Economic thresholds, nature of damage, and losses caused by the brown planthopper

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The brown planthopper is primarily a phloem feeder. A single female adult discharges 13 μl or more honeydew per day during sustained feeding.

Rice plants infested by the brown planthopper before maximum tillering stage have fewer panicles per unit area and fewer grains per panicle, while plants infested after the heading stage have lower percentages of ripened grain and gram weight. The heavily infested plants exhibit the characteristic symptom commonly referred to as hopperburn. Their leaves show a remarkable decline of protein nitrogen and an increase of free amino nitrogen, although the total nitrogen remains comparable to that in the healthy leaves

Based on the assessment of the yield loss caused by the brown planthopper, a control threshold of 20 to 25 planthoppers per hill has been tentatively recommended in tropical countries. The critical economic injury level may be much lower—2 to 5 planthoppers per hill.

SPORADIC BUT CATASTROPHIC outbreaks of the brown planthopper (BPH) have been recorded throughout the history of rice cultivation in Japan (Suenaga and Nakatsuka 1958; Miyashita 1963). Since about 1970, epidemics have occurred frequently in several tropical countries. With the spread of high yielding rice varieties and of intensive cultivation, the BPH has become the most destructive of rice pests because of the severe direct damage it causes and because it is a vector of grassy stunt disease. The feeding damage is commonly referred to as hopperburn. It first appears as browning of plants in patches in the middle of paddy fields. In severe cases the patches spread rapidly. The ecology of the BPH population has been studied in detail with special reference to causes of hopperburn damage (Kisimoto 1965). However, basic and practical studies of the feeding damage caused by the insect are still meager. This paper presents available information about the planthopper feeding and hopperburn damage and discusses the possible causes of hopperburn. It also deals with the

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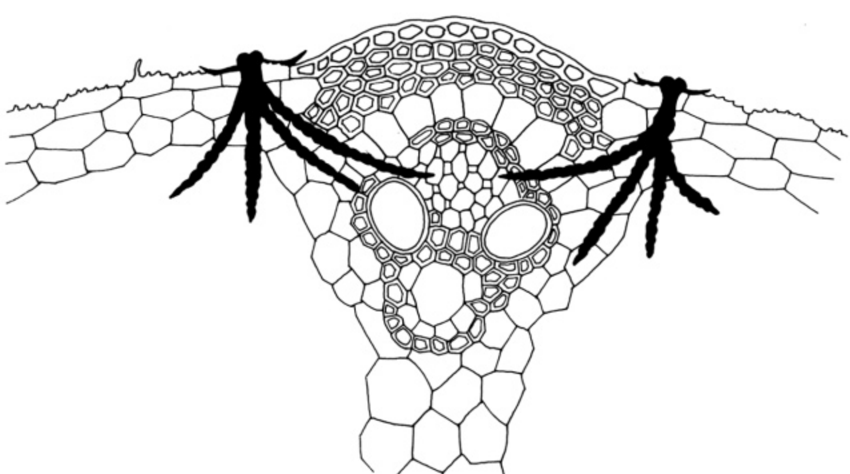
relationship between insect infestation and rice yield with special reference to the assessment of yield losses and economic thresholds.

