DYNAMICS OF INSECT BEHAVIOUR

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Chapter - 10

BIOLOGY, BEHAVIORAL AND POPULATION DYNAMICS OF THE RICE LEAFFOLDER COMPLEX

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1. Introduction

Insect pests attack the rice crop from the time the nursery bed is prepared until harvest, the actual species complex varying in abundance and distribution from locality to locality and from year to year (Kiritani, 1979). Among the rice insect pests Rice leaffolder complex is the major one attacking vegetative stage of the rice and they are polyphagous defoliators causing yield losses of 15% to 25%. Two or three crops a year, often overlapping, of heavily fertilized monocultures of "Green Revolution", high-yielding cultivars were considered a vulnerable pest breeding ground. Developing strongly pest-resistant rice cultivars was a high priority, but these were threatened by "resistance breakdowns," particularly to the *Cnaphalocrocis medinalis* (Guenée) (Lepidoptera: Pyralidae) and brown planthopper (BPH), *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) (Kiritani, 1979)

Insecticides used according to economic thresholds were considered a valuable complement to varietal resistance and synchronized planting as the basis for integrated control. Unfortunately, pest problems increased with the intensification of irrigated rice production, which included increased investments such as insecticides. In particular insecticide use preceded outbreaks of secondary pests, notably the brown planthopper, *N. lugens*, that was previously of minor significance (Kenmore, 1991). Although the problem of insecticide-induced secondary pests (sucking pest) was recognized and attributed to the devastation of natural enemies, insecticides used according to economic thresholds were considered a important complement to varietal resistance and synchronized planting as the basis for integrated control (Ananthakrishnan, 1999).

Crop intensification has been suggested as a reason for the changes in the insect pest fauna in rice (Loevinsohn, 1985). Loevinsohn defines intensification as "an increase in resources devoted to rice cultivation." Intensification involves (1) an increase in the number of crops grown per year, (2) an increase in the use of agricultural chemicals; fertilizer and pesticides, (3) planting of varieties responsive to fertilizers and pesticides, and (4) increased plant densities, further Loevinsohn (1985), provides evidence that ecologically specialized species have been favored by crop intensification. Until the 1960s, the stem borers were considered the most serious pests of rice throughout the tropics. In recent years, however, damage from them has declined, rice leaffolder and plant hopper were attained there status as major pest causing significant losses in crop productivity.

C. medinalis was believed to be the only pyralid rice leaffolder species. Since 1981, however, seven rice leaffolder species in the genus *Marasmia* were identified (Pathak and Khan, 1994). The shift from minor to major pest status has been attributed to the adoption of new rice growing practices that accompanied the introduction of high yielding varieties (Litsinger, 1989). *C. medinalis* were considered as minor or sporadic pests in the past in many Asian countries (Alam and Alam 1964; Dale, 1994) and became a major threat in the tropical and sub-tropical countries (Heinrichs et al., 1985) with extension of rice cultivation with modern varieties in upland and lowlands area. Expanded rice areas with new irrigation systems, multiple rice cropping, reduced genetic variability of high-yielding semi-dwarf rice varieties, application of high levels of nitrogenous fertilizers, and insecticide-induced resurgence have further compounded the leaf folder problem (Khan et al., 1989).

The review analyses literature relevant to the rice leaf folder complex, biology, population dynamics, behaviour of rice leaffolder, *C. medinalis* practical application of host-plant resistance and there analyses will be effective in implication of biocontrol agents in the integrated pest management.

2. Rice leaffolder complex-diversity and distribution

The rice leaffolder complex is widely distributed pests of rice growing tracts of humid tropical and temperate countries in

Asia, Oceania, Australia and Africa. (Bautista et al., 1984; Khan et al., 1989; Dale, 1994; Khan et al., 1988; Senthil-Nathan,2006 ; et al., 2006).

