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REVIEW

RICE PLANTHOPPERS AND THEIR MANAGEMENT

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More than 20 species of planthoppers are found on rice worldwide (Table 1). They cause **hopperburn** by their direct feeding and as vectors, transmit several viral diseases, indirectly. Only four species cause economic damage: the brown planthopper, *Nilaparvata lugens* (Stal.), the small brown planthopper, *Laodelphax striatellus* (Fallen), the whitebacked planthopper, *Sogatella furcifera* (Horvath) and the rice delphacid, *Tagosodes (=Sogatodes) orizicolus* (Muir). The first of three species occur in Asia and *T. orizicolus* occurs in the southern USA and in the north central region of South America.

These planthoppers are members of Delphacidae, a family of Fulgoroidea whose members possess spur in the hind tibia. Other rice associated planthoppers are found in the Meenoplidae (*Nisia nervosa* (Motschulsky) in Africa and Asia) and the Lophopidae (*Pyrilla perpusilla* (Walker), the sugarcane leafhopper infesting rice in India) (Wilson and Claridge, 1991).

***Nilaparvata lugens* (Stal.)**
Brown planthopper (BPH)
Asian rice brown planthopper
Delphacidae: Homoptera

Synonyms : *Delphax lugens* Stal.
Delphax sordescens Motschulsky
Nilaparvata greeni Distant
Kalpa aculeata Distant
Delphax ordovix Kirkaldy
Delphax parysatis Kirkaldy
Dicrronotropis anderida Kirkaldy
Delphax oryzae Matsumura
Hikona formosana Matsumura

The outbreaks of *N. lugens* on rice crop have been recorded in Korea since 18 AD (Okamoto, 1924) and in Japan since 697 AD (Suenaga and Natkasuka, 1958). But it has become a major pest in many tropical countries in the Oriental region and some Pacific islands since 1960s only (Mochida *et al.*, 1977). In the world 14 determined and two undetermined species are reported as the members of the genus *Nilaparvata* (Mochida and Okada, 1979).

Nilaparvata is defined on the possession of small spines on the first tarsal segment. Its species are distributed in three groups in Asia and the Pacific, in the Astrotropical region in South and Central America. But only in Asia and in Africa, species of *Nilaparvata* have been noted from rice. Among the Asian species, only *N. lugens* is known as a rice pest, and in Africa, *N. meander* has been found on rice. Other Asian species *viz., N. muiri* and *N. bakeri* are frequently collected on rice but their host plants are species of *Leersia*, a genus of grasses related to *Oryza* (Wilson and Claridge, 1991).

In addition, *N. albotristriata, N. myersi* Muir, *N chaeremon* Fennah and *N.semulina* Melichar have also been recorded in various countries.

Damage to rice by BPH is both by its direct feeding and by transmission of Grassy stunt and Ragged stunt viruses.

DISTRIBUTION

N. lugens is widely distributed throughout Southeast Asia and parts of the Pacific and Australia. It has been recorded from Australia, Bangladesh, Bhutan, Burma, Cambodia, Caroline and Marine Islands, China, Fiji, India, Indonesia, Japan, Korea, Laos, Malaysia, Micronesia, Nepal, New Caledonia, New Guinea, Pakistan, Papua New Guinea, Philippines, Sarawak, Solomon Islands, Soviet Maritime Territory, Sri Lanka, Taiwan, Thailand, and Vietnam (Mochida and Oakda, 1979; Wilson and Claridge, 1991).

Table 1. Planthoppers associated with rice (Wilson and Claridge 1991)

Scientific name	Common name	Distribution	Vector of
DELPHACIDAE			
Nilaparvata lugens (Stal.)*	Brown planthopper	Southeast Asia and parts of the Pacific and Australia	Rice grassy stunt virus Rice ragged stunt virus
N. bakeri (Muir)		Asia	Rice grassy stunt virus Rice ragged stunt virus
N. muiri China		China, Japan, South Korea, Taiwan	Rice grassy stunt virus
N. meander Fennah		West Africa	
Sogatella furcifera (Horvath)*	Whitebacked planthopper	The eastern Palaearctic the Oriental region, thewestern Pacific and Australia	
S. nigeriensis (Muir)		The Ethiopian region, the southwestern portion of Palaearctic region and Madagascar	
S. kolophon (Kirkaldy)		Australia, the Oriental region, the Pacific, the Ethiopian region, the Atlantic is lands, the New World and the eastern Palaearctic	*Digitaria* striate virus
S. vibix (Haupt)		The Palaearctic region, the Ethiopian region, Australia and the western Pacific	Maize rough dwarf virus
Tagosodes pusanus (Distant)		Asia	
T. orizicolus (Muir)*	Rice delphacid	Southern USA, Mexico, South and Central America, Caribbean	Rice hoja blanca virus
T. cubanus (Crawford)		South and Central America,West Africa	Rice hoja blanca virus
Laodelphax striatellus (Fallen)*	Smaller brown planthopper	The Palaearctic and the tropical	Rice black-streaked dwarf virus, Rice
Harmalia anacharsis Fennah		Sri Lanka, Philippines Indonesia Vietnam	
Unkanodes sapporonus (Matsumura)		India, Korea, China, Taiwan, Soviet Mari-time Territory	Rice stripe virus, Rice black-streaked dwarf virus
U. albifascia (Matsumura)		The eastern Palaearctic region	Rice stripe virus, Rice black-streaked dwarf virus, Northern cereal mosaic virus
Terthron albovittatum (Matsumura)		China, Taiwan, Japan, Korea	Rice stripe virus, Rice black-streaked dwarf virus
Euidellana celadon Fennah		India, Sri Lanka, Philippines	
Sardia rostrata Melichar		Asia	
Opiconsiva spp.		Africa, Asia, Australia and the Pacific	
Coronacella sinhalana (Kirkaldy)		Sri Lanka, Taiwan, Philippines, Fiji, Micronesia Australia	
Toya propinqua (Fieber)		The Nearctic and the Old World regions	
MEENOPLIDAE			
Nisia nervosa (Motschulsky)		Africa, Asia and Australia	
LOPHOPIDAE			
Pyrilla perpusilla (Walker)**	Sugarcane leafhopper	Asia	

* Major pest ; ** Occasional pest

In India, BPH has been recorded in Andhra Pradesh, Bihar, Haryana, Himachal pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Tamil Nadu, Uttar Pradesh and West Bengal (Ghose *et al.*, 1960; Chelliah and Subramanian, 1972- '73; Kalode, 1974; Bhalla and Pawar, 1975; Diwakar, 1975; Channa Basavanna *et al.*, 1976; Freeman, 1976; Nath and Sen, 1978; Verma *et al.*, 1979).

HOST PLANTS

Rice is by far the most important host plant of the BPH (Dyck *et al.*, 1979). However, a few alternate hosts have been noted in the literature: *Eleusine coracana* (L.) Gaertn., *Leersia hexandra* SW., *L. japonica* Makino, *Saccharum officinarum* L., *Setaria italica* Beauv., *Triticum aestivum* L., *Zea mays* L., *Zizania eaduciflora* Hand. -Mazz., and *Z. longifolia* (Nasu, 1967; Grist and Lever, 1969; Misra and Israel, 1970; Mochida and Okada, 1971). But several *Oryza* species have also been reported to serve as host plants for BPH in tropical Asia. Seven species, for example, are found in Indonesia. *O. granulata, O. longiglumis, O.meyeriana, O. minuta, O.officinalis, O.ridleyi* and *O.rufipogon* (Mochida and Okada, 1979) in addition to *O.sativa*. Other *Oryza* species such as *O.australiensis, O. barthii, O. brachyantha, O. latifolia, O. nivara* and *O. punctata* may also become potential host plants.

L. hexandra serves as a host for *N.lugens* in the Philippines (Heinrichs and Medrano, 1984). However, the population which occurs on *L. hexandra* is distinct from that on rice as it does not survive on *L.hexandra*. In addition, *Leersia*-feeding population of BPH and rice-feeding BPH were shown not to interbreed when given a choice, primarily because of differences in the acoustic signals used during courtship. It was concluded that the *Leersia*-feeding population in the Philippines represents a distinct sympatric sibling species, differing in host plant preferences and in behaviour from the rice feeding populations (Wilson and Claridge, 1991). Similar *Leersia*-feeding populations of BPH have also been recorded from India, Sri Lanka, Indonesia and Australia (Claridge *et al.*, 1988). In all the regions, the sympatric rice and *Leersia*- associated populations differ in acoustic signals and do not interbreed in the field. It is clear, therefore, that *N. lugens* should still be regarded as a very specific feeder, restricted only to rices, with a closely related species feeding and reproducing only on *Leersia* (Wilson and Claridge, 1991). But the *Leersia* population is important in the management of BPH on rice as it is attacked by the same predators, parasites and pathogens as the rice population (Heinrichs and Medrano, 1984).