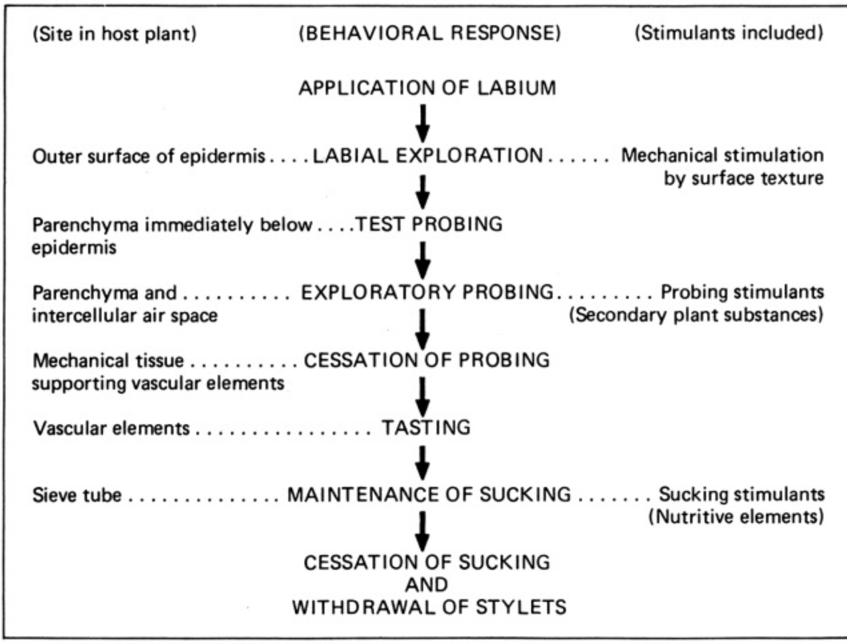
FEEDING BEHAVIOR OF THE BROWN PLANTHOPPER

The BPH, like other hemipterous insects, has mouth parts specialized for the intake of plant sap. It has an outer pair of mandibular and an inner pair of maxillary stylets, which are bundled together to form a piercing and sucking organ 650 to 700 μ long. The BPH is a typical vascular feeder; it primarily sucks the phloem sap by "stylet-sheath feeding" (Miles 1972); it secretes a coagulable saliva that forms a tubular lining (the stylet sheath) (Fig. 1). The highly localized feeding process is composed of a series of gustatory responses to specific botanical stimuli and several intermediary behavioral reactions induced spontaneously or according to the internal demands of the insect (Sogawa 1976; Fig. 2).

The feeding process can be divided into two main behavioral phases—stylet probing and sucking—according to the effects on the rice plant. The probing is done in the parenchyma outside the vascular bundles, and is associated with the secretion of the coagulable saliva. Generally the stylets are repeatedly inserted 100 to 400 μ into the parenchyma through a single point of entry, its course being shifted with each insertion. Consequently stylet sheaths are deposited in a forking pattern in the plant tissues (Fig. 1). The stylet sheaths are made mainly of stable lipoproteinaceous material and remain within the plant tissues after withdrawal of the stylets (Sogawa 1973b). The cellular contents of the epidermis and parenchyma lacerated by the insect stylets show



1. The stylet sheaths formed within the leaf sheath of a rice plant by two brown planthoppers.



2. Feeding process of the brown planthopper.

plasmolysis, but the cells are not emptied. The injury does not extend to cells beyond those penetrated (Sogawa 1973a), nor does it produce any external local symptoms. It has been shown that P^{32} absorbed from roots is accumulated at the sites of insect feeding, indicating abnormally enhanced metabolic activities there (Santa 1959). No accumulation occurs in plant tissues pricked artificially with a pin. Occasionally, necrotic lesions and occlusion by the salivary secretion are also recognized in the vascular tissues, especially in the phloem (Sogawa 1973b). Cagampang et al (1974) found that the upward flow of sap tends to be slower in the plants infested by the BPH than in uninfested plants only when the plants are cut above the feeding sites. It could be assumed that downward flow of the phloem sap is obstructed to a greater extent than the upward flow. The BPH probes much more frequently and consequently deposits more stylet sheaths in resistant rice varieties than in susceptible varieties (Sogawa and Pathak 1970; Karim 1975), but damage to the resistant varieties is less, indicating that the probing has little harmful effect upon the functioning of the plant and that the stylet sheaths are relatively inert.

When the stylet enters vascular tissues, the BPH ceases probing and salivation, and begins to suck. During sustained feeding, the insect excretes a large amount of “honeydew.” Suenaga (1959) estimated that the sap intake of a third- or fourth-instar nymph is about 6 to 11 mg/day. Sogawa (1970) recorded the total daily excretion by a female adult on a rice seedling (var. Norin 8) as about 13 μl of honeydew containing about 270 γ of sugars and 12 γ of amino acids.

