CHAPTER 2

LITERATURE REVIEW

2.1. Pest management practices and their effects on arthropod populations

It is apparently understandable that various pest management and production practices, either by cultural or chemical practices or their combination, are conducive to modifications of the field microclimates rendering a great deal of impacts on the community structure and diversity of arthropods in many ways. These practices may, if not all, consist of time and methods of planting, age of seedling, variety, plant density, tillage, water management, weeding, fertilizer use, and pesticide application.

Striking impacts on arthropods concerning pesticide-based management have been well documented. Horn (1988) noted that increasing reliance on chemicals in many phases of agriculture was part of the growing momentum towards mechanization and monoculture. Altieri *et al.* (1978), as cited by Horn (1988), and Loevinsohn (1994) pointed out that this activity concentrates food plants for specialist herbivors. Some evidence indicates that reduction in habitat diversity in monoculture reduces numbers of predators at least in some agroecosystems (Altieri *et al.*, 1978). 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 (Horn, 1988; Dent, 1995; Hardin *et al.*, 1995) and the increased pesticide resistance (Dent, 1995; de ONG, 1960). Horn (1988) gave examples of bollworms on cotton and European red mites in apple orchards whose population densities increased after widespread insecticide treatments were targeted for other pests in agroecosystem. de ONG (1960) reported the increase in the population of the Scale, insects attacking citrus, was related to the use of DDT in the control of bark beetle that disseminate the disease fungus *Ceratostomella ulmi* , which attack the elm. In the case of rice, the destruction of predators and parasitoids that followed insecticide misuse resulted in resurgence of several rice pests including the brown planthoppers, green leafhoppers, and stem borers (Ooi and Shepard, 1994).

Cultural control can be a powerful tool in efforts to suppress arthropod pests in agroecosystems (Panda and Khush, 1995; Schellhorn *et al.*, 2000). This pest control involves two basic approaches: (1) to make the environment less favorable to pests, and (2) to make the environment more favorable to the pest's natural enemies. As cited by Pathak and Khan (1994), Glass (1975) pointed out that cultural control, however, may not by itself reduce the pest population to below economic threshold levels, but may aid in reducing losses due to pests. The shifting of planting date, crop spacing, synchrony planting, crop density, varieties, fertilizer application, water management, and so on, all have influences on insect pests. Good water management can reduce damage from insects, mites, pathogens, and affect weed competitiveness. Early maturing cultivars and planting date are cultural practices employed to evade rice insect attack. However, Kiritani *et al.* (1970) reported that the introduction of early planting in Japan caused staggered planting and green leafhoppers increased five fold (Litsinger, 1994). The integration of insect-resistant cultivars with cultural management can enhance the power of pest control efforts (Heinrichs and Quisenberry, 1999; Daradjat *et al.* 1999).

As highlighted by Heinrichs and Quisenberry (1999), studies in the Philippines indicate that brown planthopper population and planthopper:predator ratios on early maturing cultivars were significantly lower than those on late maturing cultivars because the insect was not able to complete as many generations on the early maturing cultivars as compared with long duration cultivars. A shift of planting dates minimized the population build up of and damage to several stem borer species in India, Indonesia, and Malaysia. All these strategies can be integrated with plant resistance. However, caution should be taken before using pest evasion tactics because they may have negative attributes, such as yield loss caused by planting date at a sub-optimal date.

Nitrogen fertilizer is a major component for producing high yields of modern rice cultivars. High plant nitrogen generally favors an increase in population of insect pests (Pathak and Khan, 1994; Smith, 1994), regardless of the level of and type of insect resistance (Smith, 1994), which is manifested in greater pest survival, increased feeding rate, increased fecundity, and faster growth. Results of a greenhouse study by Heinrichs and Quisenberry (1999) revealed that nitrogen fertilizer was found to favor brown planthopper population growth on rice, even on a resistant cultivar. However, they reported that brown planthopper population growth was least at the higher levels of cultivar resistance. This suggests that when high fertilizer rate application is needed to maximize production, planting of resistant cultivars will minimize brown planthopper populations.