SYMPTOMS OF DAMAGE

The damage to rice plants by BPH occurs directly by feeding of nymphs and adults and indirectly by the transmission of diseases. It is a typical vascular feeder primarily sucking the phloem sap leading to hopperburn. Fifth instar nymphs can suck the sap more than adults and adult females can suck more than adult males. During sustained feeding, BPH excretes a large amount of honey dew.

The appearance of damage to rice plants is variable according to the population density and stages of BPH, duration of feeding, cultivars, stages of rice plants and probably the presence or absence of water in the rice fields. BPH prefers rainfed and irrigated wetland fields to upland rice and direct sown fields to transplanted fields. It infests the rice crop at all stages of plant growth. At early infestation, round yellow patches appear which soon turn brownish due to the drying up of the plants **(hopperburn)**. The patches of infestation then may spread and cover the entire field. Crop loss is usually considerable and complete drying of the crop occurs in severe cases. Wilting symptoms differ from those of plants under drought stress in which the leaf blades dry up with little loss of green colour (Sogawa and Cheng, 1979). The roots of attacked plants do not develop well and such plants can be pulled up very easily. No ratoons come out in hopperburned rice fields. The lower parts of the rice plants become blackish due to the development of *Cladosporium* spp. and *Dematium* spp., more on plants covered by honeydew excreted by *N.lugens*. When the population of BPH is high, many moulted exuviae are usually found on the lower parts of rice plants and also on the surface of irrigation water. The plant tissue around egg-groups laid does not change from green to yellow in colour, dissimilarly to that of *S.furcifera* (Mochida and Okada, 1979).

The more probable cause of hopperburn damage is the reduction in the rate of translocation of photosynthates to the root system which results from the drain of the phloem sap and the physiological disruption of active transportation in the phloem by sustained feeding. Disturbance of the physiological activities of the root system enhances leaf senescence (Sogawa and Cheng, 1979).

Hopperburn usually occurs after heading in Japan (Suenaga and Nakatsuka, 1958), Korea (Okamoto, 1924), China (Lei and Wang, 1958), Taiwan (Fukuda, 1934) and India (Velusamy *et al.*, 1975). In Indonesia, on the other hand, hopperburn is found occasionally from seedlings in seedbed through rice plants just before harvest in lowland and mountain areas in both wet and dry seasons at some outbreak areas in Java (Mochida *et al.*, 1977).

Besides, *N.lugens* is a vector of the virus diseases: grassy stunt and ragged stunt (Hibino, 1979; Chen and Chiu, 1981). Sheath blight incidence was high in BPH infested plants (Lee *et al.*, 1985). Similarly, stem rot caused by *Sclerotium oryzae* Tullis was more in BPH damaged plants (Narayanasamy and Baskaran, 1979). In China, BPH is reported to transmit *Helminthosporium sigmoideum* Car., also. (Chiang, 1977).

LOSSES AND FACTORS RESPONSIBLE FOR LOSSES

A BPH outbreak in 1733 was reported as one of the most damaging insect outbreaks in the history of rice production in Japan. About 2.6 million persons were affected and 12,000 died from hunger (Okutani, 1980). BPH rose from the status of a secondary pest to a major yield constraint beginning in the 1960's (Heinrichs and Mochida, 1984). In India, losses in 1976-'77 were estimated at 365,000 metric tons of milled rice; equivalent to the annual consumption of 3 million people (Dyck and Thomas, 1979).

BPH outbreak has been recorded in several states of India (Gunathilagaraj and Ganesh Kumar, 1997a). BPH was first observed in West Bengal only in 1968 and it occurred in outbreak proportions in the Hoogly district during 1973, 1975, 1976 and 1977 (Nath and Sen, 1978). In all, more than 6000 ha were affected. BPH was abundant in areas where the land was flooded, densely cropped and sprayed with contact insecticides in the early vegetative phase. At the grain filling stage, summer *(boro)* rice was more prone to BPH attack than winter *(kharif)* rice. Chatterjee (1969) reported the serious outbreak of BPH in two districts of West Bengal. Another outbreak in 1975 (Anon., 1975) has completely destroyed the rice crop.

BPH epidemics occurred once every few years in Tamil Nadu (Chelliah and Subramanian, 1972-'73). The incidence was especially high in 1969 and 1971 due to late rain and high level of nitrogen fertilisers. Madurai district suffered heavy infestation during 1973-'74 (Natarjan and Palchamy, 1978). In Coimbatore district, about 200 ha of rice fields were severely hopperburned in 1975 wet season (Velusamy *et al.*, 1975). BPH outbreak in 1983 in South Arcot district was attributed to drought with long spells of dry humid weather and delayed monsoon showers (Baskaran *et al.*, 1983). Monsoon failure, application of double the dose of N fertilisers and quinalphos might have caused the BPH outbreak in Thanjavur district in 1987 (Natarajan *et al.*, 1988). BPH as a pest was first reported in May 1975 only in Karnataka and in the same year, extensive BPH damage occurred in 10 districts during July-October (Channa Basavanna *et al.*, 1976). Hopperburn was noticed in two districts of Himachal Pradesh in 1973 and 1974 (Bhalla and Pawar, 1975) and in 1973, several thousand ha were badly damaged in Orissa (Dyck and Thomas, 1979). BPH caused 20- 25 per cent losses over 9000 ha in Andhra Pradesh in October 1959 (Anon., 1959). In the 1976 dry season, in East Godavari district, about 200 ha were hopperburned and 3,250 ha were severely infested (Prakasa Rao *et al.*, 1976) and indiscriminate and repeated spraying of insecticides beginning with the early crop stage was responsible for the outbreak.

The most severe outbreak of the BPH in India occurred in Kerala at the end of 1973 and in early 1974 (Koya, 1974; Nalinakumari and Mammen, 1975). This was the first major outbreak of BPH in Kerala, in the 'Kole' lands of Trichur district and Kuttanad area in Kottayam and Alleppy districts. Economic damage was realised in 50,000 ha of rice fields (Freeman, 1976) and over 8000 ha of rice crop was completely wiped out (Gopalan, 1974). Moderate rainfall (160 mm) and a relative humidity of 85 per cent and a wider atmospheric temperature range of 20-33°C were thought to be responsible for the multiplication of BPH in Trichur area. Most crops showing damage had already headed (Kulshreshtha, 1974), although crops suffered some damage at all growth stages (Mammen and Das, 1973). In many fields, the damage was so great that growers abandoned the crop (Das *et al.*, 1972). The loss in grain yield ranged from 10 per cent in moderately affected fields to 70 per cent in those severely affected (Kulshreshta *et al.*, 1974). The estimated losses in Kerala from 1973-'74 to 1975-'76 total almost 12 million US dollars. The estimated loss was 12,000 metric tonnes of rice in 1972-'73 and again in 1973-'74 in the district of Ernakulam alone, a loss of 36,150 metric tonnes was estimated (Mathur, 1978). Uttar Pradesh experienced the BPH outbreak in *kharif* crops during 1973 (Srivastava, 1976) and 1977 (Verma *et al.*, 1979) at the panicle initiation stage. More than 30,000 ha of rice crop in Bhojpur and Rohtas districts of Bihar was hopperburned in 1990 (Upadhyay and Diwakar, 1992). The amount of grain lost because of BPH infestation in the whole of India has never been estimated but it must be worth at least 20 million US dollars. But, by using Cramer's (1967) calculation for yield loss, it was estimated that 1.8 million tonnes of rice was lost annually in only three states: Andhra Pradesh, Tamil Nadu and Orissa. At 150 US dollars /t, that would be worth more than 277 million US dollars (Dyck and Thomas, 1979).

