CHAPTER 5

RESULTS OF FIELD EXPERIMENT

5.1. Dynamics of green leafhoppers (GLH) population

5.1.1. Dynamics of adults of *Nephotettix* spp. detected by light trap

Leafhopper populations collected throughout the rice growing season, during which 39 light trap observations were recorded, indicated that *N. virescens* were more abundant than *N. nigropictus* (Figure 2). Nevertheless, *N. nigropictus* were observed becoming more abundant in some periods just before and after the peak of population of *N. virescens*. An almost overlapping low numbers of leafhoppers were recorded at early stage of rice growth, which was about 45 days after transplanting (DAT). Afterwards, remarkably high populations, with the peak of populations recorded at 88 DAT, were observed fluctuating until 120 DAT. Followed this was a drastic decline in leafhopper populations, the periods where no leafhopper was captured in the last 4 observations.

In summary, on a monthly basis, the trends of data showed that October was the month of leafhopper population build up, which is very consistent with the natural behavior of colonizing rice fields by these species cited by many researchers. Means of populations of both species, 44.6 for *N. virescens* and 41.4 for *N. nigropictus*, captured by the light trap during October were almost equal, which were not statistically significant according to Two-tailed Student's t-test (p>0.05). It was observed as well that males of *N. virescens* were captured more frequently by the light trap than females. As revealed in this study, the result concerning the trends of temporal abundance of leafhopper population in the system is quite similar to the findings of Ishii-Eiteman's study conducted in the past 8 years.

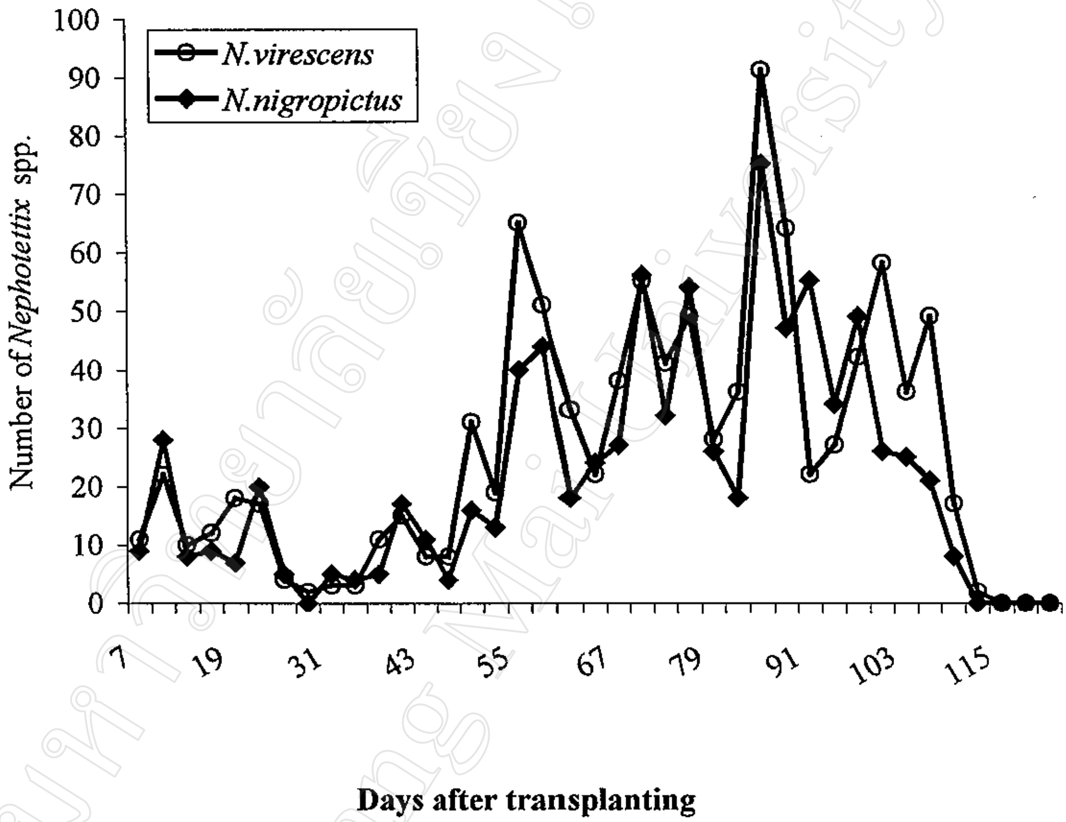


Figure 2. Trends of population dynamics of *Nephotettix* spp. detected from 07 August to 29 November 2001 by light trap placed in the vicinity of experimental rice systems conducted at the Irrigated Research Station of Chiang Mai University.

However, a complete difference is that while Ishii-Eiteman found that *N. nigropictus* was the predominant species the result of this study switched to *N. virescens*. The change in species dominance, which may have been made possible due to changes in rice cropping practices, from the less to the more virulent one should be taken seriously as an alarm to rice production in Chiang Mai valley.

5.1.2. Dynamics and abundance of *Nephotettix* spp. observed by visual count

Estimation of dynamics and abundance of leafhoppers by direct visual count revealed a very low number of populations of both *N. virescens* and *N. nigropictus* in all systems throughout the season (Figure 3). Result of analysis of variance indicated neither the number of individual species nor the sum of both species has led to statistical differences among the systems (Table 22 & 23).

Table 22. Analysis of variance of *Nephotettix* spp. recorded by direct visual count.

Source of variation	Significance level		
	All *Nephotettix* spp.	*N. virescens*	*N. nigropictus*
Replication (A)	ns	ns	ns
System (B)	ns	ns	ns
CV (%)	42.69	45.07	60.17

^{ns} indicates non-significance

Table 23. Mean number of *Nephotettix* spp. populations recorded weekly by direct visual count on 3 rice hills from 11 August to 03 November 2001 in experimental systems conducted at the Irrigated Research Station of Chiang Mai University.

System	Mean number of green leafhoppers		
	All *Nephotettix* spp	*N. virescens*	*N. nigropictus*
CPMS	3	1.25	1.75
IPMS	4.5	2	2.5
LIRCS	3.75	1.75	2
Overall Mean	3.75	1.66	2

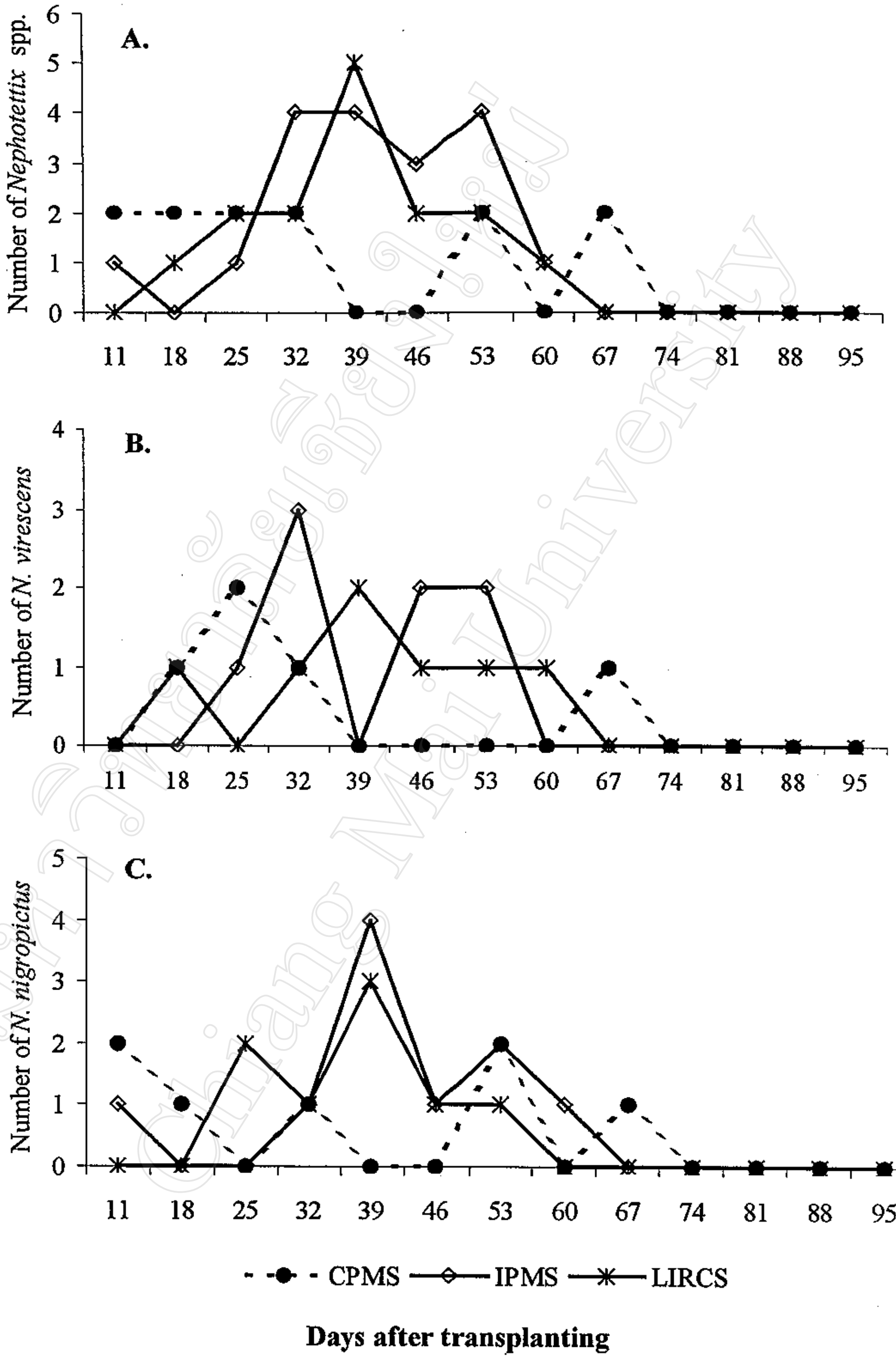


Figure 3. Dynamics of *Nephotettix* spp. in experimental systems observed weekly by direct visual count on 3 rice hills from 11 August to 03 November 2001. (A) All *Nephotettix* spp. (B) *N. virescens*. (C) *N. nigropictus*. In legend, "CPMS" refers to the Cambodian Pest Management System; "IPMS" refers to the Integrated Pest Management System; and "LIRCS" refers to Low Input Rice Cultivation System.