The leaffolder complex of the rice comprises 8 species of pyralid moths. They are *Cnaphalocrocis medinalis* Guenée, *Marasmia patnalis* Bradley, *Marasmia (=Susumia) exigua* Butler, *Marasmia bilinealis* Hampson, *Marasmia ruralis* Walker, *Marasmia suspicalis* Walker, *Marasmia trapezalis* Guenée, *Marasmia venilialis* Guenée. Among them *C. medinalis*, *M. patnalis* and *M. exigua* attained the status of pest and former two are major widespread species (Khan et al., 1988; Dale, 1994). C. *medinalis* traditionally has been accepted as the only leaffolder pest in the lowland rice fields of Asia. But the discovery of a sympatric and morphologically related species, *M. patnalis* by Bradley, in 1981, has complicated the interpretation of past results.

3. Morphology and key identification of the rice leaffolder complex

3.1. Cnaphalocrocis medinalis Guenée

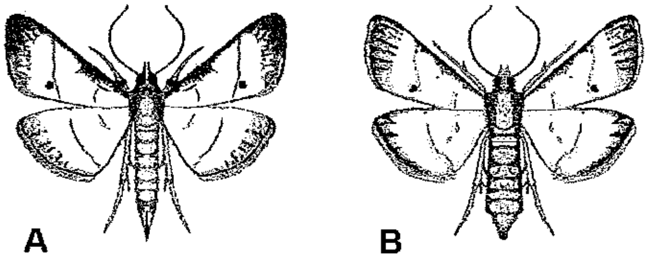

Fig. 1. *Cnaphalocrocis medinalis* Guenée adult moths (A-Male, B-Female)

Cnaphalocrocis medinalis (Guenée) (Fig. l) is monophagous, first described by Guenée (1854) from Indonesia and have been reported in many Asian countries. This moth resembles another leaffolder, *M. patnalis*. The male has a major patch of dark brown and shining androconial scales along the midcosta of forewing. Golden yellow with dark brown markings on both wings, black on the subterminal, antemedian and postmedian lines prominent, postmedian line extended straight to hind wing; median line very short, comma-like and curved outside; outer median line of hindwing much longer than the inner median line, ocelli present; antennae setaceous with 50 segments; compound eyes major portion of the head; Males similar to females except for the distinct dark brown band of androconial scales on the midcosta; thick black hair tuft on the foretibiae; and a thin but long longitudinal black band on the dorsal portion of the abdominal tip. Wing width is about 16 to 18 mm in the females and is about 14 to 16 mm in the males. Female genitalia is broad and not curved. Male genitalia is narrow, anteriorly projected and spiked cornuti on the vesica (After, Bradley, 1981; Barrion et al., 1991; Khan et al., 1988; Dale, 1994).

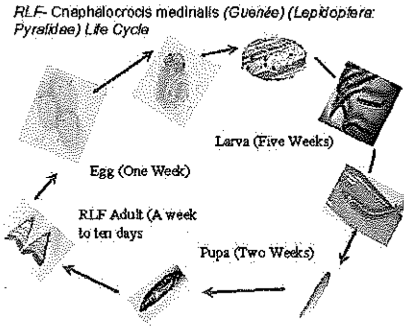

Fig. 2. Biology of the *C. medinalis*

The female attracts its mate with a pheromone call and generally mates at evenings. Adults hide on the rice plants during the day to escape from their natural enemies. Adult longevity is about a week or ten days. Egg-laying start after 24 hour after mating. Smooth, oval and whitish yellow eggs are laid singly or group (2 to 3 eggs), parallel on the both surfaces of young rice blade (Fig. 2). Each female moth lay about 300 to 350 eggs during its total life span. The incubation period vary from 5 days to one week. The newly hatched larva is whitish yellow (Fig. 2) in color, the body, turns transparent green once the larva starts feeding. The second instar migrates to healthy leaves and folds the leaf together.