Several factors have been cited as contributing to the outbreaks of BPH (Kenmore, 1980). The major factors are:

- ☆ widespread planting of modern varieties (because they are short statured and high tillering with a better. BPH micro habitat; uniformly susceptible as compared to previously resistant local varieties).
- ☆ increased use of nitrogen containing fertilisers (because it increases the nutritional value of the rice crop for BPH to speed up its growth and fecundity; encourages vegetative growth which provides favourable microhabitat for BPH)
- ☆ increased use of insecticides (because they directly destroy natural enemies which otherwise regulate the BPH population; destroy the food source of natural enemies causing further decline of natural enemy populations and tendering fields vulnerable to reinvasion of BPH; provide selection pressure for BPH to become resistant and cross resistant; stimulate reproduction if applied at sublethal doses; increase feeding rates at sublethal doses; accumulate in a resistant BPH and thus cause mortality of natural enemies further)
- ☆ rapid expansion of irrigation systems (because they create a moist microclimate preferred by BPH, allow more months of the year to be planted under rice- the sole food source of BPH, encouraging continuous population expansion; shorten the dry season when BPH population would be stressed by lack of food and expected to collapse; create poorly drained areas at the tail end of systems where ratoon and volunteer rice persist in larger populations than otherwise serving as hosts for BPH, and
- ☆ inadequate weed control (because they act as a bridge between rice crops or preferred stages of rice crops to sustain pest populations). But, except for insecticides and nitrogenous fertilisers, conclusive evidences are yet to be shown for the role of other factors that favour BPH outbreaks.

For example, dense planting increases populations of BPH (Hino *et al.*, 1970). The reason given by most researchers is that high relative humidity favours survival (Pillai *et al.*, 1979). However, phytotron studies show that BPH mortality increases at humidities over 60 per cent perhaps because of increased pathogen infection. Two other explanations are: dense plantings provide more plant surface area and less competition for oviposition or feeding sites (Kenmore *et al.*, 1984) and denser canopies impede egg parasitic wasps (Shepard and Arida, 1986).

It is generally believed, that temperatures ranging from 28 to 30°C seems to be suitable for the development of BPH in the temperate zone (Mochida, 1964). In the tropics, a low relative humidity may be suitable for population growth when there is adequate irrigation water. When supplies of water are limited, a high relative humidity is favourable. Very heavy rain seems to increase the mortality of the first and second instar nymphs. On the other hand, it is also believed that fairly high temperatures and low rainfall conditions are related to outbreaks (Abraham and Nair, 1975; Kulshreshtha *et al.*, 1974).

LIFE CYCLE

Adult emergence takes place at the basal part of the plant. It begins at dawn and continues for 4-5 h.

Adult

THe adult hopper is 4.5-5.0 mm long and has a yellowish brown to dark brown body. The wings are subhyaline with a dull yellowish tint. Adult BPH has two characteristic wing morphs: **macropterous** (long-winged) and **brachypterous** (short-winged). The long-winged macropterous adults (macropters) can fly and are responsible for migratory movement and colonisation of new rice fields. The short-winged, flightless, brachypterous adults (brachypters) can only hop within the field. The proportion of the two winged morphs within a given population fluctuates from time to time. However, the macropters dominate in rice fields at the time of colonisation, the subsequent two or three generations are largely brachypters, while towards crop maturity, the macropters become dominant again and disperse from the field. Wing morphism is influenced by several factors. Crowding during larval stage and reduction in the quality and quantity of food (Kisimoto, 1965), short daylength and low temperature (Johno, 1963) favour macroptery. Saxena *et al.* (1981) have shown a significant increase in macropterous forms among progenies reared on senescent and hopperburned rice plants.

Adult males are attracted to female hoppers even from a distance of about 80 cm in the form of sexual communication by means of acoustic signals transmitted through the substrate (Ichikawa, 1976). Males cannot mate within 24 h of emergence and the ability to mate increases up to 5 days after emergence (Takeda, 1974). Courtship behaviour may be initiated by either sex. Both virgin females and mature males start emitting signals within a few minutes of settling on a host plant. The female call consists of simple intermittent pulses produced by the visible vibration of the abdomen. On receiving the signal, the male walks rapidly towards the female. If the female stops signaling, the male stops walking and starts sending its own signals until reciprocated by the female. The male call has a more complicated structure. It consists of repeated sections which themselves consist typically of three phases: (i) a series of 3-10 complex pulses, (ii) a series of regularly and rapidly repeated pulses and (iii) further complex groups of pulses. Thus, an alternation of male and female calls eventually leads the male to make contact with the receptive female and mating may take place (Claridge, 1983; Claridge *et al.*, 1985). One male can mate with nine females in 24 h and a female more than two times in her lifespan.

Egg

The eggs are usually laid as egg groups in the leaf sheaths near the plant base or in the ventral midribs of the leaf blades. They are whitish or transparent, thrust in a straight line. They are covered with a dome shaped egg plug secreted by the female. Only the tips of the eggs protrude from the plant surface. The number of eggs laid at a site is varied: 2 to 3 in Japan, 4 to 10 in the Philippines and two to 12 in India. The average number of eggs laid was 244/female with brachypterous females laying 300-350 eggs and macropterous females laying less than that (Table 3)

Egg stage lasts for 6 to 9 days in the tropics. Nymphal period usually ranges from 10 to 18 days. *N. lugens* has five nymphal instars and the instars are distinguished by the shape of meso- and metanotum and body size (Mochida and Okada, 1979).

Table 2. Biology of *N. lugens*[a]

Characteristics	Duration (days)
Pre-oviposition period	3-4 (Brachypterous female)
	3-8 (Macropterous female)
Oviposition period	11-39 (Brachypterous female)
	6-12 (Macropterous female)
Incubation period	6-9
Nymphal instars	5
Nymphal period	10-18
Total life-cycle	19-23
Adult longevity	14-21 (Male)
	14-30 (Female)
Fecundity	300-350 (Brachypterous female)

[a] When reared on susceptible plants

Adapted from several sources

Nymph

Freshly hatched nymph is cottony white, 0.6 mm long and it turns purple brown and 30 mm long in the fifth instar.

Adult longevity varies between field populations (9.0 days) and laboratory populations of BPH (37 days). The pre-ovipositional period, on an average, is three to four days for brachypterous females and three to eight days for macropterous females. At natural temperature (25-30°C), total lifecycle takes 19-23 days. Temperature plays a major role in the lifecycle of BPH. The threshold temperatures of embryonic and post- embryonic development of the BPH are 10.8 and 9.8°C respectively (Suenaga, 1963). Egg hatching and survival is also more at 25°C. Eggs are highly sensitive to desiccation and soon shrivel when the host plant starts wilting (Kisimoto, 1977). Adult longevity and rate of oviposition is also influenced by the temperature conditions of nymphal stage (Mochida, 1964). A temperature range of 28 to 30°C during day time is ideal for the population development of the BPH. In warm and humid climates of the tropics, BPH remains active throughout the year and the population fluctuates according to the availability of host plants, activity of natural enemies and other environmental factors prevailing in the locality. In India, the peak population is observed during the late rainy season from October to November. Another peak appears during the dry season from April to May in regions where double cropping is widely practiced. In Japan and Korea, macropterous adults immigrate into rice fields from late June to early July every year. Afterwards, BPH spends several generations on rice and moves or dies at the end of the cropping season.

BPH spends several generations during the cropping season on irrigated rice in the Asian tropics depending on the duration of the crop. It completes five generations on one rice crop in southern Japan (Mochida, 1964). 5 to 6 generations in Central China (Lei and Wang, 1958) and 4 to 6 in Indonesia (Mochida *et al.*, 1977). There are usually three generations on the modern high yielding varieties in the tropics (Heinrichs *et al.*, 1986).

BPH is known to make wind assisted migratory flights each year to colonise the summer rice growing areas of China, Japan and Korea (Kisimoto, 1976) whether it migrates elsewhere is less certain (Kisimoto and Dyck, 1976) but the capture of the specimens over the sea between the Philippine Islands (Saxena and Justo, 1980) supports the hypothesis that it is a migrant throughout its range (Rosenberg and Magor, 1983a). Field and laboratory observations suggest that BPH take-off at dusk and that some continue flying for up to 20-24 h if the temperature is more than 17°C. Long distance migration can occur in surface winds when they are strong but long distance migration is more likely at 1.5 km (Rosenberg and Magor, 1983b).

