CHAPTER 6

DISCUSSION

Field Survey

6.1. Change in rice production practices in the survey site

An enormous development challenge for Cambodia in present day is to strive for fighting the pervasive poverty, which is still afflicting the majority of the population, particularly the agricultural households. Many small, marginal farmers still do not produce sufficient food for their consumption despite notable progress in rice production over the past few years has been made. This has prompted the government to retain its higher priority and commitments on boosting rice production in the country (FAO, 1999). Substantial steps, among other things, made so far towards achieving this important objective have been the release of many improved rice varieties and rehabilitation of many irrigation facilities in some areas that have the potential for increasing rice productivity. The availability of these two essential production components has allowed intensive rice farming systems in several parts of rice producing areas.

The shift in scenario of rice cultivation practice in Cambodia in a manner as described earlier is seen to have resulted in a remarkable increase in the use of some important agro-chemical inputs such as nitrogen fertilizer and pesticides. Coupled with the provision of irrigation facilities, the use of these synthetic materials have often led to the modifications in microclimate in ricefields and species dominance of rice pests (Normiyah and Change, 1997). As in the case of China, the widespread pest infestation occurred after the adoption of intensive rice farming with the use of fertilizer responsive varieties and, consequently, more pesticides were needed to prevent crop loss (Widawsky *et al.*, 1998). In another instance, the change in pest situation in Roleang Ken commune is an excellent case providing striking evidence on pest-cropping practices-related consequences.

Results of the field survey revealed that pest problems are becoming more momentously intensified. Researchers, key informant, and farmers all have reported that pest damages have increased in both their frequency and intensity over the past 2 or 3 years. Farmers had little knowledge about the causes of these repeated occurrences of pest infestations. But, from the technical point of view the mounting pest problems may have associated with, if not all, three important factors including the continued availability of food source, high application rate of inorganic fertilizers, especially nitrogen, and the breakdown of natural control system.

The conversion of the area into a rice-based development community had created a nearly all-year-round green environment. This condition tends to secure greater access to plenty of food sources for many potential pests to thrive and multiply their populations. Nitrogen fertilizer is a major input for obtaining high rice yield. However, high plant nitrogen generally favors an increase in population of insect pests which is manifested in greater pest survival, increased feeding rate, increased fecundity, and faster growth (Pathak and Khan, 1994; Smith, 1994).

The survey also found that levels of inorganic fertilizer application by farmers were relatively high that may also have facilitated the build up of arthropod pests in rice ecosystem of Roleang Ken commune. Taking as an example is the frequent outbreak of the brown planthoppers (BPH). BPH in fact may have long been one of the many rice phytophagous species inhabiting the ricefields in the area but it never caused significant damage to rice production. Yet, farmers in the study villages thought that BPH is a new, damaging pest whose damages in recent years have often assumed economic injury levels. The worst case of damage by this pest species occurred in 1998 when 111 ha of paddy fields were completely dried up. To prevent crop loss many farmers have resorted to spraying insecticides.

It is usually believed that proper control management practices have the merits to yield certain degree of success in protecting crop yield. But, it is expected that there seems to have high probability that such control practices of BPH are being improperly implemented by the farmers, particularly the non-IPM farmers, if their low level of awareness on the biological and ecological aspects of BPH is considered. Farmers reported that detecting the presence of the pests and their damages is very difficult. It may be because the pests usually confine themselves at the base of rice hills where many farmers are unable to locate them. Consequently, farmers were normally unknown about the presence and infestation of the pests until the full-blown of symptom appeared and then rescue actions of rice crop, if any, were very often too retard and unsuccessful. In this context, it can be contended that insecticide spray by farmers did little to deal with the target pest but more harm on the beneficial insects and animals. The destruction of predators and parasitoids that followed such an insecticide misuse resulted in resurgence of BPH and green leafhopper (GLH) (Ooi and Shepard, 1994; Krishnaiah *et al.*, 1988; Banerjee, 1997; Coung *et al.*, 1997) which are, in most cases, considered to be secondary pests only and kept in check by their natural enemies.

In brief, it is evident that the change in cropping practices by the farmers is placing rice production in Roleang Ken commune at stake *albeit* a substantial increase in rice productivity has been realized. It is therefore worth suggesting that if a sustainable rice production in this community is to become a reality there should be an adjustment in rice production techniques. Farmers should be well equipped with various ecologically sound pest-coping tactics as well as improved rice husbandry techniques. The recommendation may become realized given the fact that the area has been under training programme known as the integrated pest management farmer field school (IPM FFS).

6.2. Seeding practice

Most farmers in both categories grew traditional varieties and transplanting is the most preferred planting method. The most popular traditional variety was Srao

Sar, a late duration rice variety grown by 22.5% of the farmers. Approximately, 58.8% of farmers used seeds from their own stocks (seed harvested from the previous season). There was no difference in seeding rates between the non-IPM and IPM farmers. The survey results indicated that average seeding rates of the non-IPM and IPM farmers were of 92 kg ha^{-1} and 85 kg ha^{-1}, respectively. Concerning the technical principles, these seeding rates are very high. However, it should be noticed that since farmers produce and use the same seed year after year, the viability of the seed might have been deteriorated due to many reasons, for instance, impurity of the seed and self-generated change in genetic viability, etc. Interestingly, despite the seeding rates are rather high, they are closely consistent with the studies by Javier (1997) and Mak and Lando (1991). Javier (1997), as a whole, found that seeding rates used by rainfed lowland rice farmers vary from 50 to 120-kg ha^{-1}. Whereas Mak and Lando (1991) found that the estimated average seeding rate is of 86-kg ha^{-1}, and, for Kandal, a province where the survey was conducted in, they reported that the average seeding rate is of 60-kg ha^{-1}.

According to these researchers seeding rate generally varies depending on the location and fertility of nursery and the field, germination rate of the seed, and the varieties. However, only a few farmers were able to draw an association with the germination of the seed. Instead, they very often considered the high seeding rate as a rule-of-thumb to cope with the unreliable weather conditions. Certain amount of seedlings has to be reserved for replanting after extreme events such as droughts and floods.

In terms of economic aspect, the high seeding rate is actually lowering the economic benefits of the farmers in the study area. It is thus important that the seeding rate should be reduced to an optimal level. This alternatively requires the use of improved seeds. But, in present day, there appears to be impossible for the majority of farmers to get access to improved seed or certified seed from the government channel since an improved seed distribution system is yet to be fully functioning. The best alternative is therefore an attention be paid on initiating localized seed research and development program in which local genetic diversity base offers a variety of choices.

At the same times, extension and training should also be organized to provide farmers with various practical, sound seed production and storage techniques.

6.3. Nutrient management

Based on secondary data, Roleang Ken commune is characterized as one of areas with relatively low agricultural productivity given that it is positioned on the Prateah Lang soil group which is estimated to occupy about 25 to 30 percent of the rice-growing area (Oberthür *et al.*, 1997). The soil makes up a substantial part of the old alluvial terraces and some of the colluvial-alluvial fans and piedmont plains. A prominent feature of this soil group is the sandy textured surface soil overlying a loamy or clayey textured subsoil. The surface layer, in which sand grains can be distinctly felt, is overlying a more compact subsoil of heavier texture in which the sand grains cannot be as easily distinguished. The topsoil, which is structureless, is firm or hard when dry.