4. General habits and problems of the rice leaffolder complex

Several alternate hosts are reported for the rice leaffolders. Even though they have primary pest of rice, alternatively it attack various grasses, sedges and cultivated crops like maize, sorghum, sugar-cane, wheat. *Brachiaria mutica* Forssk. Stapf, *Echinochloa colona* Linn. Link, *Eleusine coracana* Linn. Gaertn., *Isachne dispar* Trin., *Leersia hexandra* Sw., *Pennisetum pedicellatum* Trin., *Saccharum officinarum* Linn., *Sorghum bicolor* Linn.Moench., *Triticum aestivum* L., *Zea mays* L. (Dale, 1994; Khan et al.,1996) are reported to be alternative plant host of rice leaffolder.

The distribution of leaffolders can be seasonal. *C. medinalis* is a long-distant migrant into temperate China, Japan, and Taiwan (Wada, 1979; Khan et al., 1988). Every year the population of this pest migrates to these temperate countries from tropical regions. The insect migrates north to south during the spring season and undergoes a reproductive diapause at the onset of seasonal emigratory periods (Zhang et al., 1981). Under favorable conditions, leaffolders produce numerous generations. During high populations rice plants dry up and show parched. First and second instar larvae are usually feed within the slightly folded basal regions of the young leaves in a tiller. Starting from third instar, the larvae fold the rice blades and they become solitary (Fraenkel et al., 1981). Generally, only one larva is present in the folded leaves and after feeding on one fold for about 2-3 days it moves to another leaf. Thus each larva demolishes a number of grown rice leaves during its growth period. The general problem is the photosynthetic ability of the rice plant becomes significantly reduced. The damaged leaves also serve as an entry points for microbial diseases (Pathak and Khan, 1994). The maximum yield loss caused by leaffolders is reported to be due to feeding on the flag leaf (Murugesan and Chelliah, 1983). As the leaffolders can attack the rice plant during the growth stage, fields should be monitored regularly.

5. Feeding behavior

The feeding of rice leaffolders is out of sight and most of the feeding takes place inside the leaf roll. The young rice leaves are generally rich in nutrients and less tough. Adult rice leaffolders lay eggs on outer mature leaves while first-instar larvae feed at the base of the slightly folded young leaves (Fraenkel et al, 1981).The feeding site of neonate larvae is away from the site where eggs are laid (Chapman et al., 1983). The larvae start feeding before stitching or after spinning one or two stitches, where the leaf were not completely folded. The feeding occurs in longitudinal axis of the leaves between veins. The feeding damage caused by *C. medinalis* shows up characteristically in pale stripes in the leaf where the chlorophyll-bearing tissues have been eaten away, and only one epidermis and cuticle remains, Inside the folded leaves vascular bundles were left intact by the feeding larvae. All feeding damage is strictly linear, i.e., occurs in the longitudinal axis of the leaf between the veins. Feeding inside a roll occurs on the upper or underside of the leaf, dependent on whether the leaf is rolled up with the upper or underside inside. The feeding carried out by mandibles scraping sideways, which with the head already bent is along the longitudinal axis of the leaf, and on the upper side, where most feeding occurs, along the grooves between the ribs. Feeding in a fifth- or sixth-instar larva may proceed at the rate of 30-60 sec per 2 mm segment. Feeding is interrupted by stitching activities, especially when the leaf is not yet fully rolled up. This behaviour certainly suggests that feeding is induced by a chemical stimulus emanating from a feeding site. Feeding by *Cnaphalocrocis* is widespread in the *Gramineae* and even the related family of the *Cyperaceae*.