It was observed that higher numbers of both leafhopper populations occurred in IPM system. However, the peaks of population of *N.virescens* and *N. nigropictus* at 39 DAT were recorded in the LIRC system. Both *N. virescens* and *N. nigropictus* were more abundant in the CPM system at the first field observation. A rapid domination of leafhoppers species in the CPM system may have been caused by the better quality of the crop due to higher rate of inorganic fertilizer applications. Their populations in the CPM system, however, dropped to zero within the periods of 39 to 46 DAT, which was one and two weeks after the first insecticide spray. A sharp decline in densities of *N. virescens* population in the CPM system continued through the entire remaining observation periods, except at 67 DAT when only one *N. virescens* was recorded. On the contrary, however, the populations of *N. virescens* were present in the IPM and LIRC system until 53 DAT and 60 DAT, respectively.

Distinct population dynamics of *N. virescens* in the IPM and LIRC system could be seen at early and middle stage of rice growth. During early growth stage of rice, beginning from 18 to 39 DAT, the population peak of *N. virescens* first appeared in IPM system at 32 DAT and then switched to LIRC system at 39 DAT. The next 4 field observations during the middle stage of rice growth, covering the periods of 46, 53, 60, and 67 DAT, were the periods when the trends of population dynamics of *N. virescens* were of similar fashion. Their populations in both systems became stable, although occurred in different population sizes.

The number of population of *N. nigropictus* in the CPM system followed a contradicting fashion as compared to *N. virescens*. As their populations at the early stage of rice growth were dropping, *N. virescens* populations were increasing. Another case could be observed at 53 DAT. While no a single *N. virescens* was found after the spray of insecticide, *N. nigropictus* population at this date regained its former level of population size occurred at the 11 DAT.

On the sampling date basis, the CPM system tended to have less relevance with the seasonal abundance of leafhoppers as compared with the light trap data trends. The already very low pest population could have been forced down by insecticide to the level that relationship could hardly be observed. However, thorough examination of data trends of the other two chemically untreated systems revealed that certain levels of correlation are visible at various points of time. The upward trends of leafhopper populations in the IPM and LIRC system at the first 3 observation periods, i.e., 11, 18, and 25 DAT, for instance, were obviously consistent with the upward trends of leafhopper populations detected by light trap from 16 to 25 DAT. The downward trends of leafhopper populations in the IPM and LIRC system within 60 to 67 DAT and 74 to 81 DAT were also correlated with the downward trends of the light trap occurred from 60 to 70 DAT and 79 to 82 DAT, respectively. Another strong correlation was observed at 95 DAT. The zero number of leafhopper that occurred in the systems was very parallel to the sharp decline in numbers of leafhopper populations, especially the *N. virescens*, captured by the light trap.

In addition to data point-based comparisons as illustrated above, monthly-based data comparison was carried out. The results revealed a relatively strong correlation concerning the seasonal occurrence of leafhoppers in the systems only at early and middle crop period (from August to September). Both the total numbers of leafhoppers and individual species recorded by direct visual count showed that leafhopper abundance in the experimental field within these crop periods was on an increasing trend which was very consistent with that detected by the light trap. Data trends obtained from the direct visual count in October were not correlated with the light trap data trends at all. The population of leafhoppers in all systems was decreasing gradually whilst the population of leafhoppers caught by the light trap was increasing drastically.

5.1.3. Dynamics and abundance of *Nephotettix* spp. observed by sweep net

Numbers of populations of *N. virescens* and *N. nigropictus* recorded by sweep catches were respectively two and three-fold higher than those observed by direct visual count, and the highest numbers of leafhopper populations were recorded in LIRC system (Figure 4). An almost equal peak of leafhopper population size was recorded in the IPM and LIRC system at 46 DAT. With exception at 32 DAT that the numbers of leafhopper populations in the CPM system were relatively high, numbers of leafhopper populations caught in this system during the later periods were very much lower than those caught in the other two systems. However, analysis of variance indicated neither the number of individual species nor the sum of both species has led to statistical differences among the systems (Table 24 & 25).

Table 24. Analysis of variance of *Nephotettix* spp. recorded by sweep net.

Source of variation	Significance level		
	All *Nephotettix* spp.	*N. virescens*	*N. nigropictus*
Replication (A)	ns	ns	ns
System (B)	ns	ns	ns
CV (%)	16.33	40.61	27.32

ns indicates non-significance

Table 25. Mean number of *Nephotettix* spp. populations recorded weekly by 3 sweep nets from 11 August to 27 October 2001 in experimental systems conducted at the Irrigated Research Station of Chiang Mai University.

System	Mean number of green leafhoppers		
	All *Nephotettix* spp.	*N. virescens*	*N. nigropictus*
CPMS	7.5	4	3.5
IPMS	11	4.25	6.75
LIRCS	12	3.5	8.5
Overall Mean	10.16	3.91	6.25

The trends of data obtained by sweeping showed that *N. virescens* moved into and colonized the fields and started to build up their population quicker than *N. nigropictus*. Higher number of *N. virescens* population in the fields was recorded since the first sweeping, which was 11 DAT, while the presence of *N. nigropictus* was observed in the second sweeping, which was 18 DAT. The presence of both species of leafhoppers in all systems continued until the last growth stage of the crop, although occurred in lower numbers.

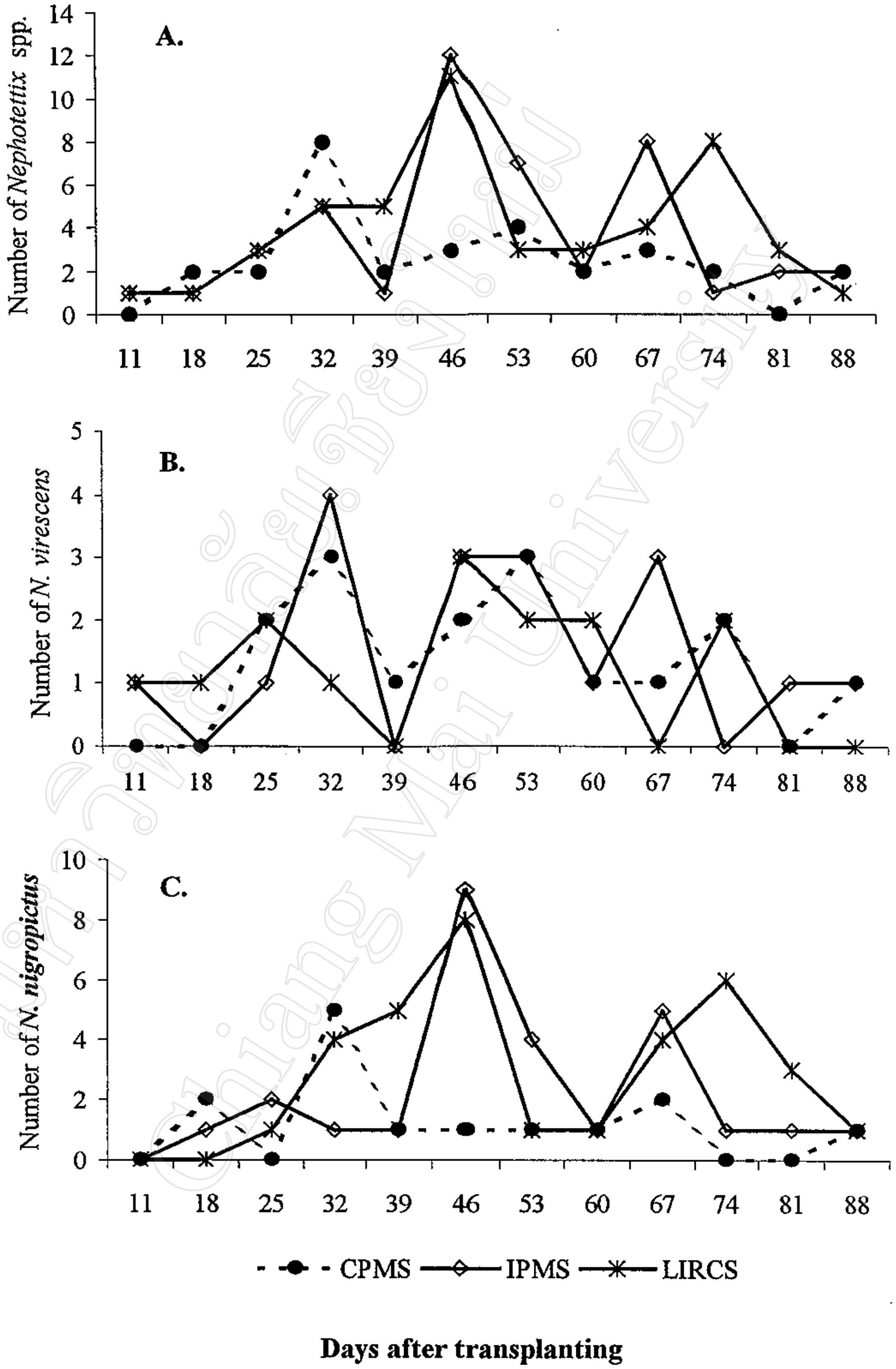


Figure 4. Dynamics of *Nephotettix* spp. in experimental systems observed weekly by 3 sweep nets from 11 August to 27 October 2001. **(A)** All *Nephotettix* spp. **(B)** *N. virescens*. **(C)** *N. nigropictus*. In legend, "CPMS" refers to the Cambodian Pest Management System; "IPMS" refers to the Integrated Pest Management System; and "LIRCS" refers to Low Input Rice Cultivation System.