Generally speaking, according to Oberthür *et al.* (1997), Prateah Lang soil group has a very poor fertility, i.e., deficient in many essential elements such as N, P, K, S, Mg, and B, and is difficult to manage for rice production. Thus, there is little potential to achieve high yields of rice. Unfertilized rice yields on these soils range from 800 to 1400 kg ha^{-1} (White *et al.*, 1997). Yet, results of the field survey revealed that rice yields in the study area were moderately high. Average rice yields of the non-IPM and IPM farmers were 2270-kg ha^{-1} and 2507-kg ha^{-1}, respectively. These estimated figures are comparatively consistent with the official average rice yield of 2.3 t ha^{-1} reported by Chhum (2001). In comparison with the yield estimated by White *et al.* (1997), it is manifested that there was a substantial discrepancy in rice productivity in the area. A question to be made in connection to this is that what factors that really contributed to this increased rice yield. The only most likely possible answer to this question is probably nothing other than the high application rates of inorganic fertilizers by farmers.

Based on the field survey results, all farmers applied chemical fertilizers in their rice production. On average, the application rates of fertilizers of the non-IPM farmers and IPM farmers were 227.5 kg ha^{-1} and 174 kg ha^{-1}, respectively. The amounts of fertilizer use by both groups of farmers were obviously considerably high, but were quite consistent with the recommended rates of fertilizer use for Prateah Lang soil group. According to Nuth (2001), an N-P-K proportion of 50:23:30 or equivalent to 80 kg of Urea (46-0-0), 50 kg of DAP (18-46-0) and 50 kg of potassium fertilizer (K) is generally recommended for Prateah Lang soil group. But, in a condition of sufficient water supply the recommended N-P-K application rate is 100:40:80 kg ha^{-1}. Nevertheless, Oberthür *et al.* (1997) suggested that inorganic fertilizers should be applied in small frequent doses after cow manure application and after the soil has been flooded for at least a week.

In brief, the high consistency in nutrient management practiced by farmers with the formal recommendation has efficiently contributed a great deal of impact on improving rice productivity of farmers in the commune. In spite of this there remains two important points that also deserve special consideration. First, attention should be paid on preserving the health of the soil in the long run by minimizing the negative effects to be originated from the use of inorganic fertilizers. This has precisely opened an opportunity for researchers to involve themselves in training farmers on integrated nutrient management in which the incorporation of organic fertilizers, such as, compost and green cover crop like *Sesbania rostrata* sound very promising.

As reported by Reichardt *et al.* (1998), the combination of *Sesbania rostrata* with NPK fertilizers have proved to be particularly effective in enhancing soil N levels and rice grain yields in the extremely infertile rice soils of Northeast Thailand. In Cambodia, Nesbitt and Chan (1997) reported that earlier experiments by Cambodia-IRRI-Australia Project (CIAP) have shown that growing green manure before rice cultivation can increase rice yields by 40% (in Chea *et al.*, 2000). Second, since inorganic fertilizers continue to be an essential component for producing high yield, their use should follow a manner that undesirable event--pest attractions--is minimized. This suggests an importance of initiating an integrated nutrient-pests research program.

6.4. Pest constraints and farmers' practices

Both non-IPM and IPM farmers are having the same frustration from the common enemies in their rice production. Brown planthoppers, stem borers, rice bugs, rats, and green leafhoppers still continue to be the most damaging insect pests that are likely to continue to exert threats on rice production in the commune.

In coping with these intensifying pest problems, farmers have explored through trial and error a variety of control methods depending on their perceptions and experiences with individual pests. But, in the face of abnormal mounting pest disturbances in recent years, farmers have realized that their pest management strategies, if they are taken, have very often tended to give special consideration on pesticides as essential components. The case is likely to become even worse given that increased use of synthesized fertilizers, especially the nitrogenous one, is conducive to pest infestations. Therefore, it is anticipated that more pesticides will be poured into the fields to protect crop yield. Unsurprisingly, the pest problems then may become even further exacerbated. Widespread use of synthetic organic insecticides, especially the more toxic forms, may lead to the almost complete extinction of the beneficial insects present (de ONG, 1960), which subsequently results in outbreaks of secondary pests (Metcalf, 1984 & 1982; Chelliah and Heinrichs, 1984; Horn, 1988; Dent, 1995; MSUE, 1996; Cisneros and Mujica, 1998; Gassoumi *et al.*, 2000).

The number of pesticide users among the non-IPM farmers (42.5%) was slightly higher than that of the IMP farmers (37.5%). However, it came with great surprise as the study found that IPM farmers sprayed more insecticide than the non-IPM farmers. Average dose of insecticide application by the IPM farmers was 0.93 l ha^{-1} $season^{-1}$ whilst that by the non-IPM farmers was only 0.56 l ha^{-1} $season^{-1}$. This amount is slightly higher than the average pesticide use of 0.65 l ha^{-1} $season^{-1}$ by wet season rice growers estimated by Jahn *et al.* (1996b), but is lower than 1 l ha^{-1}, an average amount estimated by Yang *et al.* (2001). The higher doses of pesticide use by the IPM farmers were recorded in all villages in which the highest one was found in Chamkar Tanget. This may be because the pest intensity in this village was more severe than the other villages.

In general, the results of the field survey regarding the percentage of farmers practicing control measure of a number of key pests, such as brown planthopper (BPH), rice bug, caseworms, etc., obviously indicated a less percentage on the IPM farmers. Moreover, it was observed as well that the IPM farmers appeared, based on IPM principles, to have somehow developed their thoughts in using pesticide to deal with the pest problems because they reported that the benefits to be obtained from the application of pesticides was actually relative to the pest situation to be confronted. These are inclined to infer that IPM farmers may have aptly picked up the IPM principles for their rice production. The higher dose of pesticide application by IPM farmers in the previous season might have been justified by the above thoughts though they could have possibly been incorrectly made due to knowledge gaps in analyzing pest-natural enemy composition, as well as a sense of being unsecured haunted by the past pest experience. Because, although IPM farmers were trained about IPM wherein agroecosystem analysis approach is the chief importance permitting proper field scouting and observation to determine the abundance of pests and natural enemies present in the field, they did never carry out such a practice. Inappropriate knowledge on this critical aspect of IPM paradigm is often cited as a drawback that leads to misperception and misuse of the economic threshold levels (ETL), which is still very common (Fleischer *et al.*, 1999). The case, according to Ooi (2001) and van de Fliert (1997), revealed a lack of understanding of IPM that subsequently leads to more insecticide sprays in rice fields.

Extremely hazardous pesticides--the methyl parathion--which has been strictly banned in the 1998 Agricultural Materials Standard Sub-decree, are still being used widely by farmers in the study area. It is the most popular pesticide on the market (Jahn, 1996; Yang, 1999, 2001; TVE, 2001) which kills a wide range of organisms not just the pests. This raises a question on the poor effectiveness of the policy enforcement by the government. The widespread use of extremely hazardous pesticides is expected to continue to pose a serious threat on human health and an impediment to making IPM a reality in the country.