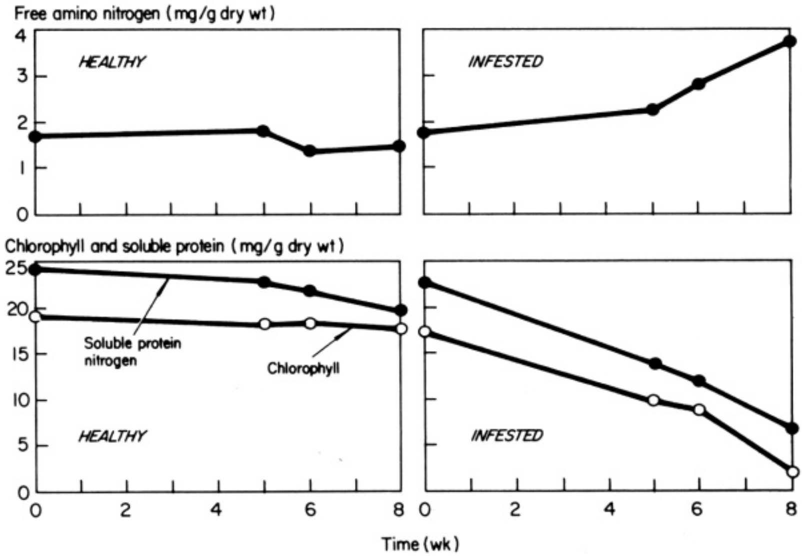
In another experiment, a female ingested about 14 to 31 mg/day on 40- to 60-day-old plants of susceptible varieties (Saxena 1976). Although critical analysis of the BPH feeding is still too limited to permit the evaluation of the damage from feeding, it seems possible that the drain of fluids and nutrients by the intensive sucking is largely responsible for hopperburn. It has been tentatively estimated that the sustained sucking of 10 to 20 female adults per rice tiller might cause nitrogen deficiency in the plants within a short period. Because the BPH takes a large quantity of sugars from the phloem, the function of a planthopper colony on rice plants is considered as that of an extra "sink" for photosynthates, which interferes with the normal partition of the products. The amount of insect feeding and the severity of damage to different rice varieties are positively correlated; BPH ingest much less from the resistant varieties than from the susceptible varieties (Sogawa and Pathak 1970; Karim 1975; Saxena 1976). Moreover, biotypes that break down host-plant resistance are apparently able to ingest plant sap from the "resistant" varieties (Saxena 1976), and induce hopperburn damage in "resistant" as well as in susceptible varieties. It seems reasonable to consider hopperburn damage as being mainly caused by the removal of phloem sap.

NATURE AND MECHANISM OF HOPPERBURN DAMAGE

The first symptom of hopperburn injury appears on rice plants as yellowing of the older leaf blades. It extends progressively to all above-ground parts of the plants, which turn brown and die. Symptoms appear more slowly if only the leaf blades or leaf sheath are exposed to planthopper feeding than if entire plants are exposed (Cagampang et al 1974). The development and physiological activities of the roots are also drastically reduced in infected plants.

The quantitative changes in the biochemical constituents of rice plants, brought about by the infestation of the BPH, have been studied. The water contents of rice plants decreased from about 84% to 72% (Santa 1959), and from 76% to 62% during ingestion (Cagampang et al 1974). Wilting symptoms differed from those of plants under drought stress, in which the leaf blades dry up with little loss of green color. However, the chlorophyll content of the leaf blades of the BPH-infested plants declined with the decline in moisture content (Cagampang et al 1974).