Complexes of biological control agents have been identified for almost all major rice insect pests and many of them provide an effective mechanism to regulate the insect pest populations (Smith, 1994; Way and Javier, 2001). In addition to the joint pest controlling roles of host-plant resistance and biological controls, there exists the longer-term significance of their interaction in delaying or preventing the development of biotypes capable of overcoming previously resistant cultivars (Heinrichs and Quisenberry, 1999). Nevertheless, finding concerning resistant cultivars revealed that they have indirect adverse effects on natural enemies through their defense chemicals (Heinrichs and Quisenberry, 1999) and reduction in prey density (Heinrichs, 1994b).

Foliar pubescence, for example, offers an effective plant defense against arthropods, but it can interfere with the mobility of natural enemies (Panda and Khush, 1995). Nevertheless it comes with no surprise that a general acknowledgement of their positive effects on parasites and predators also prevails. This refers to the capability of the resistant cultivars to minimize the chemical pesticides application. Because the toxicity of an insecticide is a function of insect bodyweight, it is expected that a lower concentration of insecticide is needed to control insects feeding on resistant varieties than those feeding on susceptible ones (Panda and Khush, 1995).

Research on the interactions between plant resistance and biological control has increased in recent years and has shown positive effects of combining the two tactics (Heinrichs and Quisenberry, 1999). The combinations of the two control tactics may be additive, or even synergistic, in their effect on decreasing pest populations. One of examples of how these two tactics can be effectively integrated is illustrated with the specific case of controlling of green rice leafhopper.

The green leafhoppers are important pests in Asia because it is a vector of the pathogen causing rice tungro disease (RTD). Combinations of green leafhopper-resistant cultivars and predation by mirid bug, *Cyrtorhinus lividipennis* Reuter, have a cumulative effect on green leafhopper populations. In greenhouse studies at IRRI on two cultivars, IR29 (highly resistant) and IR22 (susceptible), indicated that cumulative effect of antibiosis and predation by mirid bug led to 52% greater leafhopper mortality in the IR29 as compared with IR22. In sum, insect-resistant rice cultivars can enhance the activity of predators resulting in a synergistic effect of the two control tactics. *Cyrtorhinus lividipennis* pcredation rate increased when the prey, brown planhopper nymphs, fed on the resistant rice cultivar IR36. This may be caused by increased movement of planthopper nymphs on resistant plants, facilitating detection of prey (Heinrichs and Quisenberry, 1999).

In conclusion, virtually almost of rice production components are potent to give rise to modification in agroecosystem properties that may concurrently produce either positive or negative effects on the arthropods. Moreover, it should be noted that one component *per se* does not have adequate might to effectively thwart pest attacks. This strikingly suggests that in order to be able to deal with damaging pests successfully with less negative side effects on non-target ones pest management measures must be followed in a holistic fashion harnessing as many compatible components as possible. Such pest management measures unquestionably come under the currently most popular modern pest management paradigm known as 'integrated pest management'.

2.2. Integrated pest management (IPM) approach

Human have attempted a great many approaches to alleviate insect pest problems through the years with an objective to reduce the losses from pests. However, decades of struggle by human were seen to have followed by a steady incremental increase in the use of pesticides resulting in numerous adverse effects. One of numerous consequences stemming from the use of pesticides is the harmful effect on non-target organisms leading towards the upsetting of natural balance (Yazdani and Agarwal, 1997; Dent, 1995; Ooi *et al.* 1992a). Alternatives to enhancing this situation have been the emphasis on the ecologically non-destructive methods of control (Smith *et al.*, 1976; Paul, 1974), which is widely known as the integrated pest management (IPM). Being considered as a product of discontent with the purely insecticidal approach to pest control of the 1950s, Larry (1999) deemed the evolution as a newly emergent concept of pest management, and advocated explicitly that recently there has been no approach that is more popular than the "IPM" that deals with all kinds of pests with a prime objective to reduce losses from pests in ways that are effective, economically sound, and ecologically compatible. To achieve this ultimate objective, as clearly defined by Cuperus *et al.* (2000) and Strand (2000), IPM encompasses a wide breadth of control measures combining biological, cultural, physical, and chemical tools.