The trends of population peaks varied significantly between systems and growth stages of rice. The first population peak of *N. virescens* occurred in IPM system at 32 DAT. The lower population peak of the same date was observed in the CPM system. The subsequent week was the period of a sharp decline of *N. virescens* population in all systems; only a single insect was captured in the CPM system. Their second population peaks in all systems, though with relatively lower numbers as compared with the first's, were observed at 46 DAT and 53 DAT. With an exception of the IPM system wherein the population of *N. virescens* at 67 DAT jumped up again to the level of the second population peaks, following these periods, the populations of *N. virescens* in all systems were moving with a declining trend. It is thus apparent that the *N. viresecens* population decreased with times.

N. nigropictus was found more abundant in the LIRC system while a very low population of *N. nigropictus* was found in the CPM system throughout the observation periods. Their population in the LIRC system followed an increasing fashion within the periods from 18 to 39 DAT and reached the peak at 46 DAT. This is not, however, the highest peak as compared with that occurred at the same sampling date in the IPM system. The number of *N. nigropictus* population, which had been low within the periods when an increasing trend was observed in the LIRC system, augmented abruptly to the highest point, which can be considered as the highest population peak representing the abundance of this species in the experimental rice field. The later two sampling dates, 53 DAT and 60 DAT, were the periods when all systems experienced a sharp decline in numbers of *N. nigropictus* populations. Nevertheless, their populations in the LIRC and IPM system became active again at 60 DAT and 74 DAT, respectively. Following these periods, the population of this species of leafhopper was on a downward trend, although they were more abundant in the LIRC system.

In the same manner to the trend of data obtained by direct visual count, correlation of the trends of sweep catch data with the light trap data cannot be found all across the observation periods and the systems. Only at some points of times that the abundance of each species of leafhopper in the experimental field indicated certain levels of correlations. The first correlation is clearly visible at the early growth stage of rice of 11, 18, and 25 DAT. During these crop periods, the upward trends of *N. virescens* population in all systems were consistent with the upward trends generated by the light trap from 16 to 25 DAT. There was less correlation between the two trends within the periods from 25 to 39 DAT. Only data collected from the IPM system that completely followed the downward trend of the light trap data. Data collected from LIRC and CPM system within these periods was running upward until 32 DAT before approaching a common trend with the IPM system at 39 DAT, a period when a drastic decline in *N. virescens* population was observed in the two systems. Population dynamics in all systems observed by sweep net within the periods from 46 to 53 DAT were also correlated with the light trap data trends observed from 46 to 52 DAT. In the following periods, from 53 to 60 DAT, however, populations captured by sweep net were not correlated with the populations caught by light trap within similar dates. It was noticed that, while light trap indicated an increasing trend of *N. virescens* population, the infestation of this pest in the experimental field followed a decreasing trend. From these periods on, significant correlation of the data trends prevailed. Populations of *N. virescens* captured by these two methods were decreasing gradually.

Again, comparison of monthly data trends obtained from the sweep catches with those of the light trap revealed the same result as the data trends of the direct visual count. August and September were the months of population build up of leafhoppers in the experimental field. Populations of both *Nephotettix* spp. in all systems usually started to increase since the early crop period (August) and subsequently reached their peaks in the middle crop period (September). Whereas October was the month when leafhopper population in the systems started to decline, this was inconsistent with the light trap data trends.

5.2. Complex pressures by natural enemies on *Nephotettix* spp. egg mortality

5.2.1. Oviposition trends of *Nephotettix* spp.

Result of the analysis of variance indicated a significant difference in number of egg populations in the CPM system from the IPM and LIRC system whose numbers of egg population were not significantly different (Table 26). It can be seen from Table 27, mean egg population per 3 potted rice hills of 323 retrieved from the CPM system was the highest mean and significantly different from those in the other two systems.

Table 26. Analysis of variance of *Nephotettix* spp. egg population.

Source of variation	Significance level
Replication (A)	*
System (B)	**
CV (%)	65.41

* indicates significance at 5% level; ** indicates significance at 1% level.

Table 27. Mean number of *Nephotettix* spp. egg population found on 3 potted rice hills placed and retrieved weekly from 11 August to 13 October 2001 from the experimental rice fields conducted in the Irrigated Research Station of Chiang Mai University.

System	Mean egg population	Significance (LSD)
CPMS	323	a
IPMS	101.5	b
LIRCS	115.5	b

Note: - Means followed by a common letter are not significantly different at 5% level.

- $LSD_{0.05}$ for comparison = 77.6

Oviposition trends of *Nephottetix* spp. in the systems are presented in Figure 5. It showed that the 10-week-sample collection starting from 11 DAT resulted in a trend with 3 different oviposition periods, each characterized by different numbers of egg population of *Nephottetix* spp. in the systems.

The first period consisting of the first 4 field samplings carried out within the periods of 32 DAT was represented by a moderately high number of egg populations. The peaks of egg population in the three systems occurred at 25 DAT, having the highest peak existed in the CPM system. The subsequent week, which was at 32 DAT, was the period when egg population in all systems declined. However, while numbers of egg population in the IPM and LIRC system were sharply down, numbers of egg population found in the CPM system remained considerably high.

The second oviposition period, two weeks after the first peaks were observed, was the time when the highest numbers of egg population in all systems were recorded, with the peaks reached at 39 DAT. Still, the higher number was found in the CPM system. In addition, it was noticed that there was a change in the egg-laying trend within the other two systems. The numbers of egg population in the LIRC system, which were lower than the IPM system during the first period, were found to be higher.

The third period was observed commencing from the 6th sample collection, which was at 46 DAT, throughout the rest of the sampling periods. Very low numbers of egg population were recorded in all systems. However, it was apparent that a slightly higher number remained observable in the CPM system.

In general, although the trends of oviposition of *Nephotettix* spp. significantly changed with times, resulting in varying numbers of egg population, it was evident that the changing trends within systems have followed a uniform manner. An increase or a decrease in numbers of egg population in the systems appeared to have gone side by side.

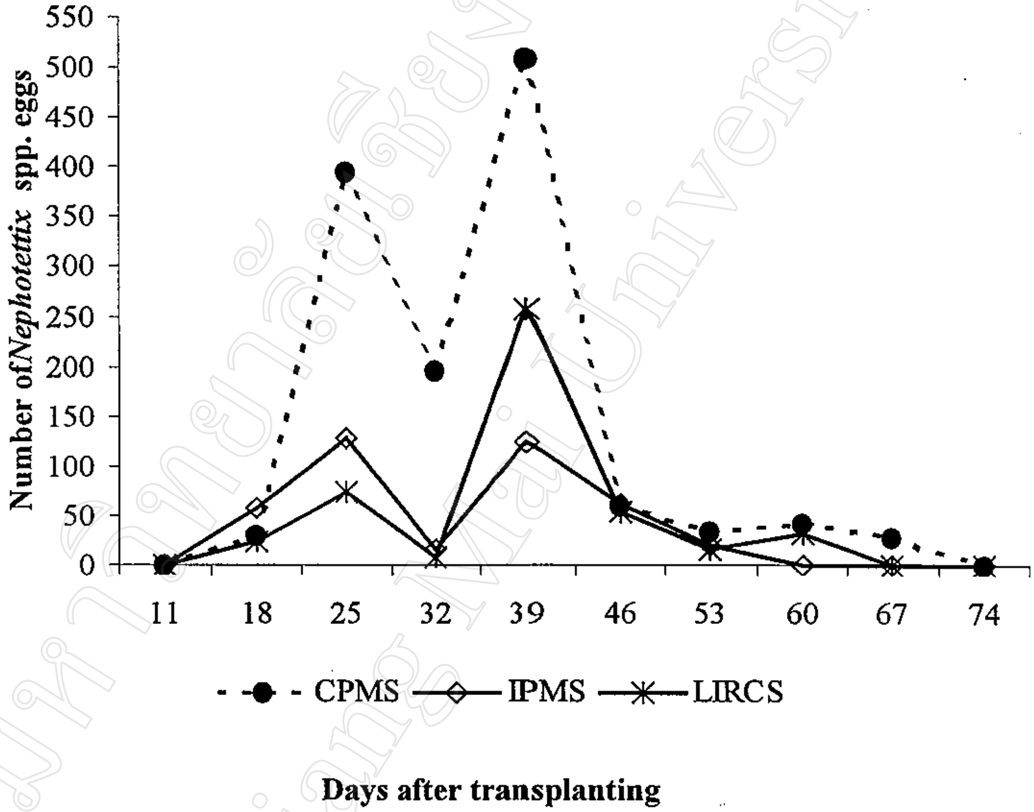


Figure 5. Oviposition trends of *Nephotettix* spp. recorded weekly from 11 August to 13 October 2001 on 3 potted rice hills from experimental systems. In legend, "CPMS" refers to the Cambodian Pest Management System; "IPMS" refers to the Integrated Pest Management System; and "LIRCS" refers to Low Input Rice Cultivation System.