6. Spinning and folding behavior

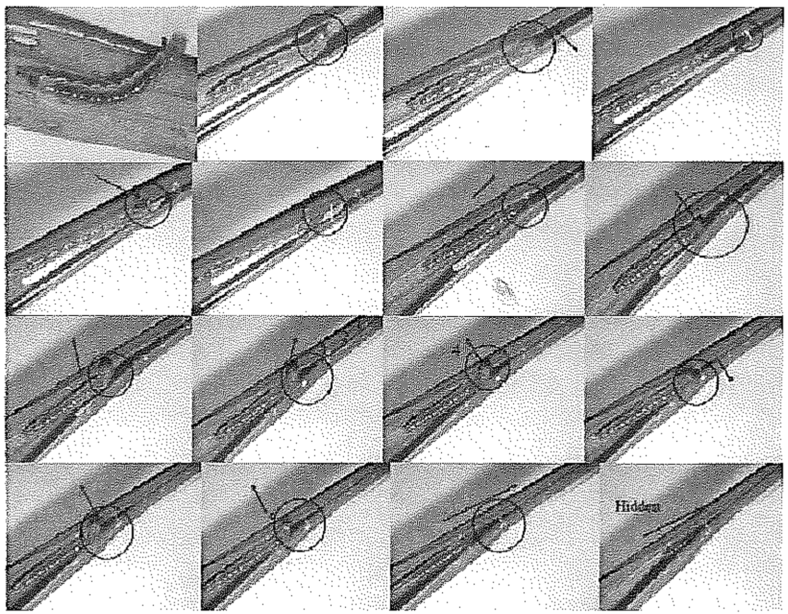

Fig. 3. Spinning and folding behavior of the rice leaffolder, *C. medinalis*

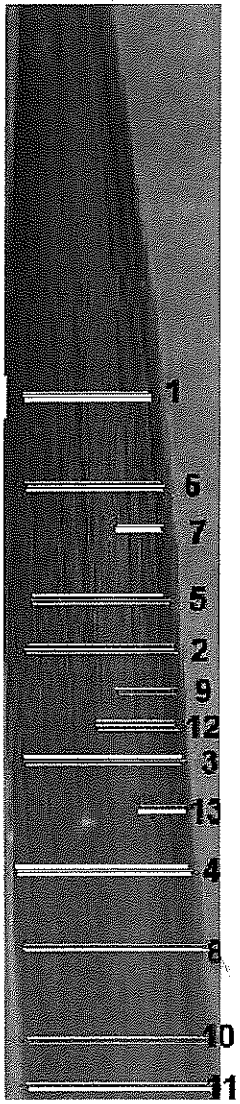

Fig. 4. Series of spinning (1 to 11) mechanism by late fourth instar *Cnaphalocrocis medinalis* larva and number of times its head swung for each spin (1-200±15; 2-280±10; 3-160±10; 4-175±15;5-110±15; 6-50±10; 7-90±15; 8-120±15; 9-40; 10-105±10; 11-125±15; 12-55±10; 13-15±10 [Observation was made in green house larvae at SPKCES, Alwarkurichi and number of head swung for spins was average of three replicates] (After Fraenkel and Fallil, 1981; Ramachandran and Khan, 1991b; Islam and Karim, 1997)

Spinning of silk threads occurs widely in many insect orders and especially in larvae of Lepidoptera, and particularly in the family *Pyralidae* to which the rice leaffolder belongs. This may take a very general aspect when random spinning often accompanies crawling and feeding, without regard to a particular webbing structure. The end product of the spinning activity is a leaf roll inside which the larva sits and feeds, and eventually pupates. For full development, a larva usually required more than one leaf (Fraenkel and Fallil, 1981; Ramachandran and Khan, 1991b; Islam and Karim, 1997). Neonate larvae of *C. medinalis* exhibit a behavior of spinning down (or silking) from plants.

Cnaphalocrocis and *Marasmia* exhibit the same leaf folding behaviour. After late second instar the folding behavior is clearly visible. If the initial leaf is not suitable, the larvae moved to another leaf. In some cases, larvae examined maximum of five leaves before final selection. On average, larvae spend upto four minutes for leaf selection (Islam and Karim, 1997) and it usually prefers a wide rice blade rather than narrow one. Leaf folding usually began at the distal mid-quarter of the leaf blade, or sometimes at the distal or proximal mid-quarter.