Based on the concepts and principles of ecology, the implementation of IPM approach is concerned chiefly with the relationships of organisms either among themselves or to their environment. One of the many applications in terms of pest management in association with IPM is known to be the biological control. By definition, biological control is an important regulatory function of natural enemies to maintain another organism's population density at a lower average than would otherwise occur on the insect pest population (Paul, 1974; Hoy, 1994) to cause severe damage of crop. However, although having recognized such a regulatory function of beneficial insects, de ONG (1960) noticed that the reduction of population of the injurious insects often reaches a point where man can survive but is faced with a dangerous ramnant. And according to Decker (1956) and Hagen and Smith (1958) should this ramnant be of sufficient size to cause economic loss then it must be checked by the use of chemicals or other control measures or the consequences be suffered (in de ONG, 1960). The applications of this economic loss concept in relation to pest damage and chemical control are well defined in what is globally known as the IPM approach.

Economic decision levels are the cornerstone of insect pest management because they indicate the course of action to be taken in a given pest situation (Headley, 1982). In association with pesticide use, they specify the possible pesticide use only with an understanding of the insect population level that causes economic damage (Larry, 1999). Overall, economic concept of pest management covers two key technical terms commonly known as economic injury level (EIL) and economic threshold (ET). The EIL is defined as the amount of injury which will justify the cost of artificial control measures, while ET is defined as the numbers of insect (density or intensity) that should trigger management action. The functional relation of these two terms is that ET is considered as the first front where control measures are taken to force down the population of insect before it could reach EIL (Dent, 1991; Luckman and Metcalf, 1982; Horn, 1988).

In reality, by using the above two important concepts and the knowledge of pests and their natural enemies, IPM attempts to reduce costs of production in crop husbandry, thus improving production efficiency, and enhance sustainability and viability of agroecosystem *via* reducing detrimental side effects from the use of agrochemicals, especially those coming from the pesticide use. However putting IPM into practice at the farm levels in order to achieve these important objectives is not that simple if its many complex, operational mechanisms are taken into account. 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). Norton and Heong (1988) reported that farmers do not adopt this integrated approach because they do not perceive it will make them better off (in Heong and Sogawa, 1994) due to no significant yield increase was observed (Normiyah and Chang, 1997; Kartaatmadja *et al.*, 1997). Goodell (1984) stressed that the steps of IPM may be far too complicated (in Heong and Sogawa, 1994). Moreover, the need to go to rice fields for frequent surveillance under IPM was a burden and tedious, especially for old farmers (Normiyah and Chang, 1997).

2.3. World distribution and destructiveness of green rice leafhoppers

The important oriental species are *Nephotettix nirgopictus* (Stål), *Nephotettix virescens* (Distant), *Nephotettix cinticeps* (Uhler), *Nephotettix malayanus* Ishihara et Kawase, *and Nephotettix parvus* Ishihara et Kawase. Table 1 shows *Nephotettix* spp. distributions and the virus diseases they transmit.

Countries that have been repeatedly plagued by tungro disease may have sufficient justification to offer the top rank for leafhoppers as rice specialists. When the epidemic is severe 100% of yield loss can occur (Dale, 1994). Outbreaks and crop losses in a number of countries in Southeast Asia can be used as striking examples to delineate the severity of these pests.

Table 1. World distribution of *Nephotettix* spp.