As chlorosis increased the protein in the leaves decreased steadily : chlorotic leaves had 33% less protein than healthy leaves; brown leaves had 73% less (Sogawa 1971). Similarly, soluble protein nitrogen declined from about 22 to 7 mg/g of dry weight in the leaf blades, and from 10 to 7 mg in sheaths as infestation progressed, whereas the total nitrogen in the infested leaves remained comparable with that in the healthy ones (Cagampang et al 1974; Fig. 3). On the other hand, the total free amino acid content of chlorotic leaf blades is

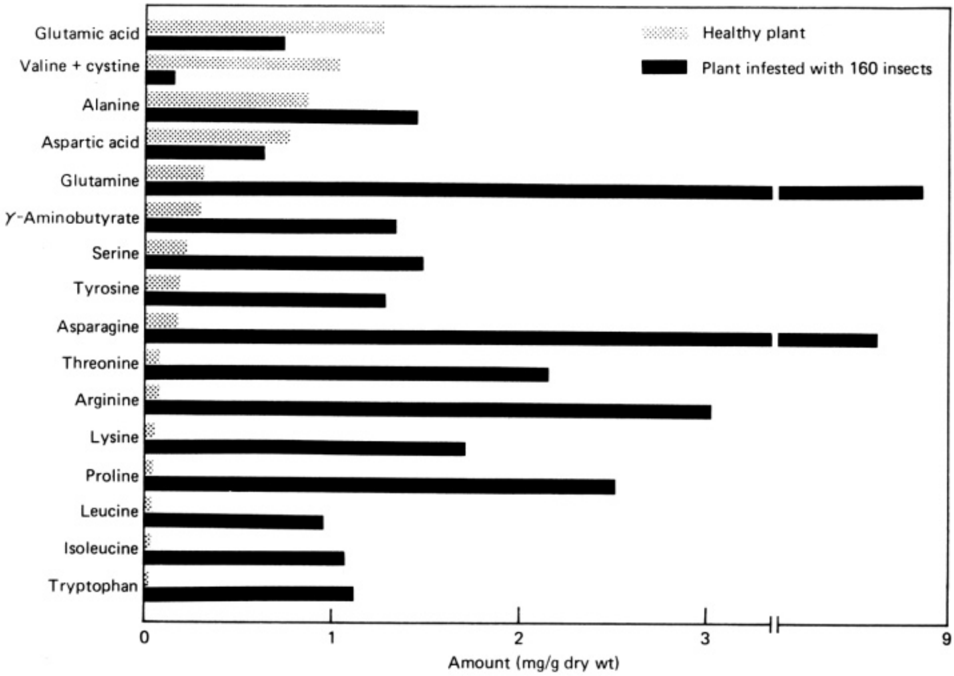


3. Changes in chlorophyll, soluble protein nitrogen, and free amino nitrogen contents in leaf blades of 8-week-old TNl plants infested with 80 brown planthopper adults (right) and of healthy plants (left).

more than four times that of healthy leaves, and that of brown leaves is about 1.8 times that of healthy ones (Sogawa 1971). When the rice plants were exposed to different populations of the BPH, the free amino acid content in leaf blades increased in step with the insect population. For example, 50-day-old plants each infested with 80 or more BPH had three to four times as much free amino acid content, as the healthy plants, and the leaf blades of the heavily infested plants had 30 times more arginine, asparagine, lysine, proline, and tryptophan than those of the healthy ones (Cagampang et a1 1974; Fig. 4).