Leaf folders are solitary in behavior. In general, leaf folder larvae fold the upper leaves of rice plants. More than 70% of the folds were present on the top leaves. The length of leaf folds averaged 8 cm, only about 22% of the total length of the leaf blade. They preferred to make a fold along the distal and proximal mid-quarters rather than the distal and proximal quarters of the leaf blade. The majority of the leaves were folded longitudinally with the abaxial surface inside the fold. The first and second instar larvae seldom fold leaves, their smaller body size probably too small to handle the difficult task of folding rice leaf blades. Third to fifth instar larvae usually constructed folds. The selection of the leaves is based on the leaf character such as width, length, toughness and the condition of the edges either normal or twisted. Younger and more flexible are selected by the larvae, Narrower and tougher leaf blades were often rejected. Starting points of the folds mostly occurred in the distal (55%) and proximal mid-quarters (27%) of the leaf blades with a very few in the proximal and distal quarters. Young larvae usually rolled one edge of the leaf blade instead of binding both edges. The rice leaffolder make more than one fold during larval development. Immediately after release, larvae begin inspecting the leaf. If the first leaf was suitable, larvae did not inspect another leaf and began constructing a fold. If the first leaf was unsuitable, the larvae moved to another leaf and repeated the same selection procedure. In some cases, larvae examined up to four leaves before final selection: On an average, larvae spent about 4 min for leaf selection and usually selected a wide rather than narrow leaf. The larva attaches itself along the mid-rib by its prolegs and started to make the first bind. It initially stretched its head, contacted one edge of the leaf blade, and fixed a very fine, transparent and elastic silken thread spun by the leaffolder. Spinning process was repeated so that the thread became thicker, whitish and visible, and the leaf began to fold, forcing the edges closer (Fig. 3 and 4).

Securing the first few strands of thread was difficult; the strands often detached, probably due to leaf toughness. In such cases, the larva repeated the process, but if unsuccessful, the larva departed the leaf or tried to bend one edge by connecting it to the middle by the silken threads. By bending the touch edges, larvae then accomplished proper edge-to-edge bind to make the fold. Initially, binds were loose and the leaf edges were not in firm contact. As the number of binds increased the silken threads contracted, thickened and ultimately forced the edges together. The silken threads later lost elasticity and became hard. The folds were extended upwards, downwards or in both directions along the leaf which was usually folded abaxially with the upper leaf surface inside the fold. When the leaf edges were twisted or bent downwards, the leaf was folded abaxially with the lower surface inside the fold. After making two to three binds, the larvae usually rested for 1-5 min inside the fold or sometimes fed on the green tissue. After each rest period, the larvae extended the folds by making additional binds and frequently inspected the existing folds. At times, the larvae reinforced the binds with additional strands of silken threads and/or added new binds among existing ones. In this way a larva constructed on average a 3.4 cm long fold, which is designated as a 'primary fold'. On average the construction of a primary fold required 20 min, after which the larva rested and/or fed within the primary fold. On average a larva swung its head 134 times to make one bind and 1226 times to make a primary fold with 9.15 binds (2.7 per cm) (Fig. 4). On average, a fold had 10 binds of silken threads with 1.4 binds per centimeter of fold. The abaxial sides of the leaves were folded longitudinally (96%); on a few occasions leaf tips were bent and folded Generally, only one leaf blade was involved in a fold (98%). Each fold was constructed of 9-10 binds and each bind and fold required an average of 134 and 1206-1340 head swings (Fig. 4). Generally, each larva made more than one fold since the food available in a single fold was probably insufficient for the completion of larval development. Larvae expended energy during fold construction by producing silken threads, selecting leaves, head swinging and inspecting binds and folds (Fraenkel and Fallil, 1981; Ramachandran and Khan, 1991b; Islam and Karim, 1997).