Leafhopper	Distribution	Virus disease transmitted
N. nigropictus	Australia, Bangladesh, Bhutan, Burma, China, Hong Kong, India, Indonesia, Cambodia, Laos, Korea, Malaysia, Nepal, Pakistan, Papua-New Guinea, Philippines, Sri Lanka, Taiwan, Thailand	Dwarf, transitory yellowing, tungro, yellow dwarf, orange leaf
N. virescens	Bangladesh, Burma, Cambodia[1], Hong Kong, India, Indonesia, Laos, Malaysia, Pakistan, Philippines, Taiwan	Tungro, leaf yellowing, transitory yellowing, yellow dwarf, orange leaf
N. cincticeps	China, Japan, Korea, Taiwan	Transitory yellowing, yellow dwarf
N. malayanus	Burma, China, India, Malaysia, Philippines, Sri Lanka, Taiwan	Waika, tungro
N. parvus	India, Malaysia, Sri Lanka	Tungro, yellow dwarf

Source: Biology and management of rice insects (by E.A. Heinrichs, 1994). [1]added after the field survey (2001).

In the Philippines, this deadly rice tungro disease (RTD) has been a serious threat ever since it first appeared as an epidemic in 1957. The early outbreaks of this disease in the 1940s in the country's major rice-growing regions had reduced yield by 1.4 million t annually (Truong *et al.*, 1999). Major outbreaks in later years, i.e., 1962, 1969, 1971, 1975, 1984, 1986, and 1989 were reported in areas associated with intensive cultivation or early recommended varieties. In Indonesia, between 1968 and 1984, the disease damaged an estimated 199,000 ha of rice. In 1995, 12,340 ha of rice in Surakarta regency, central Java, were severely infected, causing yield losses of about US$1.87 million (Daradjat *et al.*, 1999). In Malaysia, the most serious outbreak occurred in 1982 in Kedah and Perlis when more than 20,300 ha of rice fields were afflicted by tungro and yield loss was estimated to be 34,000 t, amounting to US$10 million (Othman *et al.*, 1999).

In general, in many countries, the insects were normally ignored until the explosion of the diseases. For instance, according to Alam and Islam (1959) *Nephotettix* spp. were known only as minor pests in Bangladesh until 1955 (in Dale, 1994). But, since then, 50-80% of damage has been reported from different regions of the country. One of the major causes of the dramatic emergence of GLH into a major pest in these rice-growing countries has commonly been attributed to the introduction of high-yielding cultivars and the intensive fertilizer, particularly the nitrogen, application (Dale, 1994; Heinrichs, 1979).

In Cambodia, it is apparently knowledgeable that no in-depth study on the immunology and its effects on rice production has so far been conducted. However increasing unverified reports on yellow leaf-related damages, which may have possibly been caused by the GLH-vectored tungro disease, have already occasionally been reported (Jahn *et al.*, 1996a). Due to such inadequate scientific evidence, the present status of *Nephotettix* spp. in Cambodia is thus deemed as not a major impact on rice production (Nesbitt, 1997), *albeit* their ascendancy throughout the rice cultivation ecosystems (CIAP, 1992). Yet, should this ascendancy and the growing adoption of high-input, intensive rice farming taken into account, it is foreseeable that there is a likelihood that *Nephotettix* spp., especially *N. virescens,* may become a major threat any time in the future. Outbreaks of *Nephotettix* spp. occurred in the Central Plain of Thailand where farmers have been encouraged to plant the same improved variety continuously throughout the year, and where insecticide use is high (Ishii-Eiteman, 1993).

2.4. Status of green rice leafhoppers (GLH) as pest

Green leafhoppers are important insect pests of rice throughout Asia and have gained great economic significance in recent years as their infestations very often assume epidemic proportions. In many areas, they frequently occur in numbers large enough to cause complete drying of the crop, but even spare populations reduce rice yields (Pathak and Khan, 1994). Among the three *Nephotettix* species-*Nephotettix cincticeps* (Uhler), *Nephotettix virescens* (Distant) and *Nephotettix nigropictus* (=apicalis) (Stål)-. *Nephotettix virescens* is the most damaging GLH, causing heavy crop losses throughout South and Southeast Asia (Pathak and Khan, 1994; Hasanuddin and Hibino, 1989).

With their feeding sheaths, leafhoppers damage plants by sucking the sap and by plugging xylem and phloem, which is confined mostly to the leaf and leafsheath of rice. Mild infestations may reduce the vigor of the plants and the number of productive tillers while heavy infestations cause withering and complete drying of the crop (Dale, 1994).

