meaningful exchange of information among neighboring countries and researchers. This is essentially due to long distance migration (eg Watanabe *et al.* 1994, Watanabe 2002). To solve the problem created by this potential pest in every country in the region (e. g. China, Korea, Japan, Thailand, Cambodia, Laos and Vietnam) will require sharing information and experience among neighboring countries. A network for exchange of information and databases for BPH is being set up for the region. Food and Agriculture Organization (FAO) and Rural Development Administration (RDA) are funding a project called "Development of Information System for Brown planthopper in Asia".

However in Southeast Asia outbreaks are localised and the detection of initial population at the time of crop establishment would be very helpful. The use of yellow pan traps to detect macropters immigrating into the seedbeds or later crop stages is a very simple tool that Cambodian farmers could use. If the number of macropters caught by yellow pan trap is less than 2 per trap per day seedlings will be safe for transplanting. With 2 or more per trap seedlings are highly infested and need to be treated before transplanting or they should be discarded. To increase confidence in this warning indicator a study over a wider range of locations and sampling over a wider range of densities is needed.

Cambodian rice ecosystems have an abundance of natural enemies (Preap *et al.* 2001a, 2001b), which play an important role in keeping the rice pest situation relatively stable compared to some other counties in the region. However the role of each natural enemy in the population dynamics of BPH is not yet understood. Research into maintaining high levels of natural enemies to manage BPH in Cambodian rice fields will be indispensable.

REFERENCES

Berryman A. A. 1987. The theory and Classification of Outbreaks. *In* Insect outbreaks. Washington University. Academic press Inc. 3-30.

Chang S. J., C. C. Li and D. S. Tzeng. 2001. Effect of nitrogen, calcium and silicon nutrition on bacterial blight resistance in rice (*Oryza sativa*). *In* Peng S. Hardy B, [eds]. Rice research for food security and poverty alleviation. Proceedings of the International Rice Research Conference, 31 March-3 April 2000. Los Baños, Philippines. IRRI 441-448.

Chelliah S. and A. Subramanian. 1972. Influence of nitrogen fertilisation on the infestation by the gall midge, *Pachydiplosis oryzae* (Wood-Mason) Mani, in certain rice cultivars. *Indian Journal of Entomology* 34: 255-256.

Cohen M. B., N. Syed, N. Alam, B. M. Edith and C. C. Bernal. 1997. Brown planthopper, *N. lugens* Stål, resistance in rice cultivar IR64: mechanism and role in successful *N. lugens* management in central Luzon, Philippines. *Entomologia Experimentalis et Applicata* 85: 221-229.

Clark L. R., P. W. Geier, R. D. Hughes and R. F. Morris. 1974. The Ecology of Insect Populations in Theory and Practice. New York. London, Chapman and Hall**:** 232.

Cook A. G. and R. F. Denno. 1994. Planthopper/plant interactions: feeding behaviour, plant nutrition, and plant defence and host plant specialization. *In* R. F. Denno and T. J. Perfect [eds]. Planthoppers: their ecology and management. New York, Chapman and Hall 114-139.

De Kraker J., R. Rabbinge, A. Van Huis., J. C. Van Lenteren and K. L. Heong. 2000. Impact of nitrogenous-fertilisation on the population dynamics and natural control of rice leaffolders (Lep.: Pyralidae). *Institute Journal of Pest Management* 46: 225-235.

Denno R. F. 1985. The role of host plant condition and nutrition in the migration of phytophagous insects. *In* The movement and dispersal of Agricultural Important Biotic Agents. Claitor's Pub. Div., Inc. Baton Rouge, LA. 151-172.

Denno R. F. and G. K. Roderick. 1990. Population biology of planthoppers. *Annual Review of Entomology* 489-520.

Denno R. F. 1994. Influence of Habitat Structure on the Abundance and Diversity of Planthopper. *In* R. F. Denno and T. J. Perfect [eds]. Planthoppers: their ecology and management. New York, London, Chapman & Hall 799 pages.