MANAGEMENT

Mechanical/Physical

A traditional method to control BPH is to pour 30-40 l of kerosene per ha onto a flooded field (Suenaga, 1966). In a young crop, two men can drag a rope across the foliage bending it into the kerosene film on the water (Misra, 1919). Older rice plants are beaten with bamboo poles or branches or brushed with a rope soaked in kerosene to dislodge insects into the oil. Most insects are killed if the operation is done early in the morning when the insects are lethargic after raising the water level as high as possible. This technology dates from the 1600s in Japan where whale oil was used before kerosene became available. A kerosene film is made more toxic if mixed with pyrethrum. Fields were drained after six h to prevent phytotoxicity. Oil films on the paddy water are highly toxic to many predators and may have caused resurgence of BPH (Kenmore *et al.*, 1984).

Sweeping rice plants with nets, bags or baskets coated with sticky materials (jack fruit latex, castor oil, grease) has been used to remove BPH in olden days (Miller and Pagden, 1930). Light traps are said to control planthoppers. Greater numbers of hoppers are collected during a full moon. At peak adoption of this method in 1930s, over one million traps were set out 1-1.5 m above the crop canopy in China (one trap per 2.3 ha) and in Japan (20 traps per ha). As further proof of the value of light traps, pest outbreaks have been reported to occur in our country after power blackouts because many insects are normally killed at street lights (Israel and Sheshagiri Rao, 1954). But the use of light traps to control insects has been criticised for many reasons: high cost, theft, erratic attraction and killing of beneficial insects (Litsinger, 1994).

Cultural

Draining the field is a common practice to control the planthoppers including BPH (Das and Thomas, 1977). Draining the field is reported to harden the plant tissue making the crop more resistant to insect feeding. Calcium is readily taken up when the field is drained which may be an explanation for this observation (Litsinger, 1994). BPH can also be controlled by alternate flooding and draining. Draining minimises BPH incidence if carried out for 5-7 days but reflooding is necessary to control weeds and prevent crop desiccation. Frequency of the action is important because alternate flooding and draining causes high losses of nitrogen. The degree of control is enhanced by other management factors acting at the same time. BPH outbreaks are also frequently associated with certain cultural practices, such as irrigation, mainly by increasing host plant availability through the practice of double and triple cropping (Kenmore, 1980). Natural enemies may be able to track population increases associated with some of these practices but the extensive use of insecticides along with these other practices precludes any conclusion concerning their effect on the pest-natural enemy interaction and its subsequent influence on outbreak. Oka (1979) has proposed the use of synchronous culture of rice and a defined rice-free period within regions and help reduce BPH densities. This practice may also reduce the effect of specialist natural enemies, such as *Anagrus* spp. without consideration of alternate hosts during the rice-free period. In addition, the use of rice-free periods may interrupt the numerical response of generalist predators, such as, spiders, in response to BPH densities (Kenmore, 1980). Current knowledge is insufficient to predict the outcome of interaction between cultural practices and biological control for BPH.

Planting rows oriented north-south lessens interplant shading and consequently is said to reduce BPH incidence (Oka, 1979). The trap-crop technique relies on the attraction of insect-pests to plantings other than the main crop (Isley, 1951). Timing is important in utilising a trap crop as the pest should not be allowed to reproduce. A trap crop should not sacrifice the field area. A final technique, only tested experimentally, is to plant 2-3 border rows of a field ahead of the main crop to a highly susceptible cultivar to attract BPH (Saxena and Justo, 1984). The border areas are then sprayed. The problem with earlier plantings are that more extended water delivery is required, the pest-free fallow period is reduced and synchronous planting is less effective.

Split application of nitrogen, first with a basal soil application for slow release and using judicious amounts to help meet the dual goals of high yields and low pest incidence (Israel and Prakasa Rao, 1968) is also recommended for BPH management. Because, the beneficial effect of nitrogen on plant yields outweighs the pest controlling effect of entirely omitting its use (Oka, 1983). Potassium suppresses BPH populations through higher proteogenesis in plants, a physiologic phenomenon correlated with the elimination of amino acids and reducing sugars in the sap and the greater production of allelochemics, thicker cell walls and greater silica uptake (Baskaran, 1985).

Tillage soon after harvest prevents unwanted crop growth (volunteer ratoon) which perpetuates BPH (Sakanoshita and Koide, 1971). Stubble burial kills the ratoon to stop pest cycles, particularly monophagous pest like BPH, if carried out community wide. Stubble burial should be combined with synchronous planting for best results.

Host plant resistance

Distinct differences in levels of resistance to the BPH under greenhouse conditions were first observed at IRRI in 1963 (Pathak *et al.*, 1969). Hence, a systematic evaluation of the world collection of *O. sativa* began in 1967 and by 1986, 400 accessions out of 50,000 accessions screened have been identified as having resistance to *N. lugens* (Rapusas and Heinrichs, 1987). Most of the resistant accessions are from India and Sri Lanka. In addition, 132 wild *Oryza* spp. accessions have been identified as resistant (Heinrichs, 1988).

Breeding programmes for BPH resistance have been established in most of the Asian countries and numerous varieties have been released since that of IR 26 in 1973 (Heinrichs, 1994). In India, many BPH resistant varieties, *viz.*, Jyothi, Co 42, Parijat, Bharti, Shakti, Sonasali, PY 3, Suraksha, Sagar-Samba, Chandan, Vajram, Prathiba, Chaitanya, Krishaveni, Nandi, MTU 4870, Bhadra, Asha, Pavizham, Karthika, Aruna, Makam, Remya, Kanakam and Udaya have been released. But, biotype selection in BPH has impeded the development of resistant varieties in many areas. Resistant rice sources identified in India have been listed recently (Gunathilagaraj and Ganesh Kumar, 1997b).

Biological

The role of natural enemies in the management of BPH and WBPH and the research needs to realise the full potential of biological control of hoppers have been highlighted recently by Guanthilagaraj and Ganesh Kumar (1997c).

Chemical

Insecticides effective against BPH include chlordimeform, isoprocarb (Velusamy *et al.*, 1978), carbofuran, quinalphos, phosphamidon, chlorpyriphos (Rao and Rao, 1979b), carbosulfan (Pillai *et al.*, 1983) BPMC (Patnaik *et al.*, 1986), monocrotophos (Senguttuvan and Gopalan, 1990), ethofenprox (Krishnaiah and Reddy, 1992), plant extracts from the roots of *Eclipta alba*, leaves of neem and *Bacillus thuringiensis* (Rao and Rao, 1979c), neem oil and other neem based products (Jena and Dani, 1994) and others. As insecticides were reported to cause resurgence of BPH, plant products are now increasingly exploited for BPH management. Neem oil treatment disrupted normal courtship signal emission and the mating behaviour of BPH females (Saxena *et al.*, 1993). Neem oil and a few of the neem products are phytotoxic to rice plants above one per cent concentration. Older plants (above 60 days) could tolerate foliar sprays up to two per cent concentration (Jena and Dani, 1994).

Success of insecticidal treatments is dependent on several factors. Proper placement of foliar sprays is important in obtaining effective control. BPH feeds primarily at the base of rice plants and hence insecticidal sprays applied above the canopy often provide poor control of BPH. High reproductive capacity and oviposition behaviour tenders the insecticidal control of BPH very difficult. As eggs of BPH are inserted into the stem tissues at the base of the rice plants, insecticides with ovicidal action can be used to kill eggs. Rao and Rao (1979a) reported that carbofuran applied on paddy water and BPMC, carbaryl and isoprocarb applied to water or soil inhibited egg hatching.

Careful and appropriate timing of application is the simplest way to enhance insecticide effectiveness. Kiritani (1972) suggested that appropriate timing will achieve insecticide specificity. As eggs of BPH are difficult to kill, it is best to apply insecticides when the majority of the nymphs are in the third or fourth instar stages. In the People's Republic of China, three BPH generations occur on the first crop and damage is caused by the third generation. Most effective control was obtained by treating the second generation (Anon., 1977).