In addition to damaging plants by direct feeding, leafhoppers are also vectors of most currently known rice viral diseases. Of the damaging species, *Nephotettix virescens*, the principal vectors in which about 85% of its individuals are active transmitters (Ou, 1973), has caused heavy crop losses as a vector of a number of diseases in which tungro is the most devastating one. Tungro disease stunts the plants and changes the leaf color to shade of yellow or orange. The symptoms are somehow different among varieties, environmental condition, age of plant, and strains of virus. Infected plants have somewhat fewer tillers than healthy plants.

2.5. Taxonomic and ecological status of *Nephotettix virescens* (Distant)

The green rice leafhopper, *Nephotettix virescens* (Distant) (Homoptera: Cicadellidae) is synonymously known as *Nephotettix bipunctatus* Distant or *Nephotettix impicticeps* Ishihara et Kawase (Dale, 1994). Host plants other than rice of *N. virescens* (Distant) include *Cynodon dactylon* (L.) Pers., *Echinochloa crus-galli* (L.) Beauv., *Eleusine indica* (L.) Gaertn., *Leersia hexandra* Sw., *Panicum ramosum* L., *Saccharum officinarum* L., wild rices, *Zea mays* L.

2.6. Biology of green rice leafhopper *Nephotettix virescens* (Distant)

The newly emerged adult is yellowish in color. It gradually turns yellow green and then green after three hours after emergence. Most of adults emerge early in the morning. The adult green leafhopper is about 4 to 5 mm long. It has a pointed vertex and a green head. Males have green forewings with a small dark brown or black band in the middle while in females there is no such band.

The premating period ranges from 1 to 2 days. The females use their ovipositors to pierce the plant tissues and eggs are laid in small slits made in the soft parts of the leaf sheath. The number of eggs in a batch seldom exceeds 30 and the total eggs laid during the life cycle are around 350. Unmated females lay sterile eggs randomly on the leaf sheaths; while mated females lay fertile eggs which are inserted in the leaf sheath in an arranged manner. Newly laid eggs are barely visible and are oblong, bent and pale yellow. The incubation period varies from 6-12 days.

Young nymphs are creamy white with black longitudinal stripes on the sides of the body. They turn yellow or yellow-green in about an hour after molting. First instar nymphs are more numerous on the lower surface of older leaf blades, but from the second instar onwards, they distribute themselves rather evenly on all leaves. Nymphs and adults suck sap from leaf sheaths and blades.

2.7. Seasonal occurrence and abundance of green rice leafhoppers

In the warm and humid tropics, different species of leafhoppers remain active year-round, and populations fluctuate according to the availability of food plants, presence of natural enemies, and environmental conditions (Pathak and Khan, 1994). Chancellor *et al.* (1996) reported that early immigration of leafhoppers into rice plots was greatest in the wet season. The hibernating insects become active when the weather warms around March to April, and appear in rice fields shortly after transplanting in June or July. The peaks population periods in a year resulting from these two favorable climatic conditions, as reported by Dale (1994), occur in March during the first crop season, starting from February to May/June, and in October-November during the second crop, starting from June to December.

Nephotettix spp. complete three generations on rice from June to August and in the fourth generation hibernate as nymphs in late September to October. The abundance and incidence of *Nephotettix* spp. has been attributed to high temperature, low rainfall, and abundant sunshine (Pathak and Khan, 1994; Dale, 1994). 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). In addition, Pathak and Khan, (1994) noticed that fields receive large amounts of nitrogenous fertilizers and subjected to indiscriminate use of pesticides are more heavily infested, and rice plants at the tillering and panicle initiation stages are most favorable for the rapid build-up of pest populations (Dale, 1994). Chancellor *et al.* (1996) articulated that peaks in population density of leafhoppers occurred by 50-65 days after transplanting.