5.2.2. Identification of natural enemies of *Nephotettix* spp. eggs

In the course of observation, 360 plant samples collected from 11 DAT to 74 DAT were brought to the laboratory for identification of important natural enemies of *Nephotettix* spp. eggs in the experimental rice systems. Thorough whole plant examination done by dissecting all leaves and leaf sheaths revealed leafhopper egg masses containing healthy eggs, parasitized eggs, eggs damaged by predation, and the freshly abandoned egg cases remaining after healthy leafhopper emergence.

Three important natural enemies were identified to be determinants to certain levels of *Nephotettix* spp. egg damage. However, analysis of variance of compound pressures by these natural enemies indicated non-significant differences between the systems (Table 28). On average, 40% of *Nephotettix* spp. in the systems attacked by natural enemies (Table 29). Trends of complex pressures by these natural enemies are presented in Figure 6.

Table 28. Analysis of variance of *Nephotettix* spp. eggs damaged by natural enemies.

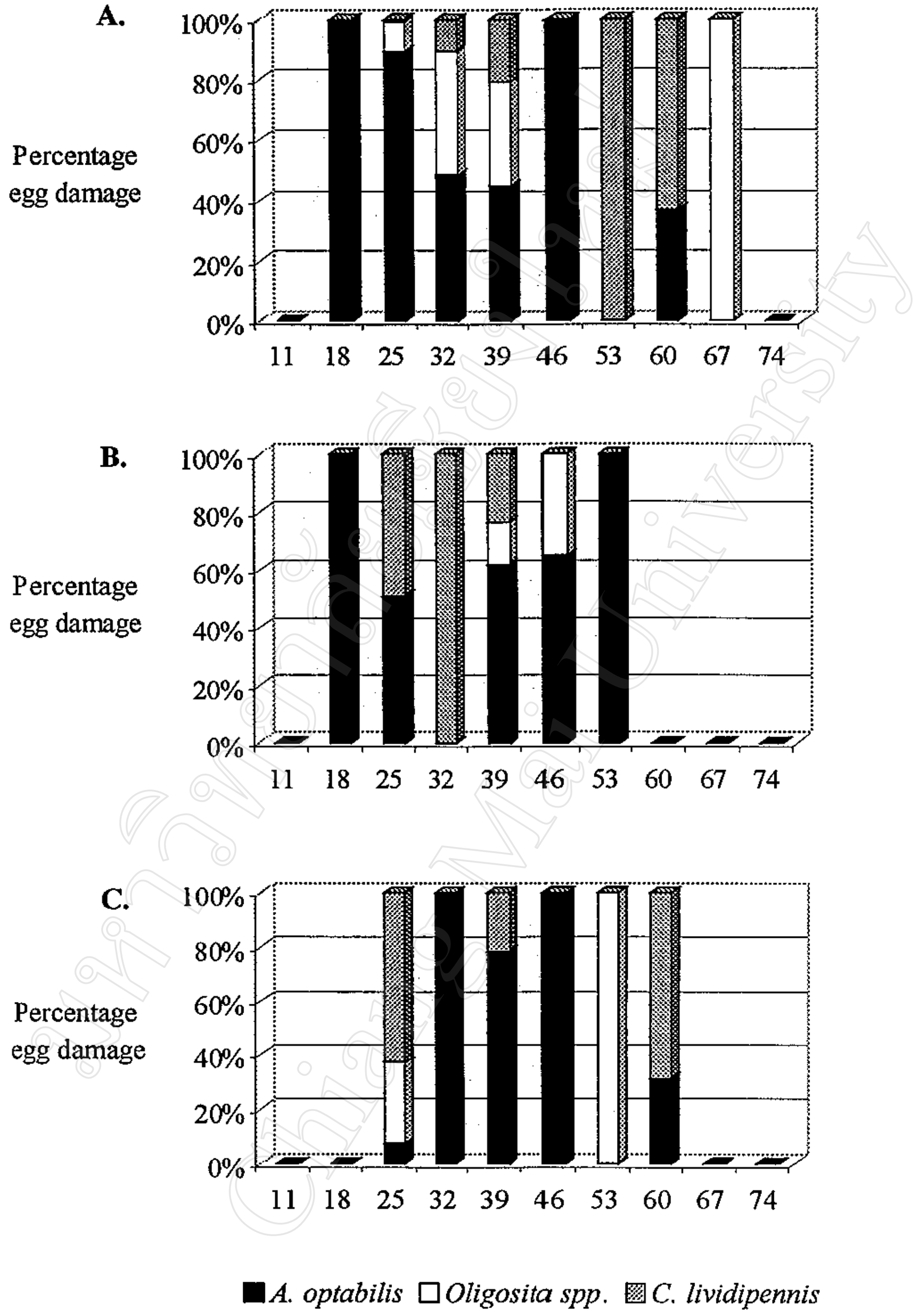
Source of variation	Significance level
Replication (A)	*
System (B)	ns
CV (%)	12.79

* indicates significance at 5% level.

ns indicates non-significance.

Table 29. Mean damage rate of *Nephotettix* spp. eggs found on 3 potted rice hills placed and retrieved weekly from 11 August to 13 October 2001 from experimental systems conducted at the Irrigated Research Station of Chiang Mai University.

System	Egg damage rate (%)
CPMS	39.82
IPMS	37.13
LIRCS	44.00
Overall Mean	40.31



Days after transplanting

Figure 6. Trends of complex pressures by natural enemies to *Nephotettix* spp. egg damage in each system recorded on 3 potted rice hills placed and retrieved weekly from 11 August to 13 October 2001 from experimental systems. **(A)** Cambodian Pest Management System **(B)** Integrated Pest Management System **(C)** Low Input Rice Cultivation System.

Of the three important natural enemies that were identified to have contributed to these levels of leafhopper egg damage, two are parasitoids and another is egg predator. The two parasitioids were identified as *Anagrus optabilis* Perkins, and *Oligosita* sp. whereas egg predator was known as mirid bugs, *Cyrtorhinus lividipennis* Reuter. The confirmation of the identification of these natural enemies was made with the familiarization of the distinct discoloration of leafhopper eggs when damaged by each natural enemy. Eggs parasitized by *Anagrus optabilis* Perkins and *Oligosita* sp. are identified to be red and yellow, respectively, while eggs preyed upon by *Cyrtorhinus lividipennis* Reuter turn into black. The dynamics of their relative contributions to leafhopper egg mortality in each system are presented in Figure 7.

A. optabilis was a more abundant parasitoid than *Oligosita* sp. and *C. lividipennis*, and was active in all systems from the start of the season (Figure 7A). However, results of the analysis of variance of parasitism rates by this species among the systems indicated an insignificant difference (Table 30). Overall mean parasitism rate on leafhopper eggs in the systems by *A. optabilis* was 24% (Table 31).

Table 30. Analysis of variance of *Nephotettix* spp. eggs parasitized by *A. optabilis*.

Source of variation	Significance level
Replication (A)	ns
System (B)	ns
CV (%)	15.33

ns indicates non-significance .

Table 31. Mean parasitism rates by *A. optabilis* on *Nephotettix* spp. eggs found on 3 potted rice hills placed and retrieved weekly from 11 August to 13 October 2001 from experimental systems conducted at the Irrigated Research Station of Chiang Mai University.

System	Egg parasitism rate (%)
CPMS	27.98
IPMS	23.15
LIRCS	22.19
Overall Mean	24.44