7. Damage potential

Infestation usually occurs during late vegetative growth stages of the rice crop. The larvae fold the leaves and scrape the green tissues of the leaves from within and cause scorching and leaf drying. 1.5 larvae per plant cause 4% of damaged leaves reduce the yield of rice variety IR36 by 200kg/ha and is considered to represent the economic injury level (Rejesus, 1984). In Asia pest populations causes >4 % damaged leaves. The rice leaffolder make more than one fold during larval development. Under heavy infestation, each rice plant may have several rolled leaves, which severely restricts its photosynthetic activity. Folding and feeding behavior of the rice leaffolder greatly reduce the general vigor, photosynthesis and transcription activity in plant. The total reduction in photosynthesis in folded leaves is the result of the combined effect of reduction of the maximum rate of net photosynthesis per unit green leaf area due to folding and reduction of the green leaf area due to feeding (de Jong.,1992; Yamamoto,1997). The damaged leaves also serve as entry points for fungal and bacterial infections (Pathak, 1975). The yield was significantly decreased at 17.5% damaged leaves resulting in 16.5% yield loss, and a 21.3% yield loss occurred with 26.6% damaged leaves. Murugesan and Chelliah (1983) reported that a 10% increase in flag leaf damage by the leaffolder reduces grain yield by 0.13 g per tiller and the number of fully-filled grains by 4.5%. A close correlation between the intensity of leaffolder attack and loss in grain yield very often exists (Upadhyay et al., 1975). Barrion et al. (1991) also reported a positive correlation between damage rating index and leaf width.

8. Plant Resistance

Resistant cultivars alter the physiology and behavior of rice insects which in turn affects the insects susceptibility to chemical and biological controls. Resistant cultivars have an indirect adverse effect on natural enemies because of lower prey density. They have also been shown to adversely affect the development of parasites and predators by decreasing the suitability of the prey (insect pest) as a food source. However, resistant cultivars and biological controls are generally considered to be compatible. Resistant cultivars have a major impact on conserving natural enemies by decreasing the insecticide load. Wild relatives of cultivated crop plants often possess disease and insect resistance. Several wild relatives of *Oryza sativa* also were found to be resistant to rice leaffolders (Heinrichs et al., 1985; Khan et al., 1989), of which several accessions of *Oryza brachyantha* were identified as highly resistant (Heinrichs et al., 1985; Ramachandran et al., 1991a). Egg deposition and establishment of neonate larvae is successful of establishment of insect in the plant and it is based on the crop resistance. Leaffolder resistance in the rice cultivars and the wild *Oryza* species associated with establishment of the neonate larvae on the plant and do not appear due to difference in ovipostion behavior of adults but factors. (Wada, 1979) Differences in plant factors associated with the successful location of neonate larval feeding sites has been suggested as the cause of resistance of plant. The mechanism of rice leaffolder resistance in TKM6 may be a combination of antixenosis and antibiosis. Rice varieties with narrow and long leaf blades likely offer resistance to rice leaffolder species. A plant resistance to insects could be due to the disruption of one or more of the physiological and behavioral responses of the insect to the plant characteristics. Behavioral and physiological responses are considered important during insect establishment on plants: Six main categories of insect (1) orientation and settling; (2) feeding; (3) metabolism of ingested food; (4) growth; (5) survival and fecundity; and (6) oviposition (Wada 1979). Behavioral and physiology responses of insects alter to resistant plant.

The integration of host plant resistance with insecticides, cultural controls and biological control agents in a crop production system is more effective, environmentally safer, economically more profitable, and more stable than complete reliance on insecticides to control insects on susceptible cultivars. Research is needed to develop rice varieties with morphological and biochemical attributes conferring resistance to rice leaffolder species.