6.5. Farmers' awareness and attitudes towards natural enemies and pesticide use

Because of the activities of IPM farmer field schools in the survey area farmers seemed to have possessed relatively high knowledge and awareness of natural enemies. In general, farmers were commonly aware of the co-existence of beneficial and non-beneficial insects. They had a great ability to recognize the natural enemies, particularly the predatory insects. Overall, however, a higher percentage of reported individual natural enemies took side on the IPM farmers. For the sake of information only, the nationwide pest management survey conducted by Jahn *et al.* in 1996 reported that farmers were poor in this ecological aspect because they could recognize only three natural enemies on average particularly the large beneficial animals. These two findings however cannot be compared with each other given the fact that they are different in scope of study.

The study revealed that misperception on the use of pesticides remains remarkably widespread among both non-IPM and IPM farmers. Nevertheless, it indicated that a larger percentage of misperception normally prevailed within the non-IPM farmers. For instance, while the majority of IPM farmers, 57.5%, made a rejection on the statement that pesticide use increases rice yield, only 37.5% of the non-IPM farmers expressed the same disagreement. Chronic health problems associated with misuse of pesticides were reported by a few farmers, who have sought medical treatments for several years but still cannot get recovered.

IPM farmers' knowledge and awareness on the pesticide use and its associated negative effects on human health and ecosystems as a whole, and, on insect and natural enemies population, and their association with pest resurgence and outbreak, in particular, was comparatively higher than that of the non-IPM farmers. One critically essential finding of the study that is igniting great curiosity is that of the poor awareness of arthropod ecosystem analysis which serves as a strategic tool of the integrated pest management farmer field schools (IPM FFS). By keeping aside the non-IPM farmers since they are not trained in IPM principles, no a single IPM farmers reported practicing field scouting to identify the proportion of insect pests and beneficial insects. The case implicitly elucidated one of the many setbacks in the implementation of IPM FFS. However, this may be one of normal contemporary obstacles to seeding of IPM concept given a wide assumption on the complexity of the IPM principles. Castillo (1995) pointed out that policy makers in the Philippines assumed that the scientific principles underlying crop management decisions were too complicated for farmers to understand. In this environment, the concepts of agro-ecosystem balance and natural control of insect pests did not take root easily, and it is not difficult to understand why Filipino farmers were not so much attracted to IPM.

6.6. Economic considerations

Result of the field survey showed that rice yield of IPM farmers was higher than that of the non-IPM farmers. However, they were not significantly different ($p>0.05$). Gross margin of the IPM farmers was approximately 100217 Riels (about US$25) higher than that of the non-IPM farmers, which was significantly different ($p<0.05$). This increased income level is somewhat lower than the US$42 ha^{-1}--an estimated increased income contributed by the IPM FFS run on rice reported by Nuth (2000). The difference in gross margins between the two groups of farmers resulted, in part, from the lower variable costs of the IPM farmers. Non-IPM farmers used higher inputs, i.e., seed and fertilizer, in their production. Assuming that data acquired from the farmers are adequately reliable, it thus can be concluded that, in the context of the survey area, the IPM approach was proved to have significantly contributed to increasing economic returns for farmers.

However, it should be noticed that this small amount of increased income may not be substantial for farmers. Intangible income from the IPM implementation often leads to underestimation by farmers. The case may discourage many farmers from adopting IPM approach. The challenge ahead to overcome this dilemma must be a concerted effort to widen farmers' holistic thinking. According to van de Fliert (1997), in an ecological agriculture farmers should be able to understand, analyse and react adequately in ecological processes existing on their farms, each under specific ecological and economic conditions. From this noble concept, it is therefore hoped that the handover of important yardsticks relative to economic and ecological standpoint would help enhance farmers' perception, attitude and analytical capability. Once these farmers' critical behaviors are enhanced there seems to have higher possibility that the IPM's economy be comprehended, which may thereafter lead to an increased adoption of IPM approach at the farm level.

6.7. Implications for the integrated pest management farmer field school (IPM FFS)

There is growing evidence that improved pest management, in part, has the virtue for achieving sustainable rice production. This has led to a special emphasis being placed on the institutionalization and implementation of the integrated pest management program (IPM) in many rice-growing countries. Cambodia, for instance, is seen as one of countries in the region actively promoting the implementation of this crop protection approach. Several programs and research projects have been conducted under the banner of integrated pest management (IPM), wherein different control tactics are deployed. However, few attempts have hitherto been made to independently look into and reliably confirm the impacts of these new pest management practices on the adoption by the Cambodian rice farmers.

In addition to its intangible economic return, the IPM paradigm has generally been perceived as a complex method, knowledge intensive, and a time consuming approach. It is thus widely perceived to be financially not viable (Fleischer *et al.*, 1999). This has very often resulted in a rear adoption by farmers, thereby leading to the failure in its implementation in the farm level in many regions (Ooi, *et al.*, 1992b; Fleischer *et al.*, 1999). In Malaysia, for example, Normiyah and Chang (1997) reported that in many cases farmers did not continue these IPM practices after the projects ended because they perceived them to be financially nonbeneficial or too tedious, especially to old farmers. It is maybe because no significant yield increase was observed after practicing IPM, although chemical use may be reduced (Normiyah and Chang, 1997; Kartaatmadja *et al.*, 1997). In brief, present-day IPM implementation seems to be trapped with two common dilemmas including economic and ecological spiral.

In spite of this, the IPM practice in the context of Roleang Ken commune found to be fairly promising. Given the findings of the survey pertaining to both the ecological and socioeconomic standpoints, it is clearly delineated that IPM has been fairly well rooting in the rice farming community of Roleang Ken commune. In addition, although misperception remains at large farmers have expressed their acceptance and impression about the principles and usefulness of IPM pest management approach as such that it may first help them reduce the pesticide use, thereby lessening the frequencies and possibilities of being exposed to pesticides and dangers. Impression and acceptance of the IPM concept by farmers have created a favorable condition for researchers and farmers to come even closer and cooperate with each other. Participatory IPM or "farmer-driven" concept in which farmer's knowledge and farmer's decision making are respected is considered by modern crop protection specialists to be very essential for a successful IPM project (Fleischer *et al.*, 1999). Further steps to be taken to achieve a sustainable rice pest management in the commune would be a renewed, concerted effort to improve and, ultimately, realize farmers' harmonious acceptance through the improvement on every important aspects deemed as prerequisites for a successful institutionalization of IPM program. These apparently would include the farmers' perception and attitude toward IPM (Li *et al.*, 1997; Huan *et al.*, 1999), on the one hand, and ecological understanding (Mangan *et al.*, 1998), on the other hand. In addition, according to Fleischer *et al.* (1999), it is crucially important that the quality standards of the IPM that is being passed on from one level to another, i.e., from master trainer to provincial trainer and then to farmer trainer, be maintained.