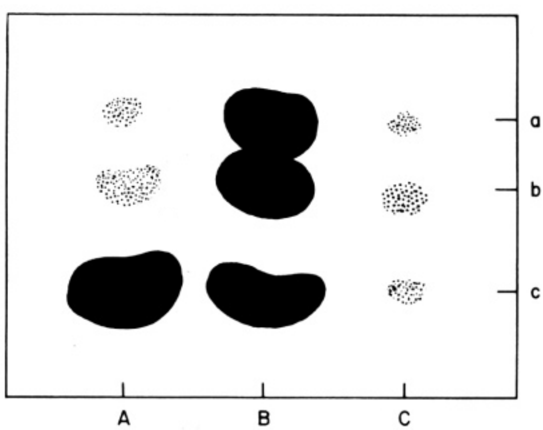
The healthy and chlorotic leaves differed little in total sugar content but the amounts of such reducing sugars as fructose and glucose increased markedly in the chlorotic leaves (Sogawa 1971 ; Fig. 5). A striking reduction of starch content also occurred in the culms of infested plants (Santa 1959). An unusual increase in the iron content of leaves of infected plants was considered the result of a deterioration of physiological activity of the root system (Santa 1959; Fig. 6).

The leaf blade of the rice plant generally has a higher potential for protein synthesis and maintains a higher level of protein nitrogen content than other portions of the plant. However, leaf blades of infested plants have significantly reduced protein content, and accumulate free amino acids and amides. Such changes, however, may be only a part of a complex of metabolic changes associated with hopperburn. A similar change in nitrogen constituents occurs in rice leaves detached from their root system (Kiuchi and Watanabe 1969; Oritani and Yoshida 1969). In that case, it is considered that the protein

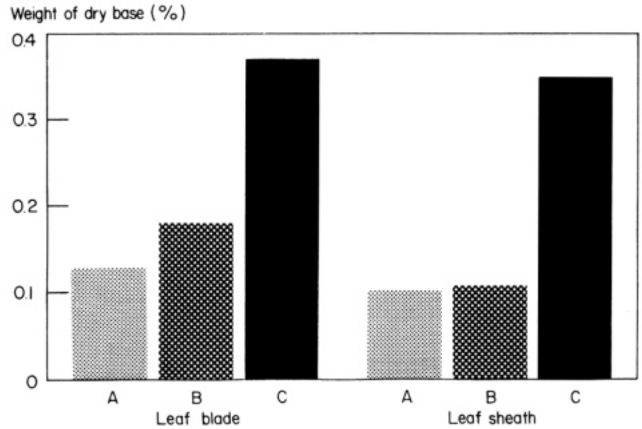


4. Effect of infestation of adult brown planthoppers on composition of free amino acids in plants.

degenerates because of a deficiency of root-produced cytokinins, which play an essential role in ribonucleic acid and nitrogen metabolism in the leaf blades (Yoshida et a1 1970), and that the resultant amino acids and amides accumulate



5. Paper chromatogram of soluble sugars in the leaf blade of a healthy rice plant (A), and in the chlorotic (B) and brown (C) leaf blades of a BPH-infected plant (Sogawa 1971). a, Fructose; b, glucose; c, sucrose.



6. Iron content of leaves of healthy and BPH-infested rice plants. A = healthy plant, B = plant at periphery of a hopperburn patch, C = plant in the center of a hopperburn patch.

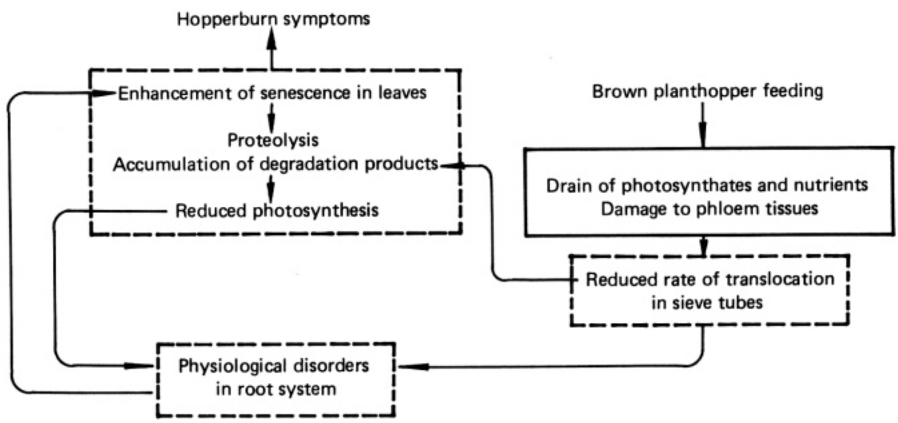
in the leaf-blade tissues because translocation systems are not functioning. The systemic nature of hopperburn damage has led to speculation that during feeding, the BPH injects a phototoxic saliva into the rice plant (Hisano 1964). Cagampang et al (1974), however, suggested that such a phytotoxin, if involved, is not systemic because ingestion at a restricted site does not cause widespread symptoms. There is no experimental evidence that indicates that the insect injects a toxin while feeding.