9. Phototactic behavior

The lepidopteron insect pest responds to various environmental factors such as light and gravity. First-instar larvae of the rice leaffolder *Cnaphalocrocis medinalis* (Guenée) oriented downwards on a rice leaf when the light source was from above. The direction of orientation was reversed when the light source was from below. The opposite directions of orientation on these substrates persisted when the substrates were held horizontal with light source from the sides. The larvae posses positive phototactic and negative geotaxis. Orientation of larval stages of insects to light has been considered important in several insect species choice of feeding site (Ramachandran, 1988; et al., 1991b). The responses of the first-instar larvae of to environmental factor (light or gravity) are altered by certain factors associated with the host plants. In leaffolders, the reduction in phototaxis occurs only in the presence of the volatiles. The rice plant volatiles along with some other unidentified rice plant factor cause a reversal of phototaxis, leading to downward orientation on the rice leaf. Host-plant induced changes in response to environmental factor may govern the insect's orientation and selection of ultimate feeding site on a plant. Understanding the factors that bring about such changes may be of value in the management and control of these insects.

10. Outbreaks

The rice leaffolder, *Cnaphalocrocis medinalis,* earlier considered as a minor and sporadic pest of rice in many Asian countries, appears to have become increasingly important with the spread of high-yielding rice varieties and accompanying changes in cultural practices. Misuse of insecticide and excessive use of nitrogenous fertilizers have been cited as the cause for high populations (Dhaliwal et al., 1980). Outbreaks of *C. medinalis* frequently occur after a prolonged dry spell. Drought followed by rainfall often creates *C. medinalis* populations reaching outbreak proportions. There are varying reports on the effect of nitrogenous fertilizers on rice leaffolder incidence.

11. Population dynamics

Knowledge of rice leaffolder population dynamics, and insight into the factors determining leaffolder abundance, such as natural enemies, is essential as a basis for more rational pest management. Rice leaffolder population dynamics have been well-studied in China and Japan, where the pest is mainly migratory with distinct generations (Liang and Pang, 1987).

The mortality due to natural enemies and the changing attractiveness of the plant considerably affect the leaf-folder population dynamics in a rice crop. Population dynamics of rice leaf-folders was incorporated into the ecosystems model in order to study the plant-herbivore interactions in general and the effect of defoliation on rice yield formation in particular. Population changes due to birth, growth, mortality and migration. Simulation model, distributed delay models are model used to study the population dynamics. A simulation model for the population dynamics of rice leaf-folders (Lepidoptera: Pyralidae) interacting with rice (*Oryza sativa* L.). It was designed to improve the understanding of the role of rice leaf-folders as elements of the rice ecosystem and to detect crucial knowledge gaps in view of a holistic assessment of their 1pest status. The model represents a synthesis of experimental results on leaf- folder biology and behaviour. A distributed delay model including attrition was applied to simulate dynamic population changes such as birth, ageing, mortality, migration and growth in terms of numbers and biomass. The host-plant on the one hand is assumed to affect leaf-folder survival, migration and growth rates while leaf-folders on the other hand influence plant growth and development by feeding and folding of leaves. The metabolic pool approach, leaf-folder feeding and hence leaf mass losses to the rice plant were described with a generalized functional response model which is 'source' and 'sink' driven. Rice leaffolder management can be improved when the effect of natural enemy densities on leaffolder infestations is known. Natural enemy abundance might be accounted for in the threshold for chemical control, or conservation measures could be taken to sustain natural control (Shepard and Ooi, 1991). Tropical rice fields harbour a large complex of natural enemies, that may keep rice leaffolder populations below damaging levels most of the time (Khan et al., 1988; Barrion et al., 1991).Natural enemies are the factors determining the population dynamics of the leaffolder complex and determine their temporal abundance and survival during a crop season. The dynamics of leaffolder natural enemies and leaffolder parasitism rates were determined in relation to leaffolder abundance and survival rates.

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