In conclusion, despite results of this field study reflected impressive positive development of the IPM program in the Roleang Ken commune, it is impossible to come up with a clear-cut, ultimate conclusion on the levels of adoption of the IPM concept by the farmers due to various constraints and limitations, particularly the timeframe. The period in which the study was conducted was an off-season period, which was found to be unsuitable for carrying out an actual field observation of farmers' practices. Nevertheless, these factual information remain, to a certain degree, worthwhile providing fundamental understandings on various pictures of farmers' rice production and pest management practices and attitudes under a condition of pest pressure. Moreover, it also revealed about the various ongoing socioeconomic aspects. These have substantially paved the way for further research to be conducted in the future.

Field Experiment

6.8. Abundance and population dynamics of leafhoppers in the systems

The results of this field experiment indicated that the population of leafhoppers in rice growing areas of Chiang Mai valley was very low and the generalist *N. nigropictus*, was more abundant in the experimental fields than the rice specialist *N. virescens*. These were very consistent with Ishii-Eiteman' study's result conducted from 1989 to 1993 in the same location. This seems to have led to an assumption that although rice production practices by farmers and annual climatic conditions in the area might have undergone some changes with times there appears to have no impact on the abundance and species dominance of leafhoppers in Chiang Mai valley. In addition, the geographically high altitude landscape of Chiang Mai surrounded by high mountains may provide particular determinants for the low insect pest intensity. First, the high mountains may stand as a barrier making Chiang Mai valley rather an isolated island and blocking the immigration of leafhoppers, especially the *N. virescens*, from the Central Plain. Second, Litsinger *et al.* (1987) reported that few insects are normally found in upland site than at the rainfed lowland sites due primarily to the lower number of rice crop per year, followed by areas devoted to rice.

Both species quickly colonized the experimental rice systems in the first two months of rice growth stage (August to September). It was, however, observed that *N. virescens* colonized the field more rapidly and reached its population peak earlier than did the *N. nigropictus*. Pathak and Khan (1994) and Dale (1994) reported that *Nephotettix* spp. normally complete three generations on rice from June to August and in the fourth generation hibernate as nymphs in late September to October. *Nephotettix* spp. caught by light trap revealed that October was the month of leafhopper population buildup, which is the seasonal behavior of these species according to Dale (1994). This finding does, however, not correlated with that found with the actual field sampling in which both the direct visual and sweep net count found a very low number of leafhopper population. As discovered by Chancellor *et al.* (1997), however, peak numbers in light trap did not always correspond with peak numbers in the field and greater aerial abundance of leafhoppers at the end of each season may result from a behavioral response to the deterioration in the nutritional status of maturing rice plants as they began to senesce. On the other hand, Widiarta (1999), Cooter *et al.* (2000) and Marcos *et al.* (2001) reported that the population density of leafhoppers increased only at the early stages of rice growth and decreased thereafter with plant age. Based on these, the less numerous leafhoppers in the experimental systems in this month may be considered a reliable dynamic given the fact that rice had already become more mature during the month.

In general, various management practices in rice production such as different levels of fertilizer application, insecticide spray, seeding rate, plant density, plant age, etc., adopted for a particular agroecosystem all would hypothetically lead to the manipulation of a particular microclimate of the rice field that would have varying degrees of effects on the community structure, abundance and diversity of arthropods in the system. However, a package of production and pest management practices superimposed as research hypothesis in this experiment did not bring about significant changes and effects on the abundance and dynamics of leafhoppers in the system.

Insecticide application remains one of many possibilities for controlling leafhoppers and reducing rice tungro disease (RTD) (Macatula *et al.*, 1987; Batay-An and Mancao, 1999). It was suggested that in epidemic areas prophylactic measures, preferably with the use of insecticides with knock down effect are sometimes recommended to ensure the protection against virus infection (Chelliah and Bharathi, 1994; Pathak and Khan, 1994; Heinrichs, 1979). As found in this study, a split-spray of Folidol, which is known as one of broad-spectrum insecticides with the most extremely poisonous effect, at a dose of 0.5 l ha^{-1} as practiced by the Cambodian farmers in the surveyed area could keep leafhopper population, especially *N. virescens*, at a numerically lower level throughout the season. But, the reduction in number of leafhopper population in the treated system was proved to be statistically insignificant as compared with those in the other two systems where no insecticide spray was implemented. In addition, based on sweep net catch data, it also was observed that insecticide spray seemed to have exacerbated the pest incidence in the CPM system. The population of *N. virescens* had even recovered at some points of time after the first control action was taken. This maybe partly resulted from the decline in the population of the natural enemies, whose roles are essential in keeping the *N. virescens* population in check in most of situations, due to side effects from insecticide. On the other hand, this incidence might associate with a continuous recolonization of the trial system of *N. virescens* (Villareal, 1999).

Nitrogen and phosphate are important elements contributing to increased rice yield. However, it is widely known that their uses, particularly the nitrogen fertilizer Litsinger (1994), may increase the incidence of insect attack (Horn, 1988; Jahn *et al.*, 2001). According to Horn (1988) and Jauset *et al.* (2000), nitrogen content of plant tissues and sap is much lower (about 1-2%) than in the insects themselves, and many studies have shown a clear relationship between nitrogen availability in plants and fecundity of their insect fauna. There are no other nutrients that appear to influence insect quality as much as nitrogen (Murdoch *et al.*, 1998). Phytophagous insects respond with a number of adaptations that enhance their efficiency in nitrogen removal from plants (Horn, 1988). High plant nitrogen generally favors an increase in population of pests (Pathak and Khan, 1994; Smith, 1994; Kashyap and Bhanot, 1987;

Cate, 1987). For example, it was reported that nitrogen fertilizer was found to favor brown planthopper and leafhopper population growth on rice, even on resistant cultivars (Heinrichs and Quisenberry, 1999; Litsinger *et al.*, 1987; Litsinger, 1994).

In fact, it is probably no use to discuss about the effect of fertilizer use on leafhoppers since there was no significant difference in total mean populations. Nevertheless, the results showed that *N. virescens* recorded by both the direct visual count and sweep net seemingly appeared to have responded positively to the split-application of N:P fertilizer at the rate of 91:28 kg ha^{-1}, for CPM system, and 41:32 kg ha^{-1} for IPM system, at the tillering and panicle initiation stage, respectively. Mean population of *N. virescens* in these fertilized systems, in which the CPM system may have had higher numbers if insecticide spray had not been taken, was slightly higher than that recorded in the LIRC system where no fertilizer was applied. From field observation, a high dose of N fertilizer in these systems have not only made rice become more juicy, but also produced a denser plant density and canopy patch providing sacred harbor for leafhoppers.