Fisher K. and K. Fiedler. 2000. Response of the copper butterfly *Lycaena tityrus* to

increased leaf nitrogen in natural foods: evidence against the nitrogen limitation hypothesis. *Oecologia* 124: 235-241.

Gallagher K. D., P. E. Kenmore and K. Sogawa. 1994. Judicial use of insecticides deters planthopper outbreaks and extends the life of resistant cultivars in Southeast Asia rice. *In* R. F. Denno and T. J. Perfect [eds]. Planthoppers: their ecology and management. New York, Chapman and Hall 599-614.

Georghiou G. P. 1972. The evolution of resistance pesticides. *Annual Review of Ecology Systems* 3: 133-168.

Heinrichs E. A. 1994. Impact of Insecticides on the Resistance and Resurgent of Rice Planthoppers. *In* R. F. Denno and T. J. Perfect [eds]. Planthoppers: their ecology and management. Chapman and Hall, New York, London.

IRRI. 1970. Annual report for 1969. Los Baños, Philippines.

IRRI. 1975. Annual report for 1974. Los Baños, the Philippines.

Jahn G. C., E. R. Sanchez and P. G. Cox. 2001. The Quest for connections: Developing a Research Agenda for Integrated Pest and Nutrient Management. Discussion Paper. No. 42. International Rice Research Institute18 pages.

Javier L. E., S. Men, K. H. Pith, P. Say, S. Sin, M. Ouk, Y. Hun, S. Suy, V. Thun, G. S. Sidhu, D. P. Mishara, V. N. Sahai, R. C. Chaudhary and D. R. Ledesma. 1999. Rice Germplasm Catalog of Cambodia III. Cambodia-IRRI-Australia Project. Phnom Penh, Cambodia.

Kamandulu A. A. N. B. and A. H. Bahagiawati. 1990. Brown planthopper, *Nilaparvata lugens* (Stål), reaction comparison study between Yogyakarta

Cisadane population and the IR64 adapted Yogyakarta Cisadane population. Paper prepared for Kongres Biologi Dasar II.

Kenmore P. E., F. O. Cariño, C. A. Perez, V. A. Dyck and A. P. Guiterrez. 1984. Population regulation of the rice brown planthopper *Nilaparvata lugens* (Stål) within rice fields in the Philippines. *Journal of Plant Protection Tropical* 1: 19 – 37.

Kenmore K. E., K. L. Heong and C. A. Putter. 1985. Political, social, and perceptual aspects of integrated pest management programs. *In* Lee B. S., Loke W. H., Heong K. L. [eds]. Integrated pest management in Asia. Kuala Lumpur (Malaysia): *Malaysian Plant Protection Society* 47-66.

Kenmore P. E. 1996. Integrated pest management in rice. *In* G. J. Persley [ed]. Biotechnology and integrated pest management. Wallingford (UK), CAB International 76-97.

Litsinger J. A. 1994. Cultural, mechanical and physical control of rice insects. In: Heinrichs E. A., editor. Biology and management of rice insects. New Delhi (India): Wiley Eastern Limited and International Rice Research Institute 549-584.

Matteson P. C., K. D. Gallagher and P. E. Kenmore. 1994. Extension of Integrated Pest Management for Planthoppers in Asian Irrigated Rice: Empowering the User. *In* R. F. Denno and T. J. Perfect [eds]. Planthoppers: their ecology and management. Chapman and Hall, New York. London 656-685.

Mochida O. and V. A. Dyck. 1977. Bionomics of the Brown planthopper, *Nilaparvata lugens*. *In* The brown planthopper. Tokyo. 1976. Asian and Pacific Council, Food and Fertilizer Technology Center, Taipei 192-198.

Nagata T. 1982. Insecticide resistance and chemical control of the brown planthopper, *Nilaparvata lugens* Stål (Homoptera: Delphacidae). *Bulletin of Kyushu National Agriculture Experimental Station* 22: 49-164.