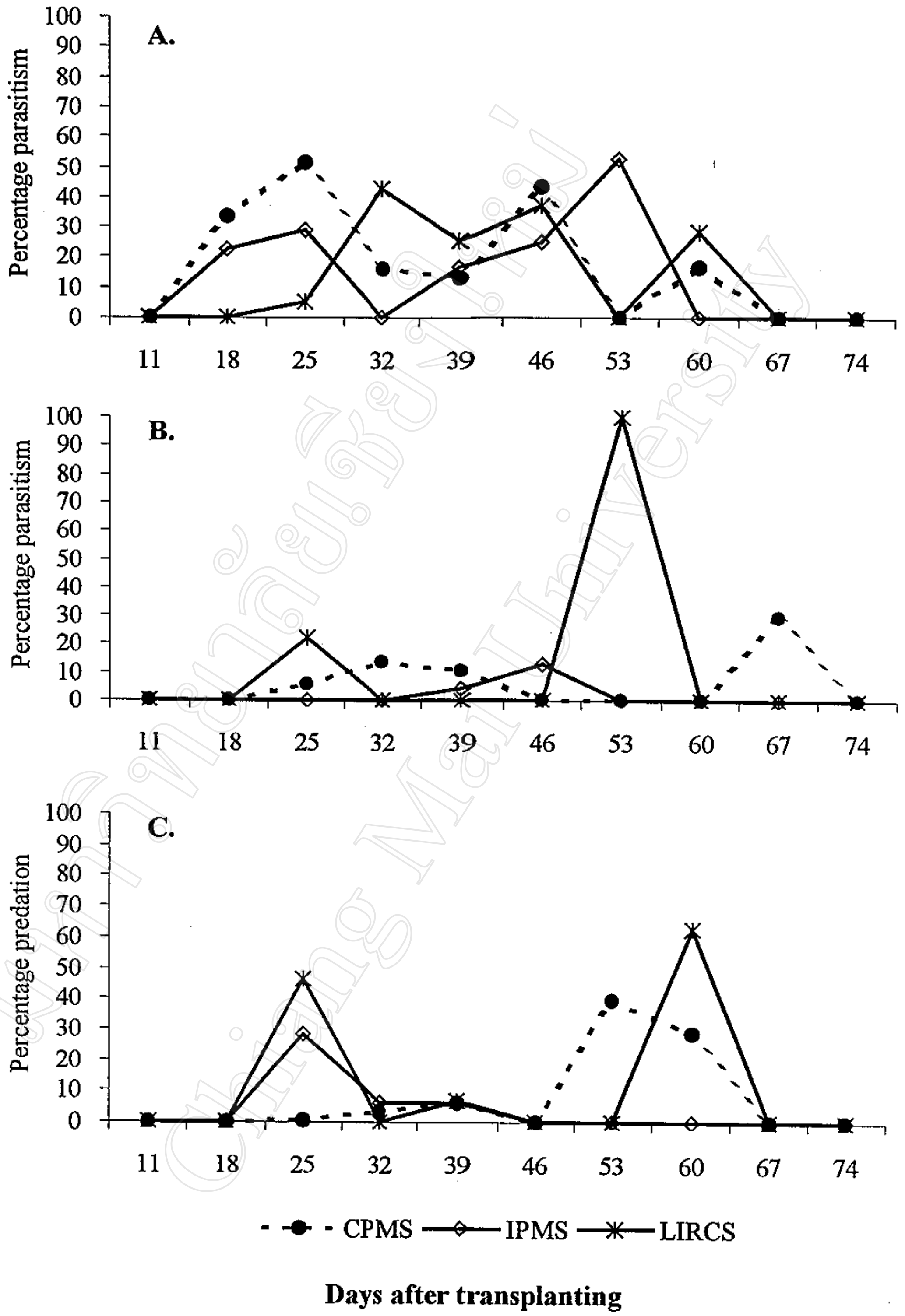


Figure 7. Percentage of *Nephotettix* spp. eggs damaged by each natural enemy recorded on 3 potted rice hills placed and retrieved weekly from 11 August to 13 October 2001 from experimental systems. **(A)** *A. optabilis* **(B)** *Oligosita* sp. **(C)** *C. lividipennis*. In legend, "CPMS" refers to the Cambodian Pest Management System; "IPMS" refers to the Integrated Pest Management System; and "LIRCS" refers to Low Input Rice Cultivation System.

In general, parasitism activities by *A. optabilis* in the experimental systems were fluctuating throughout the observation periods. Fairly high parasitism activity by this species during the early season, which was within 25 DAT, first occurred in the CPM system in which roughly 50% of leafhopper eggs were parasitized. *A. optabilis* activities later switched to the LIRC system in the periods of 32 DAT to 46 DAT, the periods when approximately 40% of egg parasitism was recorded. And they switched again to the IPM system at 53 DAT with more than 50% of leafhopper eggs were then parasitized. Parasitism rates by this species in the LIRC and CPM system at 60 DAT was 28% and 17%, respectively. Inactivity of *A. optabilis* parasitoid was observed at the last two observation dates.

Parasitism activities by *Oligosita* sp. in all systems were very low across the observation periods (Figure 7B). Its parasitism rate in the CPM system was somehow slightly higher than those in the other two systems. However, result of analysis of variance revealed that there were no significant differences (Table 32). On average, 6% of eggs found in the systems were attacked by *Oligosita* sp. (Table 33).

Table 32. Analysis of variance of *Nephotettix* spp. eggs parasitized by *Oligosita* sp..

Source of variation	Significance level
Replication (A)	ns
System (B)	ns
CV (%)	46

^{ns} indicates non-significance .

Table 33. Mean parasitism rates by *Oligosita* sp. on *Nephotettix* spp. eggs found on 3 potted rice hills placed and retrieved weekly from 11 August to 13 October 2001 from experimental systems conducted at the Irrigated Research Station of Chiang Mai University.

System	Egg parasitism rate (%)
CPMS	7.68
IPMS	5.63
LIRCS	4.39
Overall Mean	6

Parasitism activities by *Oligosita* sp. reached their highest point at 53 DAT. All leafhopper eggs on plants retrieved from the LIRC system on this date were found 100% parasitized by *Oligosita* sp. Exponentially-like low trend of parasitism, varying from 6% to 14%, by this parasitoid occurred in the CPM system within the periods of 18 DAT to 46 DAT. Parasitism activities by *Oligosita* sp. in the IPM system were extremely low because only at 46 DAT that a low percentage of leafhopper eggs, 13%, was found parasitized. No parasitism activity was found in the IPM and LIRC system during the last three observations of 60, 67 and 74 DAT, but in the CPM system in which roughly 30% of egg found parasitized.

Predation activities by *Cyrtorhinus lividipennis* Reuter were fairly significant at 3 different observation dates (Figure 7C). Result of analysis of variance revealed that its mean predation rate of 16.6% on leafhopper eggs in the LIRC system was significantly different from those in the CPM and IPM system (Table 34 & 35).

Table 34. Analysis of variance of *Nephotettix* spp. eggs preyed by *C. lividipennis*.

Source of variation	Significance level
Replication (A)	*
System (B)	*
CV (%)	56.58

* indicates significance at 5% level.

Table 35. Mean predation rates by *C. lividipennis* on *Nephotettix* spp. eggs found on 3 potted rice hills placed and retrieved weekly from 11 August to 13 October 2001 from experimental systems conducted at the Irrigated Research Station of Chiang Mai University.

System	Egg predation rate (%)
CPMS	4.16^{cb}
IPMS	10.40^{ab}
LIRCS	16.61^{a}

Note: - Means followed by a common letter are not significantly different at 5% level.

- $LSD_{0.05}$ for comparison of mean predation rates by *C. lividipennis* = 9.86

They first became active in the LIRC and IPM system at 25 DAT. Predation activities by *C. lividipennis* in both systems at this early stage caused mortality of leafhopper eggs at the rate of 47% and 28%, respectively. Following this was an insignificant predation activity occurred in all systems at 39 DAT. The second active period took place at 53 DAT. Their activities were, however, prevalent in the CPM system only and where 39% of leafhopper eggs on plants retrieved from this system were located preyed upon by *C. lividipennis*. The third predation activity occurred in the LIRC system at 60 DAT wherein 62.5% of leafhopper eggs found preyed upon, the highest predation rate ever recorded during the periods of observations.

5.3. Species diversity of natural enemies in the systems

5.3.1. Species diversity of natural enemies estimated by direct visual count

A total of 7 and 8 taxa belonging to 3 orders of predatory natural enemies of leafhoppers were respectively collected from the CPM and IPM system, and LIRC system. It was observed that while some lady beetles, *Synharmonia* sp. [Family: Coccinellidae], were found in the IPM and LIRC system, they were not present in the CPM system at all. A total of individuals of natural enemies collected in every seven days commencing from 11 to 95 DAT in the CPM, IPM and LIRC system was 47, 52 and 56, respectively. Although the numbers of predator population in the non-insecticide-treated systems were higher than that in the treated system, result obtained from the analysis of variance indicated that there were no statistical differences ($p>0.05$). A list of taxa and their abundance at each observation period in each system is shown in Table 36, 37, and 38.

In general, *Agriocnemis* spp. [Family: Agrionidae] was the most common predator in the 3 experimental systems with their relative abundance in the CPM, IPM and LIRC system of 42.5% (n=20), 42.3% (n=22) and 32% (n=18), respectively. *Oxyopes javanus* [Family: Oxyopidae] and *Tetragnatha* spp. [Family: Tetragnathidae], with their respective relative abundance of 23.4% (n=11) and 17% (n=8), was the second and third most abundant predator in the CPM system. In the

IPM system, *Tetragnatha* spp. [Family: Tetragnathidae], with relative abundance of 15.4% (n=8), was the second most common predator, whereas *Ophionea nigrofasciata* sp. [Family: Carabidae], with relative abundance of 3.4% (n=7) was the third common one. The second most common predators in the LIRC system were *Tetragnatha* spp. [Family: Tetragnathidae] and *Oxyopes javanus* [Family: Oxyopidae], with relative abundance of 19.6% (n=11) and the *Callitrichia formosana* [Family: Linyphiidae] and *Synharmonia* sp. [Family: Coccinellidae], with relative abundance of 7% (n=4), were the third most common predators. Other predators such as *Lycosa pseudoannulata* [Family: Lycosidae], *Agriope catenulata* [Family: Araneidae], were also found to be present in the experimental systems.

Two different observable population peaks of predatory natural enemies in the experimental systems were recorded at 25 DAT and 53 DAT, respectively (Figure 8). Relatively high populations of natural enemies in all systems were recorded at the first 4 field observation dates, i.e., 11, 18, 25, and 32 DAT, in which the highest peak was recorded in the CPM system at 25 DAT. Their populations dropped drastically in the following two observation dates (39 and 46 DAT). Thereafter, the populations of the predatory natural enemies in the systems, again, began to increase sharply and all reached the peaks at 53 DAT. However, it was noticed that while the same highest peak took place in the two non-insecticide-sprayed systems, the population peak in insecticide-sprayed system (CPMS) was rather lower, which was equivalent to the former peak that occurred at 25 DAT. In the subsequent weeks, i.e., 60, 67, 74 and 81 DAT, the numbers of populations of predatory natural enemies in all systems followed a declining trend. It was, however, observed that population seemed to start to increase slightly again at 88 and 95 DAT.

Based on the data presented in Table 36, 37 & 38 species diversity indices of natural enemies were computed by using Simpson formula. The highest (5.46), moderately high (4.37), and the low (3.88) index value was found in the LIRC, IPM, and CPM system, respectively.