Timing of insecticide application should take into consideration the natural enemy population in the field. As most of the insecticides eliminated natural enemies, Hienrichs *et al.* (1981) suggested that, based on light trap catches and field surveys, the best time to spray for BPH is about two weeks after peak trap catches, provided the economic threshold has been reached. Use of appropriate insecticide at the economic threshold level (ETL) places BPH control on a sound economic basis with minimum ecosystem disruption. In different countries, various ETLs have been reported. Sellammal Murugesan and Chelliah (1982b) reported that an average of 2.5 insects per tiller resulted in severe economic damage in a susceptible variety TN 1, while even a mean of 2.6 insects/tiller did not cause economic damage in a moderately resistant variety Co 42. They further reported that the damage in the resistant variety ASD 11 was low at the above population levels. Thus, it is necessary to develop ETLs depending on the level of resistance in a variety. Sellammal Murugesan and Chelliah (1982a) further observed that in moderately resistant varieties, Co 42 and Triveni, at the same level of BPH population, the yield was relatively lower in 60-day old plants than that of 45-day old plants. Thus, it is suggested that the ETL should be assessed taking also into consideration the level of resistance of the variety, stage of the crop, the natural enemy population and the climatic conditions that prevail in the region (Chelliah and Bharathi, 1994).

Additional factors that complicate the use of insecticides in the control of BPH are (Chelliah and Bharathi, 1994):

- ☆ the BPH is a phloem feeder and systemic insecticides move primarily through the xylem. Insecticide accumulates in the leaf tips and little of it accumulates in the leaf sheath area where BPH feeds.
- ☆ it is extremely difficult to control adults migrating from adjacent outbreak areas. Even when fields are sprayed, the insects are capable of laying eggs before they are killed. Many insecticides do not kill the eggs and when they hatch, the residual activity of the insecticide is not sufficient to kill the hatching nymphs and, thus additional applications are required.
- ☆ because of the high reproductive rate, BPH rapidly develops resistance to insecticides.
- ☆ many insecticides applied at sublethal rates cause BPH resurgence. Because many farmers use sublethal rates, these insecticides have caused serious problems.
- ☆ physiologically different BPH populations or biotypes have differential susceptibility to the commonly used insecticides such as carbofuran, metalkamate, diazinon and methyl parathion in contact toxicity tests.

Insecticide-induced resurgence of BPH was common in the 1970s and 1980s with reports from every rice producing country in tropical Asia (Heinrichs *et al.*, 1982; Shepard *et al.*, 1990). The degree of resurgence is dependent on an interaction of factors consisting of the insecticide and its effect on the rice plant, the BPH populations and the natural enemies of BPH (Heinrichs and Mochida, 1984). Almost all groups of insecticides can cause resurgence. Insecticide type and rate, timing of application and the number and method of insecticide application, all influence the degree of BPH resurgence. Factors contributing to BPH resurgence consists of direct effects of the insecticides on the BPH population and the indirect effects on the BPH population via the host plant and natural enemies (Chelliah and Heinrichs, 1980; Chelliah *et al.*, 1980; Kenmore *et al.*, 1984; Heinrichs, 1994). Chronic outbreak of BPH in Indonesia in the mid 1980s was attributed to the excessive use of insecticides in rice fields. The result was the Presidential decree in 1986 banning use in rice environment of more than 57 insecticides (England, 1987).

Integrated Pest Management

Pesticide management to enhance natural pest control by rice field predators and parasites, cultural control practices, the planting of resistant cultivars and non-chemical control measures form the IPM technology for BPH (Matteson *et al.*, 1994). IPM technologies have been developed in different countries. All such programmes show that almost every decision about growing rice influences the crop's susceptibility to BPH (Table 3).

A typical IPM technology developed at the Tamil Nadu Agricultural University, Coimbatore (Regupathy *et al.*, 1994) is as follows:

Table 3. Brown planthopper control recommendations (Matteson *et al.*, 1994)

1. Grow no more than two rice crops per year
2. Choose early maturing planthopper resistant rice cultivars
3. Plant neighbouring fields within three weeks of each other
4. Control weeds and do not exceed recommended rice plant density
5. Apply nitrogen fertiliser judiciously, with split applications three times during crop growth
6. Visit the fields weekly from seedbed to dough grain stage : counting the pests and their natural enemies and taking control action when the brown planthopper population reaches the economic threshold
7. Economic threshold for brown planthopper, *Neuva Ecija*, Philippines, 1986 : one mature nymph per hill, subtracting five planthoppers for each predator encountered
8. To reduce planthopper populations, drain the paddy for three or four days
9. If draining the paddy is not feasible, apply an effective insecticide (one that does not cause resurgence) at the base of the rice plants only in the infested portions of the fields of the susceptible cultivars
10. Plough down volunteer ratoon after harvest.

(Adapted from Reissig *et al.* (1985) and Smith *et al.* (1989))

- ☆ avoid use of excess nitrogen
- ☆ use resistant varieties like PY3, Co 42 and moderately resistant varieties like ADT 36
- ☆ Provide rogue spacing at every two m to facilitate insecticide application
- ☆ control irrigation by intermittent draining
- ☆ set up light traps to monitor population and control BPH
- ☆ avoid the use of insecticides causing resurgence such as synthetic pyrethroids, methyl parathion, fenthion and quinalphos
- ☆ pre-flowering stage: Phosphamidon 85 WSC 500 ml, monocrotophos 36 WSC 1250 ml, phosalone 35 EC 1500 ml, chlorpyriphos 20 EC 1250 ml, carbofuran 3G 17.5 kg per ha
- ☆ post-flowering stage: Carbaryl 10 D 25 kg/ha. Drain water before use of insecticides. Direct spray/dust towards the base of the plant.

Under Special Food Production Programme, the task force of the Directorate of Rice Research (DRR) recommends the growing of resistant variety Sonasali for BPH endemic areas in different stages. In addition, its recommendation includes application of insecticides based on the economic threshold levels.

***Sogatella furcifera* (Horvath)**
Whitebacked planthopper (WBPH or WPH)
(Delphacidae : Hemiptera)

Synonyms : *Delphax furcifera* Horvath
Sogata distincta Distant
Sogata pallescens Distant
Sogata kyusyuensis Matsumara and Ishihara
Sogata tandojamensis Qadri and Mirza

The whitebacked planthopper (WBPH), *Sogatella furcifera* has had a long history as a pest of rice. Its damage to the crop was experienced as early as AD 697 in Japan (Suenaga and Naktsuka, 1958). However, it was in 1899 that Horvath first erected the species *furcifera* under *Delphax* on the basis of a male specimen collected from Japan. The genus was subsequently changed to *Sogatella* in 1963 (Fennah, 1963).

Sogatella belongs to a group of genera that have a slender body shape, narrow vertex and frons and a white pale yellow longitudinal stripe from the head across the pro- and mesonotum. This group contains *Latistria*, *Matutinus*, *Sogatella*, *Sogatellana* and *Tagosodes* gen.n. Recently Asche and Wilson (1990) have reviewed the genus *Sogatella* and related groups. According to them, *Sogatella* species are found throughout the subtropical and tropical regions of the world. They are concentrated in Africa (13 species), Nearctic and Neotropical regions (2 species) and Asia, the Pacific and Australasia (3 species).

S. furcifera is second only to *N. lugens* as a rice pest in Asia and other species such as *S. nigeriensis* and *S. vibix*, though frequently found on rice (Amar, 1977; Amar *et al.*, 1980) are not considered to be important pests at present. *S. vibix* is the vector of maize rough dwarf virus in the middle east (Harpaz, 1966) and (as *S.longifurcifera*) is reported as a vector of Maize Sterile Stunt in Australia (Greber, 1982). *S.kolophon* is the vector of *Digitaria* stritate virus in Australia (Greber, 1979) and dry bud rot of coconut in West Africa (Julia and Mariau, 1982).

DISTRIBUTION

S.furcifera is widely distributed in the eastern Palaearctic, the Oriental region, the Western Pacific and Australia (Wilson and Claridge, 1991). It has been recorded in Australia, Bangladesh, Burma, China, Cambodia, Fiji, Hawaii, Hong Kong, India, Indonesia, Japan, Korea, Malaysia, Manchuria, Micronesia, Mongolia, Nepal, Pakistan, the Philippines, Ryukyu Islands, Saudi Arabia, Sri Lanka, Solomon Islands, Taiwan, Thailand, the USSR, Vanuatu and Vietnam (Gunathilagaraj, 1983).