We suggest that a 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 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. The proteolic products, such as amino acids and amides, will be accumulated in the leaves. The possible relationships of BPH feeding and plant response are illustrated in Figure 7.

Further critical studies of BPH feeding and of physiological reaction of rice plants to insect feeding are needed to determine quantitative relationships between phloem-sap drain and the development of hopperburn symptoms or yield reduction.

ASSESSMENT OF YIELD LOSS

The effects of insect infestations on plant growth and yield are generally complex and variable. The time of insect attack in relation to plant growth, intensity of injury (or the population density of insects), duration of the attack, and environmental factors affecting both insect activities and plant growth



7. Possible relationships between BPH feeding and the development of hopperburn symptoms in rice plants.

control the relationship between an insect infestation and its effect on yield (Bardner and Fletcher 1974).

On the other hand, the factors governing rice yield include the number of panicles per unit area, number of grains per panicle, percentage of ripened grain, and weight of 1,000 grains (Matsushima 1960). Plants infested by the BPH before maximum tillering usually have fewer panicles per unit area and fewer grains per panicle; a planthopper attack after the heading stage affects the percentage of ripened grain and grain weight.

The BPH severely damages rice plants in the postflowering stage in most rice areas (Cheng 1976a; Lee and Park 1976; Kisimoto 1976; Kulshreshtha 1974; Velusamy et al 1975). For instance, under natural conditions in Japan the BPH migrates into paddy fields between late June and mid-July and multiplies almost exponentially during two or three insect generations. The hopperburn usually occurs on rice plants nearing maturity. The yield loss due to hopperburn varies greatly according to when hopperburn occurs. When the plants suffer hopperburn within 30, 40, and 50 days after heading, the yield losses are estimated at about 80 or 90, 50, and 10%, respectively (Kisimoto 1976). Besides the yield loss, higher percentages of dead, immature, and broken grains have been recorded in the infected plants (Chou 1969; Hisano 1964; Kawada 1951 ; Tao and Yu 1967). But in tropical areas where rice grows throughout the year in continuous and staggered plantings the hopperburn tends to occur at any stage (Fernando 1975; Mochida and Dyck 1976).

The methods adopted by various workers for assessing yield loss caused by the BPH can be broadly classified into three categories : (1) comparing yields of pest-infested crops with those of pest-free crops; (2) comparing yields of crops infested with insect populations of different sizes at the same growth stage, or of crop infested with populations of similar size at different growth stages; and (3) comparing yields of crops that have suffered different degrees of damage.

Comparison of yields of pest-infested crops with those of pest-free crops

Tao and Yu (1967) compared the grain yields of crops treated with insecticides to control the BPH and those of crops exposed to natural infestation in the Chia-yi area, Taiwan, in second rice crops from 1962 to 1966. Treated plots had about 37% more rice yields than the infested plots. In another series of experiments in central and southern parts of Taiwan during the last few years, the yield reduction in the naturally infested plants ranged from 17 to 65%, averaging 44% (Table 1). The method is applicable only in areas where the BPH is sufficiently abundant to cause yield reduction. Also, the BPH population trends in the infested plots during the experiment must be known to ensure correct evaluation of the effects of the insect infestation on rice yield.