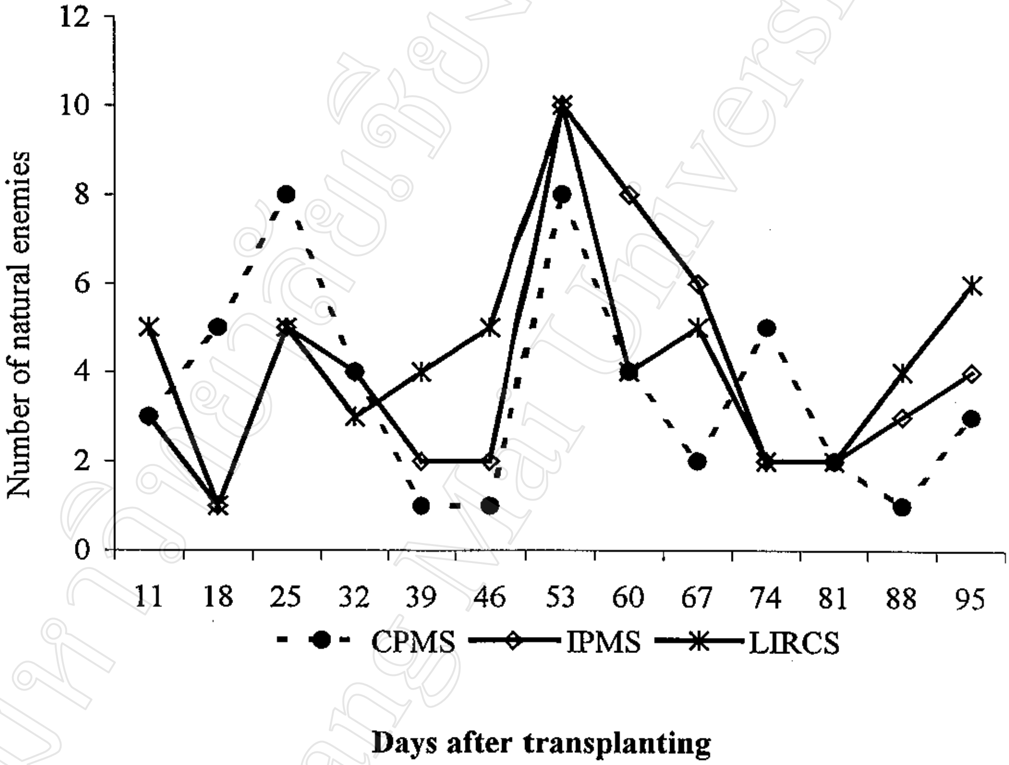


Figure 8. Abundance of natural enemies in experimental systems recorded weekly by direct visual count on 3 rice hills from 11 August to 03 November 2001. In legend, "CPMS" refers to the Cambodian Pest Management System; "IPMS" refers to the Integrated Pest Management System; and "LIRCS" refers to Low Input Rice Cultivation System.

The differences in index value reflect the abundance and distribution of species diversity of natural enemies in the systems. The higher index values in the non-insecticide-sprayed systems reveal that the systems are more diverse in terms of biodiversity and are thus more stable than the insecticide-treated system. Therefore, the results suggested that although a reduction in population of natural enemies in the chemically treated system did not yield a statistical difference as compared with those of the no-treated systems, the spray of insecticide still induced a certain level of adverse effect on the friendly insects and animals. From this point of view, it may be possible to foresee that rice production under continued insecticide application would eventually lead to depletion of natural enemies. The consequence will eventually result in pest resurgence and outbreaks.

Table 36. Abundance of predators in CPMS recorded by direct visual count in every seven days (11-95 DAT) 2001.

Order	Family	Species		Observation period (Days after transplanting)												
				11	18	25	32	39	46	53	60	67	74	81	88	95
Odonata	Agrionidae	*Agriocnemis* spp.		1	4	0	1	1	0	4	2	1	2	1	1	2
Araneae	Lycosidae	*Lycosa pseudoannulata*		0	0	2	1	0	0	0	0	0	0	0	0	0
	Tetragnathidae	*Tetragnatha* spp.		1	0	3	1	0	1	2	0	0	0	0	0	0
	Linyphiidae	*Callitrichia formosana*		1	1	0	0	0	0	0	0	0	0	0	0	0
	Oxyopidae	*Oxyopes javanus*		0	0	1	1	0	0	2	2	1	3	1	0	0
	Araneidae	*Agriope catenulate*		0	0	2	0	0	0	0	0	0	0	0	0	0
Coleoptera	Carabidae	*Ophionea nigrofasciata* sp.		0	0	0	0	0	0	0	0	0	0	0	0	1
		Total number of Individuals	N=	3	5	8	4	1	1	8	4	2	5	2	1	3
		Total number of Species	S =	3	2	3	4	1	1	3	2	2	2	2	1	2

Note: Simpson species diversity index = 3.88

Table 37. Abundance of predators in IPMS recorded by direct visual count in every seven days (11-95 DAT) 2001.

Order	Family	Species		Observation period (Days after transplanting)												
				11	18	25	32	39	46	53	60	67	74	81	88	95
Odonata	Agrionidae	*Agriocnemis* spp.		0	0	2	0	1	1	4	5	3	2	2	1	1
Araneae	Lycosidae	*Lycosa pseudoannulata*		0	1	1	0	0	0	0	1	2	0	0	0	0
	Tetragnathidae	*Tetragnatha* spp.		2	0	0	1	1	0	3	0	1	0	0	0	0
	Linyphiidae	*Callitrichia formosana*		0	0	1	0	0	0	0	0	0	0	0	0	1
	Oxyopidae	*Oxyopes javanus*		1	0	0	1	0	1	1	0	0	0	0	0	0
	Araneidae	*Agriope catenulate*		0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	Coccinellidae	*Synharmonia octomaculata* sp.		0	0	0	1	0	0	1	0	0	0	0	2	0
	Carabidae	*Ophionea nigrofasciata* sp.		0	0	1	1	0	0	1	2	0	0	0	0	2
		Total number of Individuals	N=	3	1	5	4	2	2	10	8	6	2	2	3	4
		Total number of Species	S =	2	1	4	4	2	2	5	3	3	1	1	2	3

Note: Simpson species diversity index = 4.37

Table 38. Abundance of predators in LIRCS recorded by direct visual count in every seven days (11-95 DAT) 2001.

Order	Family	Species		Observation period (Days after transplanting)												
				11	18	25	32	39	46	53	60	67	74	81	88	95
Odonata	Agrionidae	*Agriocnemis* spp.		1	0	1	0	0	2	4	2	2	1	1	2	2
Araneae	Lycosidae	*Lycosa pseudoannulata*		0	0	0	1	1	0	1	0	0	0	0	0	0
	Tetragnathidae	*Tetragnatha* spp.		1	1	1	2	2	0	2	0	1	0	1	0	0
	Linyphiidae	*Callitrichia formosana*		1	0	2	0	0	1	0	0	0	0	0	0	0
	Oxyopidae	*Oxyopes javanus*		1	0	0	0	1	0	3	2	0	1	0	1	2
	Araneidae	*Agriope catenulate*		1	0	1	0	0	0	0	0	0	0	0	0	0
Coleoptera	Coccinellidae	*Synharmonia octomaculata* sp.		0	0	0	0	0	1	0	0	0	0	0	1	2
	Carabidae	*Ophionea nigrofasciata* sp.		0	0	0	0	0	1	0	0	2	0	0	0	0
		Total number of Individuals	N=	5	1	5	3	4	5	10	4	5	2	2	4	6
		Total number of Species	S =	5	1	4	2	3	4	4	2	3	2	2	3	3

Note: Simpson species diversity index = 5.46

5.3.2. Species diversity estimated by sweep net

A total of 14 taxa belonging to 6 and 5 orders, for the CPM and LIRC system respectively, and 16 taxa belonging to 6 orders, for the IPM system, of natural enemies were captured by sweep net. The total of individuals of natural enemies (predator and parasitoid) recorded weekly from 11 to 88 DAT in the CPM, IPM and LIRC system were 148, 177 and 172, respectively. It was obvious that the number of individuals in the CPM system in which a double spray of insecticide was carried out was lower than those in the other 2 non-treated systems. However, result of the analysis of variance indicated non-significant differences (p>0.05). A list of taxa and their abundance at each observation date in each system is presented in Table 39, 40 and 41. The dynamics of natural enemies in the systems is represented in Figure 9.

As shown in these tables, it was clear that predatory natural enemies were the dominants in all systems in terms of both percentage of species composition and numbers of individuals. The percentage of predators present in the CPM, IPM and LIRC system was 21.4, 31.25 and 28.57, respectively. The percentage of parasitoids found in the CPM, IPM and LIRC system was 8, 11.8 and 7.5, respectively.

In general, among the predatory natural enemies, *Tetragnatha* spp. [Family: Tetragnathidae] was most common in all systems. Their relative abundance in the CPM, IPM and LIRC system was 39% (n=58), 39.5% (n=70) and 43% (n=74) of the total numbers of individuals of natural enemies sampled respectively from each system. *Agriocnemis* spp. [Family: Agrionidae] was the second most common predator in the experimental systems with their relative abundance in the CPM, IPM and LIRC system at 25% (n=37), 24.2% (n=43) and 20.3% (n=35), respectively. It was noticed that there was a slight change in uniformity of the third most common predator species. Because while *Oxyopes javanus* [Family: Oxyopidae] was found to be the third most common predator species in the CPM and LIRC system, with their relative abundance of 6.5% (n=10) and 10.46% (n=18) respectively, the same ranking in the IPM system was found to be *Synharmonia* sp. [Family: Coccinellidae], with their relative abundance of 5% (n=9).

Gonatocerus spp. [Family: Mymaridae] and *Cyrtorhinus lividipennis* Reuter [Family: Miridae] were the first and second most common parasitoid in the CPM and IPM system, with their relative abundance in the CPM system of 4.7% (n=7) and 2.7% (n=4), and in the IPM system of 7.34% (n=13) and 1.7% (n=3). *Tetrastichus* sp. [Family: Eulophidae] was the third most predominant parasitoid in the CPM system although their relative abundance was very low, 0.67% (n=1), whereas *Trichogramma* sp. [Family: Trichogrammatidae] and *Temelucha sp.* [Family: Ichneumonidae] were all found to be the third most common parasitoids in the IPM and LIRC system, with their individual relative abundance of 1.1% (n=2) and 0.58% (n=1), respectively.