Many insect pests, particularly sucking insects such as aphids and leafhoppers, are attracted to succulent foliage when crops are well fertilized or even over fertilized with nitrogen (Edwards, 2000). Johnstone *et al.* (1982), as cited by Ishii-Eiteman (1993), pointed out that homopterans respond to visual contrasts between vegetation and soil background, maximizing the ratio of exposed ground to plant area tends to increase homopterans colonization of fields. Ishii-Eiteman then assumed that higher numbers of leafhoppers in transplanted field would be expected taking account of a more visible soil background in transplanted than broadcast fields because of the practice of clumping seedlings into widely-spaced hills. However, her finding was that leafhoppers were more abundant in broadcast rice than transplanted rice, which had a lower ground-to-plant ratio. So, if this was the case then the denser plant density and canopy patch of rice in the fertilized systems witnessed in recent experiment may also have provided attraction to *N. virescens* invasion. Root (1973) proposed the ‘resource concentration hypothesis’ which states that herbivores are more likely to find and remain on hosts that are growing in dense or nearly pure stands (in

Southwood, 1987). However, as Bach (1988) discovered with *Acalymma* beetles, herbivore response to patch size or plant density is not necessarily linear (In Ishii-Eiteman, 1993).

It should be noticed as well that while the CPM system was planted to older seedlings (45-day-old) with 5 to 6 seedlings per hill, the IPM and Control system were planted to younger seedlings (25-day-old) with 2 to 3 seedling per hill. The differences are also believed to have associated with leafhopper abundance in the field. Age of a plant is only one facet of plant physiological change, and it is therefore to be expected that many other types of physiological change should influence insect performance on plants (van Emden and Way, 1973). Cooter *et al.* (2000), for example, found that male and female *N. virescens* flying from aging plants was significantly greater than those flying from young plants. Ganapathy *et al.* (1999) reported that when an overlapping rice cropping pattern occurs, leafhoppers prefer young seedlings and migrate from older crops to seedbeds, which can then become infected. Based on these, it may be postulated that the lower number of leafhoppers recorded in the CPM system may have been resulted from the less preference by the insects, probably due to the development of harder tissues as crop age progressed. Since *N. virescens* attacks crop more fiercely in the early growth stage, planting of older seedlings as practiced by the Cambodian farmers may help prevent the spread of rice tungro disease (RTD), though the number of vector population may not be necessarily reduced. In spite of this, seedling age might not always be an important factor in terms of leafhopper management. As Litsinger (1994) discovered with stem borer abundance, increasing seedling density per hill is necessary when planting older seedlings, but effects of seedling age on this pest are inconsistent. In relation to seedling density, Ishii-Eiteman (1993) emphasized that despite studies which manipulate plant density in transplanted rice often warn that increasing the density of rice leads to higher leafhopper and planthopper populations, her study suggested that greater plant density can "dilute" the abundance of leafhoppers *per plant*. When adult leafhopper populations peaked in transplanted rice, the per-plant load was actually greatest in the low-density plots, and, therefore, risk of infection might be greater.

Similarly, Power (1989) reported that incidence of pathogen transmitted by *Dalbulus maidis*, vector of corn stunt, was reduced at high plant densities.

Therefore, although high fertilizer application rate and increased seedling density per hill may lead to a dense plant and canopy density, which not only create a field microclimate conducive to *Nephotettix* spp. invasion but also alter plant physical properties to become more susceptible to feeding by these species, the possibility of being infected by diseases of the crop might be low. However, these kinds of practices, particularly the spray of insecticide, may not be necessary in a situation where the *Nephotettix* spp. is scarce and the disease is absent. Because they may place rice crop in a risky condition being attacked by other insect pests and competitive among individual plants, both result in overall yield loss.

6.9. Complex pressures by natural enemies on *Nephotettix* spp. egg mortality in the systems

Findings on *Nephotettix* spp. egg distribution in each system can also help explain the effects of various production and pest management practices. Analysis of variance indicated that eggs were more abundant in the CPM system, while no difference was found between the IPM and LIRC system. Superior nutritional quality of plants and microclimatic conditions (Ishii-Eiteman, 1993) and physical properties of the plants (Bernays and Chapman, 1994) could affect the oviposition behavior of phytophagous insects. The better quality of rice plants and a favorable microclimatic condition, i.e., nutritive and soft tissues, denser plant density and canopy patch, etc., in the CPM system due to high fertilizer application rate could cause leafhoppers to have an olfaction of preference towards CPM system and chose it to be their reproductive site.

The oviposition peaks normally occurred in the early growth stage of crop and that actually coincided with the trends of leafhopper population abundance from August to September in the systems detected by both field sampling methods. But, it was observed that egg population in the IPM system was somewhat lower than that of the LIRC system although it was also applied with considerably high dose of N fertilizer. Nevertheless, van Der Meijden and Van Zoelen (1987) pointed out that oviposition or food selection does not simply follow a positive relation with nitrogen concentration. They, for example, found that oviposition by Cinnabar moth only increases with protein nitrogen of Ragwort up until a certain level, and follow an optimum curve.

Eggs of *Nephotettix* spp. in the experimental systems were found attacked by two egg parasitoids, *Anagrus optabilis* Perkins and *Oligosita* sp., and one egg predator, *Cyrtorhinus lividipennis* Reuter. Their combined attack has led to certain levels of leafhopper egg mortality in each system. There were, however, no significant differences between these levels of egg mortality. But, the results showed that there were less egg damages in the CPM and IPM system in comparison to that in the LIRC system. It came with no surprise that the level of egg damage in the CPM system was low, because the population of natural enemies was probably lowered or their roles impaired by the spray of insecticide. Detrimental effects of insecticides, especially those with the more toxic forms, on beneficial arthropods have been well documented (Oka, 1996; Edwards, 2000; Levitan, 2000; Guangjie *et al.*, 2001). Besides, several other factors could also be influencing the activity of these natural enemies. This entails a separate discussion to be focused on the ecological and biological behavior of each species in relation to actual field conditions that were differed from each other by different management practices applied.

Anagrus optabilis Perkins [Family: Mymaridae]

A. optabilis was a more common parasitoid that became active right at the early growth stage of rice and continued to search and parasitize leafhopper eggs throughout the periods of observation. Since potted plants were kept in a screened house, parasitoids developing in leafhopper eggs before transplanting would have not been possible. Therefore, parasitism observed in the fields at the beginning of the season can undoubtedly be related to immigrant wasps.

A. optabilis achieved considerably higher rates of parasitism within the first three weeks after transplanting in the CPM and IPM system as compared to that it did in the LIRC system. In general, the trends tended to indicate a correlation of early field colonization of *Nephotettix* spp. and *A. optabilis* in the systems. Growing population of leafhoppers at the first few weeks after transplanting had led to a high egg population that subsequently attracted the colonization of *A. optabilis* in the field. However, there appeared to have less correlation in the later periods of observations. The parasitism rates from 39 to 46 DAT, although they were on an upward trend, seemed to have not sufficiently responded to a sharp increase in leafhopper egg population found in all systems of the same periods. Likewise, while the trends of egg population from 46 DAT on were low, the parasitism rates were relatively high. However, although the parasitism rates varied significantly over times, the parasitism activities by this species remained noticeably high throughout the season as compared to those achieved by the other two natural enemies. Therefore, *A. optabilis* is probably the most promising egg parasitoid in rice ecosystem of Chiang Mai valley.