2.8. Management of green rice leafhoppers

Several cultural control strategies have commonly been practiced to deal with many destructive agricultural pests. These control strategies have somehow met with varying degrees of success depending on the level of severity of pest infestation and the particular favorable condition of the cropping system. For the control of leafhoppers, Truong *et al.*, (1999) advocated that cultural practices are the most realistic way to manage rice tungro disease (RTD) because these activities are close to farmers' experience. Sanitation of ricefields is a necessary option through which the crop residues, infected plants, and other weeds known to be the alternative host of leafhoppers are removed. Rotation rice with another crop often provides an effective and economical control measure, especially in areas of one rice crop a year (Pathak and Khan, 1994). According to Truong *et al.*, (1999) growing legumes, especially mungbean, after rice can reduce leafhopper infestation. In addition, trap plants planted 15 days earlier than the main crop sprayed with insecticide weekly for up to 60 DAT can reduce incidence of *Nephotettix virescens* and its transmitted tungro virus in the main crop (Pathak and Khan, 1994). In addition, synchronous planting is considered to be the key to success of the control of leafhoppers (Truong *et al.*, 1999; Hasanuddin *et al.*, 1999; Cooter *et al.*, 2000; Cabunagan *et al.*, 2001). Hasanuddin *et al.*, (1999) recommended that the minimum area for synchronized planting is 20-40 ha. However, simultaneous planting is difficult to practice by farmers for various reasons (Widiart, 1999; Cabunagan *et al.*, 2001). One of the many difficulties may be the water management. Truong *et al.* (1999) reported that synchronized planting can only be achieved with sufficient irrigation water. As to refer to Cambodia's rice growing conditions, this kind of practice might be deemed even less applicable for Cambodian rice farmers whose fields are largely characterized as rainfed lowland ricefields where water is very often an erratic and uncontrollable factor. Early planting time was suggested by Shukla and Anjaneyulu (in Litsinger, 1994). Hasanuddin *et al.*, (1999) studied the relationship between RTD incidence and planting time and synchronized planting at Subak Padang Galak, Badung regency, Indonesia. They reported that the early planting of synchronized fields showed the lowest risk of RTD infection, and confirmed that the finding was similar to that of Chancellor (1996) in the Philippines. Planting older seedlings was also recommended in order to escape RTD damage (Widiart, 1999).

Moreover, planting resistant varieties has long been ascertained especially essential for the suppression of the outbreak of RTD. Most of the screened varieties have resistance to the major virus vector resulting in a low level of tungro disease in the field (Azzam *et al.*, 2000; Dahal *et al.*, 1997) even though there is a general increase in vector survival and phloem feeding rate (Dahal *et al.*, 1997). However, the full potential of the resistant varieties in insect control has often been limited by the development of new biotypes and virulent of GLH population (Pathak and Khan, 1994; Dahal *et al.*, 1997; Batay-An and Mancao, 1999). Resistant varieties to *N. virescens*, for example, turned out to succumb to tungro infections after a few years of intensive cultivation. Some of the confirmed cases were found in Indonesia by Manwann *et al.* (1985), the Philippines by Hibino *et al.* (1987) and Hasanuddin *et al.* (1999), Thailand by Inoue and Ruay Aree (1977), and Malaysia by Nemoto and Habibuddin (1992) (Azzam *et al.*, 2000). The short-lived success of the use of resistant cultivars, according to Batay-An and Mancao (1999), has suggested that the control of the insect vector with insecticides remains the only possibility for reducing RTD incidence in the field, since the use of anti-viral chemicals has not been successful (Heinrichs, 1979), and greater use of insecticides by farmers was expected because other control strategies such as intensifying the role of biocontrol agents takes time and are limited in some scope.