Figure 9 showed that population of natural enemies in all systems increased sharply in the early growth stage of rice with the population peaks reached at 32 DAT, in which the highest peak was recorded in the IPM system. The following weeks were the periods when a gradual decline in numbers of populations of natural enemies in all experimental systems was observed.

It was, however, seen that a drastic decline occurred in the CPM system at the 39 DAT, which was one week after the insecticide spray. Afterwards, numbers of population of natural enemies in this system started to increase again within the periods of 46, 53 and 60 DAT. Nevertheless, it was noticed that the increasing trend was not as significant as those in the other 2 systems. During the later periods, the downward trends occurred in the systems were of similar fashions.

Based on data presented in Table 39, 40 and 41 species diversity indices were calculated by using Simpson species diversity formula. Unlike the indices computed from the population of natural enemies recorded by direct visual count in which the index value of the CPM system was the lowest, the opposite index value of this system was found with the sweep net catch data. Although the CPM system's total number of individuals of natural enemies recorded was relatively lower than those in the IPM and LIRC system, its species diversity index value turned out to be notably high, which was equal to and even higher than that of the IPM and LIRC system respectively.

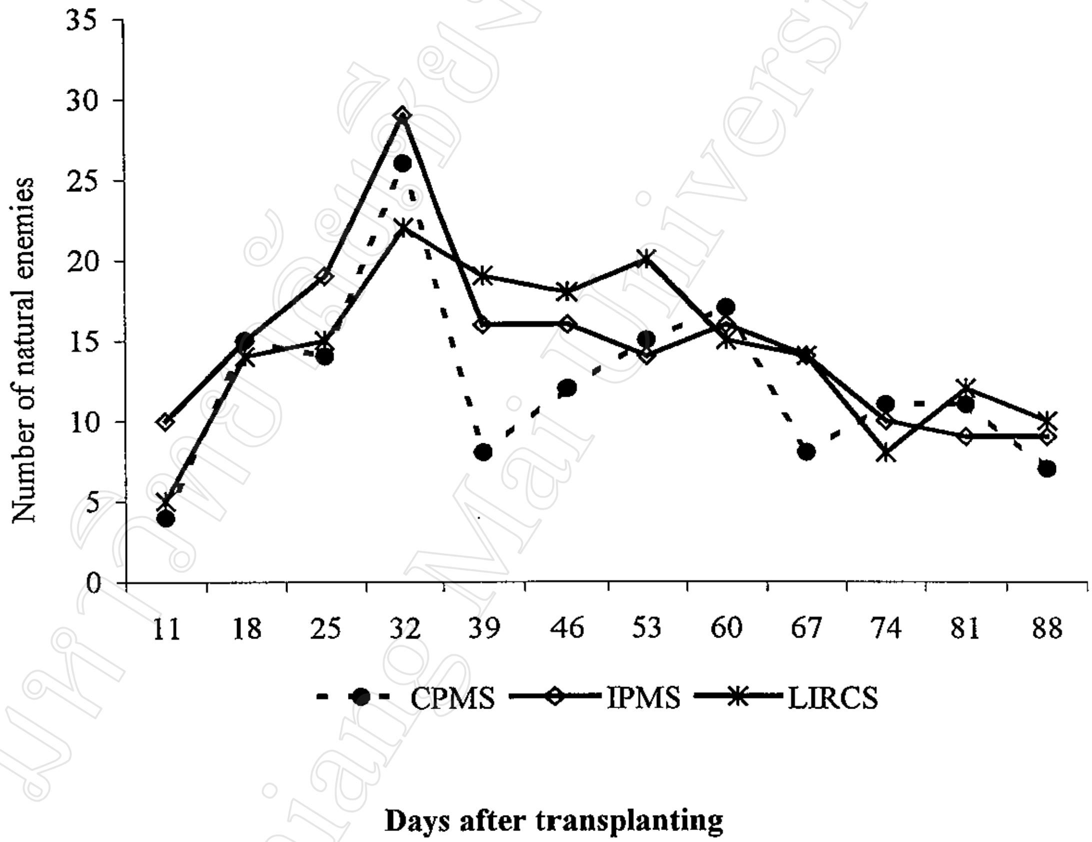


Figure 9. Abundance of natural enemies in experimental systems recorded weekly by 3 sweep nets from 11 August to 27 October 2001. In legend, "CPMS" refers to the Cambodian Pest Management System; "IPMS" refers to the Integrated Pest Management System; and "LIRCS" refers to Low Input Rice Cultivation System.

The case suggested that species diversity of natural enemies in the CPM system was more diverse and evenly distributed *albeit* lowered number of natural enemy population due to detrimental effects of insecticide application was observed. This finding has led to the emergence of a hypothesis as to what factors that actually constituted these opposite findings produced by the two field sampling techniques.

Table 39. Abundance of natural enemies in CPMS recorded by sweep net in every seven days (11-88 DAT) 2001

Order	**Family**	**Species**		Observation period (Days after transplanting)											
				11	18	25	32	39	46	53	60	67	74	81	88
Predator															
Odonata	Agrionidae	*Agriocnemis* spp.		1	1	0	4	3	3	7	10	2	2	3	1
Araneae	Lycosidae	*Lycosa pseudoannulata*		0	2	1	1	0	1	0	0	1	0	0	0
	Tetragnathida	*Tetragnatha* spp.		3	8	11	13	2	6	6	1	2	2	2	2
	Linyphiidae	*Callitrichia formosana*		0	0	0	0	0	0	0	2	0	0	0	0
	Oxyopidae	*Oxyopes javanus*		0	1	0	0	1	2	1	0	1	0	3	1
	Araneidae	*Agriope catenulate*		0	0	1	0	1	0	1	0	0	1	0	0
Coleoptera	Coccinellidae	*Synharmonia octomaculata* sp.		0	0	0	1	0	0	0	1	0	1	1	1
	Carabidae	*Ophionea nigrofasciata* sp.		0	0	0	0	1	0	0	0	0	2	0	0
	Staphylinidae	*Paederus fuscipes*		0	2	0	1	0	0	0	0	0	0	0	0
Hymenoptera	Dryinidae	*Echthrodelphax* spp.		0	0	0	0	0	0	0	2	2	2	1	0
Diptera	Dolichopodid	*Dolichopodid fly*		0	0	0	0	0	0	0	0	0	1	0	0
Parasitoid															
Hemiptera	Miridae	*Cyrtorhinus lividipennis* Reuter		0	1	0	2	0	0	0	1	0	0	0	0
Hymenoptera	Mymaridae	*Gonatocerus* spp.		0	0	1	4	0	0	0	0	0	0	1	1
	Eulophidae	*Tetrastichus* sp.		0	0	0	0	0	0	0	0	0	0	0	1
		Total number of Individuals	N=	4	15	14	26	8	12	15	17	8	11	11	7
		Total number of Species	S=	2	6	4	7	5	4	4	6	5	7	6	6

Note: Simpson species diversity index = 4.44

Table 40. Abundance of natural enemies in IPMS recorded by sweep net in every seven days (11-88 DAT) 2001

Order	Family	Species		Observation period (Days after transplanting)											
				11	18	25	32	39	46	53	60	67	74	81	88
Predator															
Odonata	Agrionidae	*Agriocnemis* spp.		2	0	3	2	3	3	2	9	7	4	5	3
Araneae	Lycosidae	*Lycosa*		1	3	0	0	0	0	0	0	0	0	0	0
	Tetragnathidae	*Tetragnatha* spp.		3	8	10	11	7	6	5	5	6	3	3	3
	Linyphiidae	*Callitrichia formosana*		0	1	0	3	1	0	1	0	0	1	0	0
	Oxyopidae	*Oxyopes javanus*		2	1	1	0	0	0	0	0	1	2	0	0
	Araneidae	*Agriope catenulata*		1	1	0	0	0	0	0	0	0	0	0	0
Coleoptera	Coccinellidae	*Synharmonia octomaculata* sp.		0	0	0	4	1	1	1	1	0	0	0	1
	Carabidae	*Ophionea nigrofasciata* sp.		0	0	0	6	0	0	0	0	0	0	0	0
	Staphylinidae	*Paederus fuscipes*		1	1	0	0	0	0	0	0	0	0	0	0
Hymenoptera	Dryinidae	*Echthrodelphax* spp.		0	0	0	0	0	1	4	0	0	0	0	0
Diptera	Dolichopodidae	*Dolichopodid fly*		0	0	0	0	0	0	0	0	0	0	0	1
Parasitoid															
Hemiptera	Miridae	*Cyrtorhinus lividipennis* Reuter		0	0	1	0	1	1	0	0	0	0	0	0
Hymenoptera	Mymaridae	*Gonatocerus* spp.		0	0	3	3	2	4	1	0	0	0	0	0
	Trichogrammatid	*Trichogramma* sp.		0	0	0	0	1	0	0	1	0	0	0	0
	Ichneumonidae	*Temelucha* sp.		0	0	0	0	0	0	0	0	0	0	1	1
Diptera	Ephydridae	*Ochthera* sp.		0	0	1	0	0	0	0	0	0	0	0	0
		Total number of Individuals	N=	10	15	19	29	16	16	14	16	14	10	9	9
		Total number of Species	S =	6	6	6	6	7	6	6	4	3	4	3	5

Note: Simpson species diversity index = 4.44

Table 41. Abundance of natural enemies in LIRCS recorded by sweep net in every seven days (11-88 DAT) 2001