The western limits of the distribution of WBPH are still unclear (Asche and Wilson, 1990). Species recorded from Africa, Europe or the New World as *S. furcifera* proved to be other species. Similarly, those recorded from Europe, North Africa and tropical Africa concern either *S. nigeriensis* or *S.vibix*. Records of *S.furcifera* from the New World countries in most cases concern *S.molina* or *S. kolophon*. The western-most populations of true *S. furcifera* examined by Asche and Wilson (1990) were from Pakistan and Saudi Arabia. Its closest relative *S.nigeriensis* is widely distributed in Africa and occurs sympatrically with *S.furcifera* in Saudi Arabia. However, no transition zone (hybrid belt or cline) between these two species has been found (Wilson and Claridge, 1991).

In India, WBPH attack on paddy was reported first from Surat, Pusa, Poona and Nagpur as early as 1903 (Lefroy, 1903-04). Subsequently, it was observed in Bihar and Bengal (Fletcher, 1916, 1917, 1919), Jabalpur and other neighbouring districts in Madhya Pradesh (Berg, 1960). WBPH appeared for the first time in 1966 in Punjab (Jaswant Singh *et al.*, 1986) and in Rajasthan in 1986 (Tripathi and Pandya, 1987). It is a major pest of rice in the hilly tracts of Uttar Pradesh (Sachan and Garg, 1992) and in Haryana after rice root weevil (Kushwaha *et al.*, 1982). It attained higher level of incidence in Gujarat, Haryana, Rajasthan, Maharashtra, Madhya Pradesh and Punjab during mid-tillering phase in September/October. However, it was of no significance till early 1980s (Upadhyay and Diwakar, 1992). It has also been recorded in Andhra Pradesh, Assam, Bihar, Delhi, Haryana, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Manipur, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal (Chelliah and Gunathilagaraj, 1990). In general, it is reported to be more severe in areas where resistant varieties of BPH have been grown.

HOST PLANTS

As compared to the BPH, *S. furcifera* has a wide range of host plants (Table 4). For example, it grows on *Echinochloa glabrescens* as well as *Oryza sativa*. It was observed to repeat some generations on graminaceous grasses: *E. glabrescens, Cynodon dactylon, Leersia japonica, Zizania caduciflora* and *Glyceria acutiflora* (Suenaga, 1956). In India, it has been observed on rice, finger millet, sorghum, wheat, jungle rice and *Leersia hexandra*. The barnyard grass, *E. crus-galli* var. *oryzicola* does not have antifeedant effect on WBPH which grows to become normal adults on grasses as on rice unlike BPH for which it is an antifeedant. Recently, the WBPH has been observed to breed on *Bergia capensis* L. (Elatinaceae) at Madurai, Tamil Nadu (Guanthilagaraj, unpublished).

Table 4. Host plants of *Sogatella furcifera*

Scientific name	Common name	Reference
Alopecurus aequalis Sobol	short awn foxtail	Nasu (1967)
Cynodon dactylon (L.) Pers	Star grass	Suenaga (1956)
Digitaria adscendens (H.B. & K.) Henr.	Finger grass	Nasu (1967)
D. decumbens Stent.	Pangola grass	Bisessar (1966)
Echinochla colonum (L.) Link	Jungle rice	Misra and Israel (1970)
E. crus-galli (L.) Beauv.	Barnyard grass	Nasu (1967)
E. crus-galli var *oryzicola*		Kim *et al.* (1975)
E. glabrescens		Suenaga (1956)
Eleusine coracana (L.) Gaertner	Finger millet	Misra and Israel (1970)
E. indica (L.) Gaertner	Fowlfoot grass	Nasu (1967)
Glyceria acutiflora	Creeping Manna grass	Suenaga (1956)
Hordeum vulgare L.	Barley	Nasu (1967)
Leersia hexandra Sw.	Rice grass	Misra and Israel (1970)
L. japonica Makino	....	Suenaga (1956)
Oryza sativa L.	Rice	Nasu (1967)
Phalaris arundinacea L.	Reed Canary grass	Nasu (1967)
Poa annua L.	Dwarf meadow grass	Nasu (1967)
Saccharum officinarum L.	Sugarcane	Nasu (1967)
Setaria italica (L.) Beauv.	Italian millet	Nasu (1967)
Sorghum vulgare Pers.	Sorghum	Misra and Israel (1970)
Sporobolus elongatus R.	Australian smut grass	Nasu (1967)
Triticum aestivum L.	Wheat	Misra and Israel (1970)
Zea mays L.	Maize	Nasu (1967)
Zizania caduciflora Han-Mazz	American wild rice	Nasu (1967)

SYMPTOMS OF DAMAGE

The WBPH is usually more abundant during the early stage of the growth of the rice crop, especially in the nurseries. It attacks plants of less than four month old in the fields with standing water and shows a marked increase with the age of the crop. Rice is more sensitive to the attack at tillering phase than at the boot and heading stages. Damages caused by the immigrants occur soon after their landing through feeding and egg laying. Under favourable conditions, WBPH produces several generations and can cause **"hopperburn"** in the rice crop. Both nymphs and adults suck the phloem sap (Auclair and Baldos, 1982) causing reduced vigour, stunting, yellowing of leaves and delayed tillering and grain formation. Rice crop fails frequently to produce complete grains (seedless glumes) and a condition known as "red disease" in Malaysia. It is seldom that rice plants are killed by WBPH except early stages. However, yellowing of grownup rice plants has been reported. When the hoppers are present in large numbers late in the crop growth stage, they are seen infesting the flag leaves and panicles. Gravid females cause additional damage by making ovipositional punctures in the leaf sheaths. Feeding punctures and lacerations caused by the ovipositor predispose rice plants to pathogenic organisms and honeydew excretion encourages the growth of sooty mold such as *Cladosporium* spp. and *Dematium* spp. but not so abundantly as in BPH (Mochida, 1964)

Symptoms of rice plant attacked by WBPH are variable according to population density, duration of feeding, rice cultivars and stages of the plant. Damage in the form of hopperburn frequently appears in large areas of a region comparatively uniformly in a rice field whereas it appears as circular patches in the case of BPH (Table 5). The sequence of development of symptoms by the feeding of WBPH is documented by Mochida (1982). Fortunately, unlike BPH, *S.furcifera* is not a vector of any rice virus disease but was reported to be a vector of virus disease of Pangola grass, *Digitaria decumbens* (Bisessar, 1966).

LOSSES AND FACTORS RESPONSIBLE FOR LOSSES

Outbreaks of WBPH have been recorded in recent times from several states in India (Gunathilagaraj and Ganesh Kumar, 1997a). Over 1000 ha of rice were hopperburned in Punjab during September 1983 (Saini, 1984) and around 8000 ha in Cachar and Karimganj districts of Barak valley in Assam during May-June 1985. This outbreak was favoured by high rainfall in early April followed by prolonged dry period with high temperature and humidity in May (Saha, 1986). Damage to early rice during 1983 in Manipur was attributed to the unusually heavy rains and flooding in the Imphal valley at that time (Barwal, 1984). In Karnataka, WBPH outbreak was reported during 1986 *kharif* in the Viseswaraya canal tract of Mandya. Higher N fertilisation (130 kg/ha) with

Table 5. Comparison between WBPH and BPH (Modified from Mochida, 1982).

Characteristics	WBPH	BPH
Adult	3-4 mm long distinguished by the absence of a median transverse ridge on vertex	3 mm long, light or dark brown in colour with three longitudinal stripes on the pronotum
Egg period (days)	6.5	10.4
Nymphal Period (days)	12.8	14.2
Adult longevity (days) (Macropterous female)	15.6	27.6
Life-cycle (days)	19.3	24.6
Fecundity (eggs/female)	around 300 (0-1172)	200-400 (0-1474)
Migration	longer distance	long distance
Hopperburn	uniformly over large areas	in circular patches
Vector of	------	Grassy stunt Ragged stunt
Distribution within the plant	only the nymphs found at the base and the adults invariably stay at the upper portion of rice plant	both nymphs and adults found at the base of rice plants
Ovipositional injury	plant tissue around egg groups changes from green to yellow colour.	does not change

frequent heavy rains might have favoured WBPH outbreak (Gubbiah *et al.*, 1987). More than 80 per cent damage to rice is common in West Bengal in areas of water stagnation. Artificial infestation studies (Khatri *et al.*, 1983) revealed that the grain loss varied from 11 to 39 per cent when 15 insects per hill was released at varying stages of plant growth. Yet precise estimates on the damage caused by WBPH and the resultant losses are yet to be quantified in the field.