Comparison of yield based on growth stages and insect populations

It has been observed in Japan that if rice plants at the tillering stage are attacked by about 10 planthoppers/hill for a week, the lower leaves turn yellow and die, and yield eventually decreases by 10 to 40%. If the plants at the heading stage are infested by 10 to 50 planthoppers for 10 to 14 days, they eventually show hopperburn damage and the yield is reduced by 20 to 50%. According to Bae and Pathak (1970), rice plants infested by 100 to 200 first-instar nymphs for only 3 days at 25 days or at 50 to 75 days after transplanting suffer 40 to 70% or 30 to 50% yield losses, respectively; if the same plants are attacked by 8 to 32 adults for the same period. the yield decreases by 30 to 70%. A "control threshold" of 20 to 25 planthoppers/hill that has been recommended for tropical countries (Mochida and Dyck 1976) may be too high. A different experiment has shown that 2-week infestations by 5 to 25 or more nymphs per tiller at 26–39 and 40–53 days after seeding caused 8 and 70% or more yield losses, respectively (IRRI 1974). Yen and Chen (1976) reported that the tolerance to the BPH of rice variety Tainan 5 at different growing stages varies greatly. Grain

Table 1. Effect of insecticide application on rice grain yield (Cheng 1976a).

Year	Grain yield (t/ha)		Yield loss (%)
	Treated plots with insecticide[a]	Control plots	
1969	5.78	3.57	38
1970	4.39	2.34	47
1971	4.46	2.60	42
1972	5.01	4.13	17
1975	3.62	1.26	65
Mean	4.49	2.50	42

[a]Average yield from the treatments with insecticides recommended for controlling the brown planthopper.

Table 2. Yield losses of rice caused by the brown planthopper.

Type or variety[a]	Plant stage[b]	Insect density (no./hill)	Insect stage	Duration of infestation (days)	Yield loss (%)	Reference
Japonica	Tillering	Several	Nymph and adult	7	10	Suenaga 1959
		10	Nymph and adult	7	40	
	Heading	10	Nymph and adult	10	50	
		50	Nymph and adult	14	80	
TN1	25 DT	100	1st-instar nymph	3	40	Bae and Pathak 1970
		200	1st-instar nymph	3	70	
		8	Adult	3	30	
		16	Adult	3	60	
		32	Adult	3	70	
	50–75	100	1st-instar nymph	3	30	
		200	1st-instar nymph	3	50	
		8	Adult	3	30	
		16	Adult	3	40	
		32	Adult	3	55	
IR22	26–39 DS	25/tiller	Nymph	14	≥ 85	IRRI 1973
	40–53 DS	225/tiller	Nymph	14	≥ 79	
Tainan 5	Tillering	20	Adult	14	75	Chen 1976
	Booting	40	Adult	14	90	
	Milky	160	Adult	14	20	

[a] All are susceptible to the brown planthopper [b] DT = days after transplanting. DS = days after seeding.

yields were reduced by 40 to 60% when plants were infested at the tillering stage by 20 to 40 insects/hill for 2 weeks; grain yields were reduced by about 75 to 90% when plants were infested at the booting stage by the same number of insects. When the plants were infested at the milky stage by 80 insects/hill yield was not significantly reduced. Even an infestation by 160 insects/hill caused only 20% decrease in grain yield (Table 2). The data indicate significant differences in the relative susceptibility of rice plants at different growth stages, and in the relative intensity of damage caused by constant population of insects during given periods. In spite of large variations, the experiments show that rice plants are most sensitive to the damage by the BPH during the active tillering and booting stages. That provides practical information for the timing of pest control. However, it is necessary to evaluate the cumulative damage caused by varying insect population densities throughout the rice growth period under natural conditions at various localities to determine the control threshold for the BPH.