Order	Family	Species	Observation period (Days after transplanting)											
			11	18	25	32	39	46	53	60	67	74	81	88
Predator														
Odonata	Agrionidae	*Agriocnemis* spp.	0	1	1	0	1	8	5	8	5	1	3	2
Araneae	Lycosidae	*Lycosa pseudoannulata*	0	2	0	0	0	0	0	0	0	0	1	0
	Tetragnathidae	*Tetragnatha* spp.	2	6	10	15	10	3	7	3	4	4	5	5
	Linyphiidae	*Callitrichia formosana*	2	0	0	0	3	0	1	1	1	1	0	0
	Oxyopidae	*Oxyopes javanus*	0	0	2	3	3	1	2	0	3	1	1	2
	Araneidae	*Agriope catenulata*	0	0	2	0	0	0	0	0	0	0	0	0
Coleoptera	Coccinellidae	*Synharmonia octomaculata* sp.	0	0	0	0	1	1	1	0	1	1	2	1
	Carabidae	*Ophionea nigrofasciata* sp.	0	0	0	1	0	1	0	0	0	0	0	0
	Staphylinidae	*Paederus fuscipes*	1	3	0	0	0	0	0	0	0	0	0	0
Hymenoptera	Dryinidae	*Echthrodelphax* spp.	0	0	0	0	0	2	1	1	0	0	0	0
Parasitoid														
Hemiptera	Miridae	*Cyrtorhinus lividipennis* Reuter	0	2	0	1	0	0	3	1	0	0	0	0
Hymenoptera	Mymaridae	*Gonatocerus* spp.	0	0	0	2	0	2	0	0	0	0	0	0
	Trichogrammatidae	*Trichogramma* sp.	0	0	0	0	0	0	0	1	0	0	0	0
	Ichneumonidae	*Temelucha* sp.	0	0	0	0	1	0	0	0	0	0	0	0
		Total number of individuals N=	5	14	15	22	19	18	20	15	14	8	12	10
		Total number of Species S=	3	5	4	5	6	7	7	6	5	5	5	4

Note: Simpson species diversity index = 4.13

5.4. Comparison of sampling methods

5.4.1. Relative variations

As indicated by the results of analysis of variance in Table 22 & 24 there were no significant differences among the experimental systems in terms of means of numbers of both all leafhoppers and individual species recorded by direct visual count and sweep net. Two-tailed Student's t-tests were then performed in order to seek significant differences in means of leafhoppers recorded by both sampling techniques in each system. The results obtained were that all the means of data obtained from the sweep net catches were significantly different from those obtained via direct visual counts ($p<0.05$). Further investigation to verify whether or not the sweep net sampling technique is statistically more efficient than the direct visual count in estimating the relative population density of green leafhoppers in the experimental fields a relative variation (RV), as suggested by Kogan and Pitre (1979), was calculated (Table 42).

It can be seen from Table 42 that all RV values and the mean obtained from sweep net method were slightly less than those obtained from direct visual count.

Table 42. Relative variation (RV) of sweep net vs. direct visual count in estimating *Nephotettix* spp. population in the experimental systems conducted at the Irrigated Research Station of Chiang Mai University 2001.

System	Mean number of leafhoppers		Difference	Relative variation (RV)	
	Sweep net	Direct visual count		Sweep net	Direct visual count
CPMS	2.5	1	1.5	23.93	30.06
IPMS	3.75	1.5	2.25	27.36	33.33
LIRCS	4	1.25	2.75	21.53	34.22
Mean	3.42	1.25	2.17	24.27	32.54

Note: - Means are expressed as number of leafhoppers per observation (week). The last observation of the direct visual count was excluded in order to get a common 12 observation.

- RV = $\frac{100S_{\bar{X}}}{\bar{X}}$, where $S_{\bar{X}}$ = Standard error of mean ($S_{\bar{X}} = \frac{S}{\sqrt{n}}$; S = Standard deviation, n = number of observation)

According to Southwood (1978) (in Titayavan, 1989) a RV value less than 25 is usually adequate for most extensive sampling program. In this sense, mean RV of the sweep net sampling (24.27) is considered sufficient for the estimation of the abundance of leafhopper in this experiment. However, it should be noticed that the IPMS' RV (27.36) is slightly higher than the recommended value. This may have been caused by the sampling error.

Data obtained from the light trap from 10 to 80 DAT were chosen for use in calculating RV to be compared with RV of the sweep net and direct visual count. Two sets of data collected in every 3 days were pooled and assumed to be equivalent to a weekly data. The RV value calculated from these data was 19.26 which was considerably lower than that calculated from the previous two sampling methods. The case suggested that light trap is even more efficient in studying the abundance of population of leafhoppers.

5.4.2. Labor requirement

Table 43 showed that mean times consumed by sweep net sampling method in each experimental system were all less then those did by the direct visual count method. A statistically significant difference between pairs of means was common.

Table 43. Mean time consumed by sweep net vs. direct visual count in sampling *Nephotettix* spp. population in the experimental systems conducted at the Irrigated Research Station of Chiang Mai University 2001.

System	Mean time consumed (minute)		Difference	P
	Sweep net	Direct visual count		
CPMS	9.79	15.25	5.46	0.0094
IPMS	9.46	14.67	5.21	0.0122
LIRCS	9.29	12.54	3.25	0.0486
Overall mean	9.51	14.15	4.64	0.0054

Note: - Means are expressed as number of minutes spent/observation (week). The last observation of the direct visual count was excluded in order to get a common 12 week observation.

- P values are determined by Two-tailed Student's t-test.

In addition, the comparison of the overall mean deriving from the pooling of means of time consumption by each method in each system revealed a strongly significant difference ($p<0.01$).

These results firmly revealed that the direct visual count consumes more time and is thus, probably, more tedious than the sweep net method. Direct visual count is actually recognised as one of the simplest sampling procedures in sampling a number of pests, especially the non-active and less active insect pests, at the farm level. However, it may not be suitable for sampling the flying insect pests like leafhoppers, which are generally known to be very active ones. Field sampling had to be carried out slowly and patiently, otherwise there would be no leafhoppers to be counted as they normally keep displacing from one rice hill to another when they are disturbed.

5.5. Rice yields and economic returns

It can be seen from Table 45 that the highest, moderately high, and the lowest mean yields were obtained from the IPM, CPM, LIRC system, respectively. Nevertheless, analysis of variance showed that there were no significant differences between these rice yields (Table 44).

Table 44. Analysis of variance of rice yield obtained from the experimental systems.

Source of variation	Significance level
Replication (A)	ns
System (B)	ns
CV (%)	11.34

Table 45. Mean rice yields obtained from the experimental systems conducted at the Irrigated Research Station of Chiang Mai University 2001.

System	Mean rice yield (kg ha^{-1})
CPMS	3682
IPMS	3837
LIRCS	3480
Overall Mean	3666

The overall mean yield was 3666 kg ha^{-1}. A relatively high yield recorded in the LIRC system where no fertilizer was applied should not be taken as an indicator to underestimate the yield responses in the other two fertilized systems. Because a better crop yield achieved in this system perhaps should be attributed to high nutrient contents in the experimental fields left from the previous crop season. Tracing the field background revealed that the field was planted to leguminous green manure *S. rostrata* and maize. In addition, pest infestation during the rice growing season was very low that even rice production under such a low input condition was not threatened.

To better understanding efficiency of rice production under different input levels and pest management practices, a partial budgeting was performed. It should be reminded at the outset that labor cost such as land preparation, nursery preparation, and transplanting were excluded from this analysis since they are identical. Table 46 presented the details of variable costs (*VC*) and gross margin (*GM*) included and obtained in each production system.

Table 46. Gross margin (*GM*-Riels) obtained from experimental rice systems under different input conditions conducted at the Irrigated Research Station of Chiang Mai University 2001.

Indicator	System		
	CPMS	IPMS	LIRCS
Variable cost (*VC*)			
Seed	59940	29700	29700
Fertilizer	169740	122535	0
Insecticide	11025	0	0
Insecticide spray cost	90000	0	0
Total variable cost	330705	152235	29700
Gross Returns (*GR*)[2]	2309958	2309958	2309958
Gross Margin (*GM*)[3]	1979253	2157723	2280258

Note: - *VC* calculation were based on the unit price per commodity obtained in Chiang Mai and then converted to the Cambodian currency (Riels) based on the 2001 exchange rate of 90Riels/Baht or 3900Riels/US$.

- *GM* = Overall Mean Yield * Price of Paddy/kg (Baht7=Riels630). [3]*GM* = *GR* – *VC*.

Since mean yields in the systems were not significantly different, the overall mean yield was used for the calculation of the gross returns (*GR*). This resulted in an equal *GR* in all systems. The gross margins (*GM*) were obtained as total gross returns less variable costs (*GM* = *GR*- *VC*). The highest *GM* (2280258Riels), moderately high (2157723Riles), and the lowest *GM* (1979253Riels) was obtained in the LIRC, IPM and CPM system, respectively. It came with no surprise that the LIRC system had the highest *GM* because no external inputs such as chemical fertilizers were used. The CPM system had the lowest *GM* because it had greater *VC* due to higher level of fertilizers and insecticide applications, both led to an increase in added cost of production. In comparison with the IPM system, the CPM system's added cost was 54% greater. This led to an increase in the IPM system's *GM* by 7.7% greater than that of the CPM system.

The greater *GM* value in the IPM system indicated that cultivation and pest management practices adapted on the basis of IPM principles are both economically and technically sound. High level of inorganic fertilizer application and a double insecticide spray practiced by the Cambodian farmers in the surveyed area perhaps were not justified because they were not effective to tangibly increase rice yield and economic returns as compared to the IPM system where lesser input was applied.