Factors recognised to favour outbreak in different countries were degree of humidity (Miller and Pagden, 1930), low rainfall (Murata and Hirano, 1932), absence of typhoons during summer (Yashiro, 1939), above average temperature and less rainfall (Kuwayama, 1940), increased sunshine in April- June (Mochida, 1964), transoceanic migration (Kisimoto, 1971), prolonged monsoon with intermittent rain and use of heavy doses of nitrogen (Majid *et al.*, 1979). Weekly averages of 28.59^{0}C, 69.55 per cent relative humidity, 8.18 h of sunshine and 0-71.7 mm of rain were reported to favour WBPH outbreak in Delhi (Garg and Sethi, 1980).

LIFE CYCLE

The life-cycle of WBPH has been studied by several workers (Atwal *et al.*, 1967; Misra and Israel, 1968; Kittur, 1969; Vaidya and Kalode, 1981; Gunathilagaraj, 1983; Nalini, 1990). The description of the different growth stages of WBPH has been given by Atwal *et al.* (1967). The adult hopper can tolerate a wide range (8-36^{0}C) of temperature and remain active. The macropterous females are more tolerant to temperature extremes than the males.

Adult

The adult hopper is 3.5-4.0 mm long and has a distinctive long narrow face. The forewings are uniformly hyaline with dark veins. There is a conspicuous black dot about the middle of the posterior edge of each forewing which meets when the forewings come together. The pronotum is pale yellow, the body is black dorsally and creamy white elsewhere. There is a prominent white band between the junctures of the wings.

Macropterous males and females and brachypterous females are commonly found in the field, whereas brachypterous males have not been reported yet (Kisimoto, 1965). The eggs are commonly laid as egg-groups in sheaths when the rice plant is small but in the upper part of the rice plant when the plant is large. The number of egg masses laid by the WBPH is 85 per female and each egg mass contains 6 to 8 eggs. The eggs in a group are not sealed together by material secreted by the WBPH female, dissimilar to the BPH. The brachypterous females produced more eggs (300-350) than the macropterous females (164-300).

Eggs

Eggs are cylindrical in shape, laid on the plants with the micropylar end protruding from the tissue. The operculum is long and narrow (Nasu, 1967).

The incubation period varied considerably. It was 3.4 to 14 days in different countries. Nymphal period usually ranges from 8 to 28 days and there are five nymphal instars. The five different instars took 2-3, 2-3, 3-4, 3-4 and 2-3 days respectively to complete their development (Vaidya and Kalode, 1981; Gunathilagaraj, 1983).

Nymphs

Pale to light brown in colour and range in size from 0.6 mm when young and newly hatched to 2.0 mm after 11-12 days. Fifth instar nymph has narrow head and white or creamy white body. Dorsal surface of the thorax and abdomen marked with various amounts of grey and white markings.

The longevity of adult also varied from place to place (Table 6). It was 1.9 to 31.8 days for macropterous male, 2.0 to 41.1 days for macropterous female and 5 to 21 days for brachypterous female.

The average life-cycle in India was 23 days at Cuttack (Misra and Israel, 1968), 11 to 56 days in the field and 24 to 34 days in the laboratory in Madhya Pradesh (Kittur, 1969) and 12.3 to 17.7 days in Punjab (Atwal *et al.*, 1967). The generation time was prolonged from 20 to 91 days in Ludhiana, Punjab during winter (Shukla and Gupta, 1980). Temperature has a pronounced effect on the pre-oviposition period, duration of different stages and life-cycle.

Table 6. Biology of *S. furcifera*

Characteristics	Duration
Pre-oviposition period	2-9 (Macropterous female)
	2-3 (2.7)
Oviposition period	3-12
Incubation period	6-7 (6.4)
Nymphal instars	5
Nymphal period	12-17 (14)
I instar	2-3
II instar	2-3
III instar	3-4
IV instar	3-4
V instar	2-3
Total life-cycle	18-24 (23)
Adult longevity	1.91-31.80 (Macropterous male)
	2.00-41.10 (Macropterous female)
	5.00-21.00 (Brachypterous
female)	
Fecundity	2-425 (162)

MANAGEMENT

Mechanical

In olden days, WBPH was destroyed to a large extent by the use of field bags, by squirting kerosene in the infested fields and drawing a rope across the fields so as to get the nymphs as well as the adults in kerosene on the water. The cultivators also bagged their fields with *dhoties* turned into temporary bags, previously moistened with a little kerosene (Misra, 1921). Sweeping rice plants with nets, bags or baskets: some coated with sticky materials (jack fruit latex, castor oil, grease) was also used to remove WBPH in Malaysia (Miller and Pagden, 1930).

Cultural

Draining of water from the field for about four to six days was found effective in controlling the build up of population of WBPH by manipulating humidity (Patel, 1971). WBPH incidence was low when rice was intercropped with either soybean, pigeon pea or groundnut (Gangwar *et al.*, 1994). Dryland rice intercropped with cotton or pigeonpea had also low WBPH population (Satpathy *et al.*, 1977).

Chemical

Insecticides effective against WBPH are:

Carbaryl WP 0.5 kg a.i./ha
Endosulfan EC 0.35 kg a.i./ha
Diazinon G 1.25 kg a.i./ha
Phorate G 1.00 kg a.i./ha
Carbofuran G 0.5 kg a.i./ha

Carbofuran and triazophos are also reported to be effective ovicides. The DRR recommends spraying of quinalphos, fenthion, chlorpyriphos, carbaryl, monocrotophos @ 0.5 kg a.i./ha or broadcasting of carbofuran 3G @ 0.75 kg a.i./ha or phorate 10G 1.25 kg a.i./ha, depending upon the stage of the rice crop. The insecticide application is recommended only when the population of WBPH exceeds the economic threshold level (10/hill during planting to mid- tillering stage; 5-10/hill during flowering and after). Pesticide application can be timed to coincide with the incipient outbreak of WBPH. In China, an expert system **HOPPER** for forecasting the outbreak of WBPH in the first crop season has been developed and HOPPER was able to make a reasonable prediction of WBPH attack in 1991 season (Tang *et al.*, 1994).

As WBPH is not reported as a constant threat to rice production in India, effective IPM strategies are yet to be worked out. Under the Special Food Production Programme, the task force of DRR has implemented the IPM programme in 13 states and the measures recommended for other pests were found equally effective for WBPH also.

Other planthoppers attacking rice in India are:

***Nilaparvata bakeri* (Muir)**
(Delphacidae : Hemiptera)

Synonym : *Delphacodes bakeri* Muir

N. bakeri is slightly larger and darker than *N. lugens*. It is widely distributed in Asia and has been recorded from India, South Africa, South China, Sri Lanka, Taiwan, Indonesia, Korea, Thailand and the Philippines (Wilson and Claridge, 1991). Though found in rice fields, it has been reported to feed and reproduce on *Leersia hexandra* and other species of *Leersia* (Mochida and Okada, 1979).

***Sogatella kolophon* (Kirkaldy)**
(Delphacidae : Hemiptera)

Synonyms : *Delphax kolophon* Kirkaldy
Sogatella kolophon atlantica Fennah
Opiconsiva insularis Distant
Sogata meridiana Beamer

Sogatella chenhea Kuoh
Opiconsiva derelicta Distant
Delphacodes elegantissima Ishihara
Sogatella nebris Fennah

S. kolophon is the most widely distributed of all *Sogatella* species (Asche and Wilson, 1990) and is known from Australia, the Oriental region, the Pacific, the Ethiopian region, the Atlantic islands, the New World and the eastern Palaearctic. It is most commonly found in the tropics.

S. kolophon is small, slender, light yellow to straw coloured planthopper with hyaline forewings having grey or light brown markings in the apical half (Asche and Wilson, 1990). Its pest status on rice is yet to be established even though it has been frequently recorded on grasses. It is also reported as a vector of *Digitaria* striate virus in Australia (Gerber, 1979).