In tungro epidemic areas, for instance, prophylactic measures, preferably with the use of insecticides with knock down effect (Chelliah and Bharathi, 1994; Heinrichs, 1979), are sometimes recommended to ensure the protection against virus infection (Pathak and Khan, 1994). In India, 10GLH/4 net strokes or 5LGH/hill at vegetative stage and 10GLH/hill at the post flowering stage were listed as thresholds while only 2GLH/hill has been suggested in tungro endemic areas in Tamil Nadu, India (Chelliah and Bharathi, 1994). There are a huge number of insecticides readily available for the control of *Nephotettix virescens*. Saxena (1987) reported that incorporation of 150 and 250 kg neem cake ha^{-1} into the seedbed was effective against rice tungro (in Ganapathy *et al.*, 1999). Seiber *et al.* (1977) reported that seedling root coating and root soaking with carbofuran just prior to planting gave 100 GLH mortality even at 50 day after transplanting (DAT) (in Chelliah and Bharathi, 1994). They also reported that root-coat treatment technique provided excellent control of tungro virus incidence in the field up to 40 DAT. Pathak and Khan (1994) reported that buprofezin has been reported to be highly selective molting-inhibitor for control of *Nephotettix virescens* with nontoxic to natural enemies, mammals, or fish. cypermethrin, a pyrethroid compound, and MIPC were respectively reported by Truong *et al.*, (1999), Batay-An and Mancao (1999), and Widiart (1999) as effective against GLH experimental fields in the Philippines. Shepard and Brown (1984) recommended the use of pyridafenthion and tetrachlorvinphos because they are exceptionally selective, favoring the wolf spider *Lycosa pseudoannulata* while being toxic to its prey, green leafhoppers. Antifeedants such as imidacloprid, nytenpyram, and pymetrozin as well as andrographolide were reported by Widiart (1999) as having antifeedant activity against *N. virescens*, reducing virus acquisition and inoculation without killing the insect, and also inhibited transmission of RTD. He thus recommended that the control of feeding has the potential to check tungro without disturbing the food chain. In addition, systemic granules are also recommended for the control of GLH. Some granule insecticides that were first used in Japan are disulfoton, cartap, or propaphos (Nagata and Mochida, 1984).

However, insecticides have never been seen as an endless victory against insects. The genetically acquired resistance of insects to insecticide toxicity continues to be the most serious barrier to the successful use of these chemical agents (Metcalf, 1994). In the case of controlling the GLH, for instance, some of insecticides were later found no longer effective to GLH due to the development of insect resistance. According to Chelliah and Bharathi (1994) many workers have reported cases of insect resistance to insecticides from various countries. Of those confirmed cases were the many serious insect-resistant-related cases in Japan reported by Nagata and Mochida (1984) and the remarkably lower insecticide resistance in the Philippines and Taiwan reported by Ku and Wang (1978). Many more insecticides being used presently are also losing their effects, and, in order to overcome this limitation, more new pesticide with no cross resistance to the old insecticides are needed (Chelliah and Bharathi, 1994).

2.9. Biological control of green rice leafhoppers

Natural enemies are widely known as particularly important for the control of many insect species (Yazdani and Argawal, 1997; Hoy, 1994; Dent, 1991). Parasitoids and predators, for instance, have been employed in the management of insect pests for centuries (Orr and Shu, 1998) which is long before the advent of synthetic insecticides (Ooi and Shepard, 1994). The use of these natural enemies as a control method to reduce pest population was precisely defined by Hoy (1994) as biological control-the term was, however, firstly coined by Harry Smith since 1919 (Orr and Shu, 1998; Dixon, 2000).

In the case of rice, the long histories of rice cultivation in many parts of the world have allowed stable relationships to evolve between rice insect pests and their natural enemies (Ooi and Waage, 1994; Ooi and Shepard, 1994). Ooi and Waage (1994) reported that field observations have indicated that there are many natural enemies of rice pests in the tropics. The natural biological pest control by indigenous predators, parasitoids and insect pathogens, according to Ooi and Shepard (1994), managed insect pests long before the advent of synthetic insecticides, and their actions have been seriously considered and integrated to form the cornerstone of modern Integrated Pest Management (IPM) programs in rice.

According to Pathak and Khan (1994), several predators, parasites, and pathogens attack the leafhoppers at all stages, and effectively control them under most situations. Some common predators and parasitoids are presented in Table 2.