Parasitism activity by *A. optabilis* could have been influenced by host density. According to Krips (2000) and Hoy (1994), many plants normally release attractive volatiles following the attack by herbivores and natural enemies, with their specific innate preference (van Alphen and Vet, 1986), can use these chemicals to find plant that are infested with their host or prey. One can, therefore, assume that the higher egg population density on rice plants, the higher levels of volatiles produced, leading to higher responsiveness by the natural enemies. As argued by Ishii-Eiteman (1993), the density of host eggs can be a powerful determinant of parasitoid host-finding success, particularly for parasitoids that rely on chemical cues from egg masses. Studies on these chemicals and olfactory function were documented in the host-finding behavior of *Trichogramma* spp. parasitizing Lepidopteran eggs, for instance, European corn borer (Marion-Poll *et al.*, 1987), *Heliothis zea* (Powell, 1986), and *Cotesia flavipes* parasitizing stem borers (Potting, 1996). However, the present study did neither find any studies that have determined responsiveness of *A. optabilis* to any kairomones associated with their host nor perform a statistical test to seek a correlation between leafhopper egg abundance and parasitism rates. Because, using potted plants to assess the relative abundance of leafhopper egg parasitism may not be appropriate taking account its many shortcomings. The particular quality and the microclimate of the potted plants were indisputably poorer than those of the plants transplanted to the field. The phenomena could have led to differential responses from both the leafhoppers and the host-finding *A. optabilis.*

Density of host plant, rather than of host eggs, could influence host-finding success, since as plant density in a field increases, more plant material must be negotiated during the search (Ishii-Eiteman, 1993). A denser canopy may make it more difficult for parasitoids to locate egg masses (IRRI, 1985). However, Kauffman and Kennedy (1989), as cited by Ishii-Eiteman (1993), pointed out that regarding parasitism by *Trichogramma*, stem number and canopy volume were less important than light. Similarly finding was discovered with *Ooencyrtus kuvanae* (Hymenoptera: Ecyrtidae), an egg parasite of gypsy moth (Lepidoptera: Lymantriidae), that has significant response to light (Odell *et al.*, 1989). This obviously reveals that light is crucial in increasing the host-finding success of the minute wasps. One may then surmise that light is also explicitly relevant to the parasitism performance by *A. optabilis* given the fact that it also is one of minute wasps. The denser plant tillers and canopy in the fertilized systems could have well prevented the penetration of light into the habitat, thereby keeping the plant canopy more wet or waxy which then affected the search for host egg by *A. optabilis.* As Way and Murdie (1965), cited in van Emden and Way (1973), discovered with anthocorid predators and *Brevicoryne brassicae* resistant Brussels sprouts plant, the predators were found much more abundant on a non-waxy plants than a waxy.

Oligosita sp. [Family: Trichogrammatidae]

Unlike *A. optabilis*, *Oligosita* sp. was a poor colonizer in the experimental systems. Only at 53 DAT that the pulse of *Oligosita* sp. activities achieved the highest parasitism rate in the LIRC system, with 100% of egg was then found parasitized. Either this *Trichogramma* did not immigrate to rice fields in significant numbers, or it did, but failed to find potential egg host.

Although insecticide spray was carried out, the *Trichogramma*'s activity in CPM system was still narrowly higher than those in the free-insecticide systems. This, however, does not necessarily means that the application of a broad-spectrum insecticide was not harmful to *Trichogramma*. Instead, the case can be interpreted in such a way that the number of *Trichogramma* might have been greater than the observed data if the significant high egg population of leafhoppers counted in this system is taken into account, but it was more affected by insecticide than the mymaridae. The larger leafhopper egg densities in this system might have contained relatively higher density of young egg masses. This, according to Reznik and Umarova (1990) and Hintz and Andow (1990), would also have attracted the parasitism by *Trichogramma*, by virtue of the females' preference of the young egg masses.

Besides, discussion based on other factors involved in the experiment other than insecticide left a conflicting circumstance over the parasitism rates in the IPM and the LIRC system. Because, as mentioned earlier, the high level of fertilizer application in the IPM system was theoretically supposed to lead to a higher density of egg population, thereby often resulting in an increased parasitism rate. But, there appeared that the parasitism rate in the IPM system was slightly greater than that of the LIRC system whose egg population was greater than that of the IPM system. The case thus tends to reject the hypothetical concept on relationships of parasitoid with the host egg and plant density as claimed by Ishii-Eiteman (1993). Nevertheless, the conflicting finding seems to favor the concept on plant odour-parasitoid relationship as claimed by Marion-Poll *et al.* (1987). Better nutritional crop in the IPM system may have had strong odour attracting more searching activity by the parasitoid.

In spite of these, the varying low egg parasitism rates by *Oligosita* sp. found in this field experiment may be, to some extent, attributed to the naturally poor parasitism performance of the species itself. Although, it was commonly known that parasitoids belonging to trichogrammtidae are the potential egg parasitoids in managing insect pests in various crop production systems, the natural parasitism rates of *Oligosita* sp. are usually very low, ranging from 2 to 8 eggs per day, as compared to the rate of 15 to 30 eggs per day by *A. optabilis*.

Cyrtorhinus lividipennis Reuter [Family: Miridae]

C. lividipennis, one of important predators of leafhoppers, performed in the systems better than the parasitoid *Oligosita* sp.. However, its predation activities in the CPM system was quite unsuccessful, which was very much lower than those in the other two systems. However, significant difference was found only with the LIRC system. This can be concluded that the spray of insecticide in the CPM system had severely affected the population and performance of the *C. lividipennis*. More predation normally occurred in the untreated fields than in farmers' fields which received insecticide (IRRI, 1985). The most striking evidence relating to the insecticide side effect can be observed at the later 3 weeks after the spray of insecticide. Similarly, Batay-An *et al.* (1999), in their study in which many types of insecticides were used to control leafhopper vectors, reported that *C. lividipennis* was quite affected by insecticides, that is, its population normally significantly reduced one day after treatment.

Generally, the foraging trends by *C. lividipennis* during the season varied greatly with times and were almost completely incorrelated with oviposition trends of leafhoppers. Only at the early growth stage (August) that the predation rates by *C. lividipennis* were found somewhat graphically correlated with the increased egglaying trends by leafhoppers, while the later predation activities were of an opposite fashion. Prey and plant density were most likely the most important factors influencing the predation rates of *C. lividipennis*. Obrycki *et al.* (1997) pointed out that prey abundance can determine whether a predator enters or remains in a habitat, as well as the type of prey and relative numbers of prey that the predator consume. Whereas research done by the International Rice Research Institute (IRRI) in 1985 on the yellow stem borer egg predation came out with a conclusion that predators consumed more eggs in transplanted rice fields. This suggests that a denser habitat as usually found in the direct seeded field may make it more difficult for predators to locate egg masses which result in a lower egg predation rate.