Sogatella vibix (Haupt)
(Delphacidae : Hemiptera)

Synonyms : *Liburnia vibix* Haupt
Sogatella catoptron Fennah
Sogatella diachenhea Kuoh
Delphacodes dogensis Ishihara
Delphacodes longifurcifera Esaki and Ishihara
Liburnia matsumurana Metcalf
Delphacodes panicicola Ishihara
Sogatella parakolophon Linnavuori

S. vibix is widely distributed in the Palaearctic region, the Ethiopian region, the Oriental region, Australia and the Western Pacific. It is absent in the New World (Asche and Wilson, 1990). It has been recorded as a pest of rice in Egypt (Ammar, 1977). *S.vibix* is the vector of maize rough dwarf virus in the Middle East (Harpaz, 1972) and as *S.longifurcifera* has been implicated in the transmission of rhabdovirus of *Eleusine coracana* in India (Yaraguntaiah and Keshavamurthy, 1969).

Laodelphax striatellus (Fallen)
Smaller brown planthopper
(Delphacidae : Hemiptera)

Synonyms : *Delphax striatella* Fallen
Delphax notula Stal
Liburnia devastans Matsumura
Liburnia haupti Lindberg
Liburnia nipponica Matsumura
Liburnia minonensis Matsumura
Liburnia giffuensis Matsumura
Liburnia akashiensis Matsumura
Liburnia maidoensis Matsumura

L. striatellus, a severe pest of rice in Japan, China, Korea and southern Europe has been recorded in India also (Shukla, 1979). It is vector of black-streaked dwarf virus and stripe virus in maize. It is widely distributed in the Palaearctic, from the UK where it is rare to Japan (and Soviet Maritime Territory). In tropical Asia (Northern Philippines, North Sumatra), it is a pest on upland rice at higher altitudes (Wilson and Claridge, 1991).

Unkanodes sapporonus (Matsumura)
(Delphacidae : Hemiptera)

Synonym : *Unkana sapporona* Matsumura

U. sapporonus has been recorded from Korea, Japan, China, Taiwan, India and the Soviet Maritime Territory.

Adults of *U. sapporonus* are 3.5 to 4.5 mm long, pale yellow in colour with characteristic pale white stripe on the vertex and pronotum (Wilson and Claridge, 1991). It is a minor rice pest in Japan (Mochida and Okada, 1971) and is a vector of black-streaked dwarf and stripe viruses. But, it usually lives on maize, wheat and barley and is therefore, not important in the disease cycle on rice. It was recorded in India during December 1967 to March 1968 on rice under non-irrigated condition in the fields of Central Rice Research Institute, Cuttack in association with WBPH. It attacked the lower leaves which became greenish yellow, yellowish and then dried up completely (Misra and Israel, 1968; Misra, 1975).

Tagosodes pusanus (Distant)
(Delphacidae : Hemiptera)

Synonyms : *Sogata pusana* Distant
Kelisia fieberi Muir
Unkana formosella Matsumura
Sogata striatus Quadri & Mirza
Himeuna chibana Tian & Kuoh

T. pusanus is a minor pest of rice in Asia and is known from India, Sri Lanka, Philippines, Taiwan, China, Indonesia, Malaysia and Pakistan (Wilson and Claridge, 1991). It resembles the WBPH but for the pattern of dark markings of the forewings.

Euidellana celadon Fennah
(Delphacidae : Hemiptera)

E.celadon resembles the BPH in external appearance and size but for the dark brown veins on the forewings which are pale in BPH. It is rarely found in the rice fields of the Philippines, Sri Lanka and India (Wilson and Claridge, 1991).

Nisia nervosa (Motschulsky)
White striated planthopper (WSPH)
(Meenoplidae : Hemiptera)

Synonyms : *Livilla nervosa* Motschulsky
Nisia atrovenosa (Lethierry)

N. nervosa is a minor pest of rice in Africa, Asia and Australia (Grist and Lever, 1969). It has been found attacking sugarcane in China (Bangkan Huang and Oi Shcheng, 1981). Adults of *N.nervosa* are 2.7 to 4.3 mm long, grey coloured with characteristic granulate veins in the forewing clavus and the tent-like forewings when folded over the body. Nymphs are rounded in appearance with head, thoracic plates and abdominal tergites light to dark grey. The mirid, *C. lividipennis* is an effective predator of *N. nervosa* and in Tamil Nadu, an unidentified nematode attacks *N. nervosa* during winter at Annamalainagar (Jayanthi *et al.*, 1987).

Pyrilla perpusilla (Walker)
Sugarcane leafhopper
(Lophopidae : Hemiptera)

Synonym : *Pyrops perpusilla* Walker

P. perpusilla, a major pest of sugarcane in India, occasionally attacks rice fields situated near sugarcane fields, probably transferring to rice when sugarcane was harvested (Wilson and Claridge, 1991). It was found attacking rice in Karnal and Sonapet districts of Haryana during August-October 1978-'79 (Garg and Sethi, 1983a), Delhi during *kharif* 1976 and 1978 (Garg and Sethi, 1982) and Gurdaspur district in Punjab during August-September 1980. Heavy parasitisation of eggs (75- 95%) by *Tetrastichus pyrillae* Crawford (Eulophidae : Hymenoptera) and nymphs and adults (20-60%) by *Epiricania melanoleuca* (Fletcher) (Epipyropidae : Lepidoptera) was observed in Haryana.

The egg and live cocoons of *E.melanoleuca* can be released in hopper infested rice fields @ 40,000-50,000 eggs/ha and 4000-5000 cocoons/ha respectively when the *Pyrilla* population averages 3.5 individuals/leaf same as that of sugarcane threshold (Pawar, 1981).

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EFFECT OF PREMONSOON DRYSEEDING EMPLOYING RAINFALL PREDICTION IN VERTISOLS OF ARUPPUKKOTTAI TALUK

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ABSTRACT

Thirty one years of rainfall data of Aruppukottai in Virudhunagar district were analysed for variability indicated the "Uni" model distribution pattern. Weekly rainfall prediction were made for dry seeding on vertisols. Thrity seventh STD week (Sep 10-16) had the probability of 73 per cent for 20 mm rainfall. The probability for 10 mm of rainfall in the subsequent weeks remained more than 60 per cent. Dry seeding possibility in sorghum and cotton during 35 and 36th week has been indicated. A model with minimum assured rainfall at 50 per cent probability in conjunciton with moisture availability index was developed and validated through on-farm trials in the farmers holdings. The yield increase in sorghum was 36 per cent over the monsoon crops. This technique was useful for other vertisol areas with uni model rainfall pattern with primary peak in the month of October.

KEY WORDS : Rainfall prediction, dry seeding, vertisols

In drylands, crop production is hampered by many constraints of which the rainfall is the major one as it forms the only source for soil moisture. Rainfall in the semi-arid tropics is not only low in quantity but also erratic and undependable in distribution. The length of growing season depends on date of receipt of rains for sowing and cessation of the same. Virmani and Piarasingh (1986) defined the onset of sowing rain as that a rainfed crop could be sown during a week which received 20 mm of rain in one or two consecutive days provided the following week received 10 mm rainfall at 70 per cent probability. The end of rainy season could be identified as the week, provided the weekly rainfall of subsequent week fell below 0.25 times of PET continuously (Ramana Rao, 1988). The technique for dry seeding which involves the sowing of seeds in dry soil especially for vertisols has been developed to make use of the pre-monsoon showers received. Pothiraj (1982) reported that pre-monsoon dry seeding of rainfed cotton at 38th standard week at Coimbatore was optimum for higher yield. Keeping this in view, the rainfall data of Arupukottai taluk in Virudhunagar district were analysed to determine the optimum week for dry seeding in vertisols.

MATERIALS AND METHODS

The historical rainfall data for 31 years (1959-89) were collected from the Revenue Department. The data were analysed for annual, seasonal, monthly and weekly variability through a computer programme (Chinnamuthu *et al.*, 1991). Conditional probability for specific quantity of rainfall) was worked out by adopting the method developed by Gopalaswamy *et al.* (1988). The resultant quotient was referred to 'Z' table for finding the probability. The initial probability (quantity of rainfall for fixed probability) was worked out for weekly data. The moisture availability index (MAI) was workedout as suggested by Hargreaves (1974).

The PET data worked out by Subramanian and Kulandaivelu (1986) were utilised. A model has been developed based on the minimum assured rainfall at 50 per cent probability for sorghum crop and validated in the farmers holdings in the taluk at