Most of the green leafhopper egg mortality is due to parasitism. Eggs are parasitised by trichogrammatid wasps *Paracentrobia andoi* (Ishii) and *Oligosita naias Girault*, and by mymarid wasps *Anagrus optabilis* (Perkins) and *Gonatocerus* sp. (Pathak and Khan, 1994). As cited by Suzuki *et al.* (1996), Aryawan *et al.* (1993) reported that among the four species, three mymarids and one trichogrammatids, emerged from the egg samples obtained in the study fields in Bali, Indonesia, the dominant species was *Gonatocerus* spp., which constituted 84.7% of the egg parasitoids from 300 parasitized egg masses. Similar finding was also reported by workers in Cambodia who concluded that *Gonatocerus* sp. is the most common and effective parasitoid, due to their discovery that parasitism composition by *Gonatocerus* sp. on host eggs collected from various parts of rainfed lowland rice ecosystem was comparatively higher than that by others parasitoid species (CIAP, 1994). Moreover, the eggs are also preyed upon by *Cyrtorhinus lividipennis.*

Table 2: Some common predators and parasitoids of *Nephotettix* spp.

Predators/Parasitoids species	Stage of host attacked
Predator	
Cyrtorhinus lividipennis Reuter***	Egg/Nymph
Lecosa pseudoannulata (Boesenberg and Strand)***	Nymph/Adult
Tetragnatha sp.*	Adult
Oxyopes sp.*	Nymph/Adult
Microvelia douglasi atrolineata	Nymph/Adult
Stenonabis tagalicus (Stål)	Nymph/Adult
Drapetis sp.	Nymph/Adult
Damseflies	Nymph/Adult
Dragonflies	Nymph/Adult
Parasitoid	
Gonatocerus sp.*	Egg
Anagrus optabilis (Perkins)	Egg
Paracentrobia andoi (Ishii)	Egg
Oligosita naias Girault	Egg
O. yasumatsui*	Egg
Haplogonatopus apicalis Perkins*	Nymph/Adult
Halictophagus munroei Hirashima & Kifune	Nymph/Adult
Echthrodelphax fairchildii Perkins	Nymph/Adult
Pipunculus sp.**	Nymph/Adult
Tomosvaryella sp.**	Nymph/Adult

Sources: Reviewed from E.A. Heinrichs (1994) (Biology and management of rice pests) and Pathak and Khan (1994) (Insect pests of rice). *** very important; ** important; * normal.

Nymphs and adults are parasitised by pipunculid flies *Pipunculus mutillatus* Loew and *Tomosvaryella oryzaetora* Koizumi, dryinid wasp *Echthrodelphax fairchildii* Perkins, Strepsipteran *Halictophagus munroei* Hirashima & Kifune, and

Hexamermis spp. nematodes. Dale (1994), having reviewed findings by Pena and Shepard (1986), reported that incidence of parasitism by pipunculids on *Nephotettix virescens* (Distant) and *Nephotettix nigropictus* (Stål) is higher than for any of the parasitoids species. Pipunculids thus may be an important source of irreplaceable mortality factor in green leafhopper complex (Dale, 1994; Pathak and Khan, 1994).

Tomosvaryella was also found abundantly present in rice ecosystem and a promising natural control agent against rice leafhoppers in Cambodia. Field parasitism of GLH ranged fro 12% to 60% during the wet season (CIAP, 1994).

An array of predators also attacks nymphs and adults consist of *Cyrtorhinus lividipennis, Microvelia douglasi atrolineata, Stenonabis tagalicus* (Stål), *Drapetis* sp., damselflies, dragonflies, and spiders. Of these predators Dale (1994), based on both results of laboratory studies and field observations, pointed out that *C. lividipennis* must be rated as one of most important predators of hoppers in rice ecosystem.

Nematodes and fungal pathogens also infect nymphs and adults. Common pathogens of rice planthoppers and leafhoppers are *Metarhizium anisopliae* (Metsch) Sorok., *M. flavovoride* Gams & Rozsypal var. *minus* Rombach, Humber & Roberts, *Metarhizium album* Petch, *Beauveria bassiana* (Bals.) Vuill, and *Hirsutella citriformis* Speare (Rombach *et al*., 1994).