Nagata T. 1999. Monitoring on insecticide resistance of the brown planthopper and the white backed planthopper in Asia. Inter-country forecasting system and management for brown planthopper in East Asia 167-185.

Nagata T., T. Kamimuro, Y. C. Wang, S. G. Han and N. M. Noor. 2001. Recent status of insecticide resistance of long-distance migrating rice planthoppers monitored in Japan, China and Malaysia. *In* The 3rd. International Workshop on Brown Planthopper. Hanoi, Vietnam 249 pages.

Oka I. N. 1979. Cultural control of the brown planthopper. *In* Brown Planthopper: Treat the Rice Production in Asia. International Rice Research Institute, Los Baños, Philippines 357-369.

Peng S. 1993. Physiological processes of crop growth and production and their relationships to damage by stem borer, bacterial blight and sheath blight. *In* Mechanisms of damage by stem borer, bacterial leaf blight and sheath blight, and their effects on rice yield. SARP research proceedings. Wageningen (Netherlands): Department of Theoretical Ecology and Los Baños (Philippines): International Rice Research Institute 7-21.

Pham V. L. 2001. Results of study on natural enemies of brown planthopper in Vietnam.

In The proceeding of The 3rd International Workshop on BPH. November 2001. Hanoi, Vietnam.

Pham T. V. 2002. Insect pest management on rice crop in Vietnam. *In* The proceeding of The 4th International Workshop on BPH. November 2002. Guilin, China.

Preap V., M. P. Zalucki, G. C. Jahn and H. J. Nesbitt. 2001a. Effect of fertiliser, Pesticide Treatment, and Plant Cultivar on the Realized Fecundity and Survival Rates of Brown planthopper, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae)- Generating outbreak in Cambodia. *Journal Asia-Pacific Entomology* 4: 75-84.

Preap V., M. P. Zalucki, G. C. Jahn and H. J. Nesbitt. 2001b. Effectiveness of Brown Planthopper Predators: Population Suppression by Two Species of Spider, *Pardosa pseudoannulata* (Araneae, Lycosidae) and *Araneus inustus* (Araneae, Araneidae). *Journal Asia-Pacific Entomology* 4: 187-193.

Preap V., M. P. Zalucki, G. C. Jahn and H. J. Nesbitt. 2002a. Establishment of *N. lugens* in rice crop nurseries: A possible source of outbreaks. *Journal Asia*-Pacific Entomology 5: 75-83.

Preap V., M. P. Zalucki and G. C. Jahn. 2002b. Effect of nitrogen fertilizer and host plant cultivar on fecundity and early instar survival of *Nilaparvata lugen* Stål: Immediate response. *In* the proceeding of the 4th Inter-country forecasting system and management for brown planthopper in East Asia workshop. Guilin, China 163-180.

Reissig W. H., E. A. Heinrichs, and S. L. Valencia. 1982a. Effect of insecticides on *Nilaparvata lugens* and its predators: spiders, *Microvelia atrolineata,* and *Cyrtorhynus lividipennis. Environmental Entomology* 11: 193-199.

Reissig W. H., E. A. Heinrichs and S. L. Valencia. 1982b. Insecticide-induced resurgence of the brown planthopper, *Nilaparvata lugens* on rice cultivars with different levels of resistance. *Environmental Entomology* 11: 165-168.

Reissig W. H., E. A. Heinrichs, J. A. Litsinger, K. Moody, L. Fiedler, T. W., Mew and A. T. Barrion. 1986. Illustrated guide to integrated pest management in rice in tropical Asia. Manila, Philippines: IRRI. 411 pages.

Sahai V. N., R. C. Chaudhary and S. Sin. 1992. Rice Germplasm Catalog of Cambodia I. Cambodia-IRRI-Australia Project. P. O. Box 01, Phnom Penh, Cambodia.