Nevertheless, the results obtained from the study failed to be fully consistent with both findings. For example, only the predation rate achieved in the early growth stage in the LIRC system that remarkably associated with these findings. The then increasing egg density and the low plant density could have made a condition in favor of foraging activities of the *C. lividipennis*. The later stage, i.e., from 32 to 46 DAT, the predation rates in this system as well as the IPM system were quite low when the egg density in the field was even much larger than the previous one. Another case can be observed at 53 and 60 DAT during which the predation rates in the CPM and LIRC system increased considerably while the egg density dropped drastically. These incorrelated data have posed the questions over "why" and "how" the abundance of *C. lividipennis* had increased while their prey was less prevalent and vice versa.

While explanation cannot be made for the later incorrelation, the explanation for the former might be possible. The former incorrelation might have associated with the functional response and searching activities of *C. lividipennis*. Because, as reported by Yonggen and Jia'An (1996), searching activities of *C. lividipenni* were distributed mainly on the upper and middle parts of rice plant. This means that although host egg density was high *C. lividipennis* might not be able to locate them because of the growing dense plant canopy as rice in the fertilized systems was approaching maximum tillering stage. A denser canopy may make it more difficult for parasitoids to locate egg masses (IRRI, 1985).

6.10. Species diversity of natural enemies in the systems

Results obtained from this study indicated that there were at least 16 taxa, primarily predators, of natural enemies inhabiting rice ecosystem of Chiang Mai valley. Their abundance started with an initial increase, followed by a decline as crop matures. The recruitment and abundance of natural enemies at the early crop stages seem to be an important factor that will determine later *Nephotettix* spp. population, especially the rapid field colonizer *N. virescens.* Total number of individuals of taxa recorded by both sampling techniques in the CPM system was less than those in the IPM and LIRC system. Nevertheless, result of the analysis of variance indicated insignificant differences between the systems. Orders of Simpson species diversity indices computed based on the observed population of individual taxa censused by visual count were LIRC system > IPM system > CPM system. Orders of Simpson species diversity indices calculated from sweep net catch data were IPM system = CPM system > LIRC system.

According to Gliessman (1998), Simpson diversity index presents the diversity of a system by taking into account both the number of individuals and the distribution patterns of the species. It is based on the principle that a system is most diverse when non-of its component species can be considered any more dominant than any of others. Hence, the lower index of the CPM system revealed that the natural enemy community was dominated by a few species with an uneven distribution, and the system was thus less diverse in terms of beneficial arthropods against leafhoppers. Therefore, the obtained result sufficiently demonstrated the adverse side effect of insecticide on the natural enemies of *Nephotettix* spp. Further discussion on other experimental factors that were likely to influence the species diversity of natural enemies in the systems is not necessary as it has already been discussed at length in section 6.9.

Surprisingly, the diversity index of the CPM system obtained from the sweep net catch data was rather confounding. As presented earlier, although the numbers of individuals of species were less, the index in this system turned out to be equal-and higher than that in the non-treated systems. One of many possible underlying to the case might be a postulation that the broad-spectrum insecticide applied in the experiment had an across-the-board effect on the friendly arthropods in the system. If it is corroborated, one can therefore assume that there was not any species considered the dominant any more and, hence, an even distribution of species diversity prevailed. Nevertheless, it should be cautious that any theoretically based attempt to grade the CPM system as a diverse one in the wake of this finding may not be adequately justified. Because, despite species evenness is one of two components that needs to be inferred when appraising species diversity in a particular system, its application in real world remains pragmatically difficult. Similarly, Li (1996) who himself found it difficult to draw a conclusion of the varying evenness indices of arthropod assessment in his corn field referred to Ludwig and Reynolds (1988) who pointed out that evenness indices are most often difficult to interpret.

In other word, the confounding species diversity indices attained might somewhat be attributed to errors that might have resulted from the layout of the field experiment, the field samplings, and specimen handling.

Experience acquired from this study was that while specimen management of predatory natural enemies was felt much easier, the same job done with the tiny parasitoid wasps was not that simple. Some small wasps could have been damaged in the plastic bag before being sorted out and coded, the incidence that also contributed to the bias of the data. In addition, experimental layout could also have contributed largely to the error of data. They were probably too small that the displacement of the natural enemies within the systems during sampling could have not been well prevented. To some extent, there were possibilities of reinvasion of natural enemies to the treated system from the non-treated ones and the adjacent vegetation growing densely on the bunds around or within the experimental fields.

According to Holland *et al.* (2000), several studies have demonstrated that beneficial species including Carabidae, parasitic wasps, and Linyphiidae as well as pest species were unevenly distributed within fields or even within landscape. Some species may exist as a series of local semi-autonomous populations, termed a metapopulation. These populations interact through dispersal, thus the size of each metapopulation and the distance between each will be governed by their dispersal ability. Insecticide applications may disrupt these distributions, depending on the size of the metapopulation with respect to the area treated. Holland, finally, drew a conclusion that such heterogeneous distributions within fields may confound the interpretation of insecticide trials, especially when samples are taken only from a small area, the effects found depending on the initial distribution within the field and the subsequent pattern of reinvasion.

6.11. Comparison of sampling methods

In all systems, sweep net caught higher numbers of *Nephotettix* spp. than did the direct visual count. Two-tailed Student's t-tests performed on these data indicated that there was a significant difference between the two relative data ($p<0.05$). In addition, the relative variation (RV), which expresses the statistical method to compare the efficiency of various sampling techniques as suggested by Kogan and Pitre (1979), revealed that RV values calculated from the sweep net data in each system were relatively less than those obtained from the direct visual count data. However, when the RV values of the CPM (23.9) and LIRC (21.5) system were less than 25, a threshold RV value determined by Southwood (1978) (in Titayavan, 1989) as adequate for most extensive sampling program, the RV value of the IPM system (27.3) is not acceptable. The RV value computed from the direct visual count data all were larger than the threshold value. They ranged from 30 to 34.2. In general, the sweep net data was statically sufficient for the estimation of relative abundance of leafhoppers in the experimental fields because its overall mean RV value (24.2) was less than the threshold, whereas that of the direct visual count was not.

Many factors contributing to the variability of the sampling result may have associated with (1) biological behavior of the leafhoppers, (2) change in crop habitat, (3) ability of sampling worker, and (4) time of sampling.

Direct visual count is actually recognized as one of the simplest sampling techniques at the farm level. Hassan *et al.* (1995) conducted studies comparing four sampling methods (visual, sweep net, bagging, and D-vac suction) in assessing rice field arthropod pests reported that visual inspection was the most convenient and practical method whose efficiency stands next to D-vac catch. However, his studies failed to specify the suitability of direct visual inspection to a particular arthropod pest category that has different biological characteristics and that may require different sampling technique. For example, Kogan and Pitre (1979) pointed out that slightly different techniques are required for sampling insects that are more active. As observed in this study, using direct visual count to estimate the abundance of leafhoppers seemed to be less suitable since they are more active and likely to displace from one rice hill to another when disturbed. Field sampling had to be carried out slowly and patiently, otherwise there would be no leafhopper to be counted and species identification made. This probably the only factor that contributed to increased time consumption by direct visual count.