Setboonsarng S. 1993. Environmental Constraints to Thai Agriculture. *In* A. M. Rae and A. D. Meister [eds]. Environmental Constraints to Pacific Agriculture, New Zealand: Center for Agricultural Policy Studies, Massey University 83-101.

Settle W. H., H. Ariawan, E. T. Astuti, W. Cahyana, A. L. Hakim, D. Hindayana, A. SriLestari and S. Pajarningsih. 1996. Managing tropical rice pests through conservation of generalization natural enemies and alternative prey. *Ecology* 77: 1975-1988.

Sogawa K. 1970. Studies on the feeding habits of the brow planthopper. I. Effect of nitrogen deficiency of host plant on insect feeding. *Applied Entomology and Zoology* 14: 101- 106.

Sogawa K. 1982. The rice brown planthopper : Feeding physiology and host plant interactions. *Annual Review of Entomology* 27: 49-73.

Suzuki Y., K. Sogawa and Y. Seino. 1996. Ovicidal response of rice plants against the white backed planthopper, *Sogetella furcifera* Horvath (Homoptera: Delphacidae). *Applied Entomology and Zoology* 31: 111-118.

Suzuki Y. 2002. Employment of ovicidal response for improving management strategies of rice planthoppers. In. the 4th International workshop on BPH. Guilin, China. 13-15 November 2002.

Tabashnik B. E. 1982. Response of pest and non-pest colias butterfly larvae to intraspecific variation in leaf nitrogen and water content. *Oecologia* 55: 389-394.

Vongsilabutr P. 2001. Population management of the rice brown planthopper in Thailand. *In* The 3rd Inter-country forecasting system and management for brown planthopper in East Asia proceeding, November 13-15, 2001. Hanoi, Vietnam.

Waloff N. 1980. Study on grassland leafhoppers (Auchenorrhyncha: Homoptera) and their natural enemies. *Advance of Ecology Research* 11: 81-215.

Watanabe T., K. Sogawa and Y. Suzuki. 1994. Analysis of yearly fluctuations in the occurrence of migratory rice planthoppers, *Nilaparvata lugens* Stål and *Sogatella furcifera* Horvath, based on light-trap data in northern Kyushu (English summary). *Applied Entomology and Zoology* 38:7-15.

Watanabe T. 2002. Immigration patterns on rice planthoppers in 2002 in Japan, and the effects of cultivars and growth stages of rice plant on population dynamics of the rice planthoppers. In The 4th Inter-country fore casting system and management for brown planthopper in East Asia proceeding. November 13-15, 2002. Guilin, China.

Way M. J. and K. L. Heong. 1994. The role of biodiversity in the dynamics and management of insect pests of tropical irrigated rice. *Bulletin of Entomological Research* 84: 567-587.

Wu J. C., H. M. Qu and J. L. Liu. 2002. Two effects of pesticides on rice and brown planthopper *Nilaparvata lugens* Stål. *In* The proceeding of The 4th International Workshop on BPH. November 13-15, 2002. Guilin, China 191-204.

Yamasaki M., H. Tsunematsu, A. Yoshimura, N. Iwata and H. Yasui. 1999. Quantitative trait locus mapping of ovicidal response in rice (*Oryza sativa* L.) against white backed planthopper (*Sogatella furcifera* Horvath). *Crop Science* 39: 1178-1183.

Yoshihara T., K. Sogawa, M. D. Pathak, B. Juliano and S. Sakamura. 1979. Soluble silicic acid as asucking inhibitory substance in rice against the brown planthopper (Delphacidae, Homoptera). *Entomologia Experimentalis et Applicata* 26: 314-322.

Yoshihara T., K. Sogawa, M. D. Pathak, B. Juliano and S. Sakamura. 1980. Oxalic acid as a sucking inhibitor of the brown planthopper in rice (Delphacidae, Homoptera). *Entomologia Experimentalis et Applicata* 27: 49-55.