Change of plant habitat is also believed to have an influence on the precision of the direct visual count sampling method. In the early growth stage at which time the plant and canopy density was not so dense, the sampling proceeded much easier. Locating activity for insect on plants was done more conveniently. Occasionally, following the insect that displaced from the target rice hill to another was also attempted with some success. In the later stage, however, it was apparently impossible that such a coping strategy was applicable. Following the leafhoppers to the hill they moved to had always been an abortive attempt since the crop habitat became so dense favorable for the insects to escape and go hiding, while, at the same time, quite unfavorable for the surveyor to move in the field.

In addition, efficiency of direct visual count method is extremely dependent on the surveyor's personal ability and visual acuity (Kogan and Pitre, 1979; Titayavan, 1989; Knutson, 1999). According to Titayavan (1989) there were chances that the insects were misidentified due to the surveyor had only glimpsed at the sampled specimens.

Time of sampling might also have affected the efficiency of the direct visual count method. Because, this method was usually implemented early in the morning prior to implementing sweep net sampling. Wet condition and inadequate sunshine may, to some extent, have influenced the emergence of leafhoppers in the field. Pathak and Khan (1994) and Dale (1994) reported that high temperature, low rainfall, and abundant sunshine are the determinants of leafhopper seasonal abundance. A positive correlation has been obtained in Japan between the hopper population and the amount of sunlight while a negative correlation exists between the population build-up and relative humidity (Dale, 1994).

Time consumption by each sampling technique was also considered in this study. Mean time consumptions by sweep net sampling technique, which were almost the same between systems, were also significantly different from those of the direct visual count. This apparently revealed that estimating leafhopper abundance *via* direct visual count not only underestimated the population of leafhopper but also consumed more time and is thus more tedious and costly. Similar conclusion was reported by Knutson (1999) in implementing visual search of predators in cotton crop.

In summary, sweep net sampling technique perhaps the most convenient sampling procedure for adult leafhoppers. Titayavan (1989) who used direct observation and sweep net in studying abundance patterns of stem flies in soybean also reported that sweep net was more efficient. Sane *et al.* (1998) reported that, by using sweep net, not only a satisfactory level of accuracy and precision in determining arthropod densities can be obtained, but also the cost of work-hours required was low. In this study, needless to mention its outstanding performance in assessing the abundance of natural enemies in the field, sweep net sampling method overcame the major defects of the direct visual count in that it caught more leafhoppers with less labor requirement, thereby resulting in an increase in accuracy of leafhopper estimates as well as reduction in cost of production.

6.12. Economic consideration

Analysis of economic returns is an ultimately necessary stage for the assessment of production output yielding from the investment in a cropping system (Hoang, 2000).

Economic returns from rice production are greatly influenced by damages from insects and diseases. Damages in turn are highly dependent upon quality of pest management practices (Hossain, 2000). The relationship between pesticide application and pest control can be problematic, however. Misspecification of pesticides, incorrect timing of application, insufficient or over dosages can result in high pesticide costs added to the total cost of production. The case in principle suggests that in order to gain more from the use of pesticides without leaving detrimental impacts on ecosystem and health, the decision should be made in a judicious manner. This basically emphasizes the need for an implementation of an integrated pest management (IPM) approach.

IPM pest management is a system that, in the context of associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest population at levels below those causing economic injury (Fenemore, 1984). With this definition, it is comprehended that the IPM paradigm makes it mandatory to combat pests in a way that not only the economic benefits are insured but also the ecological sustainability. Several studies conducted have demonstrated that IPM is capable of meeting with these two crucial objectives.

As demonstrated by the result of this study, a rice production that was based on optimum level of input use and rational pest management technique obviously led to a higher crop yield and economic returns, though they were not significantly different from those obtained from the conventionally based pest management approach. Increased income witnessed was attributed largely to the low expenditures on insect control. Because, a sound assessment on the actual pest situation did not warrant the application of insecticide. This resulted in a considerable amount of insecticide use avoided, thereby saving investment cost by 54% as compared to that of the system that followed the conventional practices, and potent health of rice ecosystem. In Cambodia, Nuth (2000) reported that the result from field studies carried out from 187 IPM farmers field schools (IPM FFSs) conducted countrywide in 1998 indicated that rice yield and economic benefit per hectare of IPM plots was 10% and 14% greater than those of farmer practice plots. In China, Mangan *et al.* (1998) reported that rice farmers' net return increased 18.8% after practicing IPM. In India, Suri *et al.* (1992) reported that the net realized profit varies from US$42.3 to 57.9 per hectare. In Thailand, net incomes of farmers practicing IPM in one area were three times higher than the non-IPM's (Rumakom *et al.*, 1992). According to van de Fliert (1993), the economic effects measured in the IPM programs are not overwhelming but they are encouraging.

Sustainability is another important component of IPM approach (Reitz *et al.*, 1999). Major concerns in pest management are the evolution of pesticide resistance and depletion of natural enemies; both have the potential to give rise to pest outbreaks. Assessment of pest intensity prior to carrying out certain pest management control methods is considered very important. Because this process would allow farmers to use their holistic approach to analyse and decide whether or not an expedient pest control action is necessary. In the case of present study, where pest intensity was very low, the prophylactic spray of insecticide as part of pest management efforts to shield crop yield was definitely unjustifiable in many respects. The resultant evidence of the conventional pest control practice included not only a reduced economic returns but also harmful effects to the pest-natural enemy trophic chain in the system. Although striking negative effects were not present, the numerical decline in both the populations of parasitoids and predatory insects in the treated system in comparison with the non-treated ones already signaled the possible worse case scenarios of pest situation in the future if such an unsound pest control practice is continued.

However, although this field study was undertaken with consideration of problems found at the farm level, the results cannot fully delineate the effects, biologically and economically, of the conventional pest control approach implemented by rice farmers in the surveyed area because of the discrepancy in locations of experimental site. Specific conditions of Chiang Mai valley may have different ecological and climatic conditions from the survey area in Cambodia. The difference in these biophysical conditions may have somehow distorted the effectiveness of the pest control measure taken.

In summary, the results of the study indicated a consistency with many hypothesizes pertinent to the strength of the IPM paradigm in that it can reduce insecticide use without sacrificing yield or inflating costs. In reality, however, the implementation of IPM at the farm level has continued to lag (Reitz *et al.*, 1999). Its complexity and intangible economic benefit seem to be two major constraints to adoption by farmers. In addition, frequent field surveillance on a weekly basis required by IPM against the 3 to 4 times usually practiced under the conventional approach is obviously more tedious. Nevertheless, this should not be allowed to back down the maneuver to seeding IPM in the farm levels. Instead, concerted efforts and commitments must be stepped up to overcome these impediments by providing farmers with a convincing reason (i.e. economic incentives) to adopt more IPM tactics. Farmers should be well aware of the fact that frequent field observation is a common trade-off they have to encounter in implementing the IPM tactics. But, if this trade-off is accepted by the majority of the farmers in a particular community it would turn out to be a sort of social movement through which a strong and effective social capital is founded. With this social capital, the farmers would have a more stable economic benefit from rice production in both the short and long-term. Therefore, it is necessary that farmers are encouraged to practice IPM on a group or community basis rather than an individual basis.