Lee and Park (1976) reported that hopperburn usually appears on a plant 40 to 60 days after it was infested by a single pair of adult insects per hill under experimental conditions. If a pair of adults are confined on a plant within 54 days after transplanting. the plant is burned and yields no grain; yield loss is 30% or less when insects are confined more than 80 days after transplanting (Table 3). Kisimoto (1975) pointed out that 10 to 20 brachypterous female adults per hill in August will cause limited hopperburn and if the density is

Table 3. Rice yield losses associated with time of infestation by the brown planthopper and with density of planting (Lee and Park 1976).

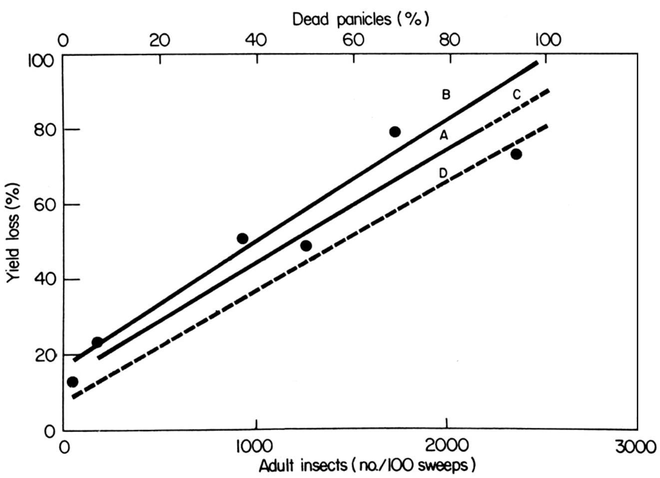
Time of infestation		1 hill/pot		4 hills/pot	
Date[a]	DT[b]	Yield (g/hill)	Yield loss (%)	Yield (g/hill)	Yield loss (%)
July 1	46	0	100	0	100
July 10	56	0	100	1	100
July 20	66	6	81	9	70
July 30	76	12	61	12	61
August 5	81	21	30	22	27
August 10	86	21	19	25	17
August 15	91	28	6	29	3
No infestation		30	0	30	0

[a] Date of transplanting: May 17. [b] Days after transplanting.

increased from 30 to 50 insects/hill, the field will be severely hopperburned. It has also been estimated that the progeny of one brachypterous female that is released 1 month after transplanting are able to kill 8 to 11 hills after heading.

In Japan Nomura (1949) and Suenaga (1959) studied the relationship between number of adults per 100 net sweeps and percentage of loss of grain yield in the field (Fig. 8). They determined the relationship at the tillering stage by walking diagonally across the field. The following equation gives: Yield loss = number of insects collected × 3.0 + 10.

Kisimoto (1975) reported that when 50 to 100 insects are caught by a water-pan trap during immigration of the BPH into paddy fields, and 30 to 50 brachypterous females of the second generation are found per 100 hills by



8. Relationship between population density of the brown planthopper and yield loss. A: Nornura (1949); B: Chubu-Kinki Agric. Exp. Stn. (1952). C: Kyushu Agric. Exp. Stn. (1957); D: Kanto-Tosan Agric. Exp. Stn. (1952). Source: Suenaga 1959.

Table 4. Relationship between degree of damage by the brown planthopper and rice yield loss (Suenaga and Nomura 1970).

Damage	Plant appearance	Panicle damage[a] (%)	Yield loss (%)
Slight	No withering; little sooty mold	25	10
Low	Little withering; much sooty mold; hopperburned areas	40	35
Medium	Withering of lower leaves; severe sooty mold; 60% lodging at the edge of hopperburned areas	45	50
High	Considerable withering; 80% lodging within hopperburned areas	70	65–70
Severe	Completely withered; few fully developed panicles in center of hopperburned area	90	> 80

[a] Number of panicles with less than 70% ripened grains.

visual count, hopperburn will occur where the brachypterous females are found. In such a case, a control program should operate during the nymphal stage of the third generation. When more than 150 immigrants are trapped, earlier control is recommended to prevent severe hopperburn.

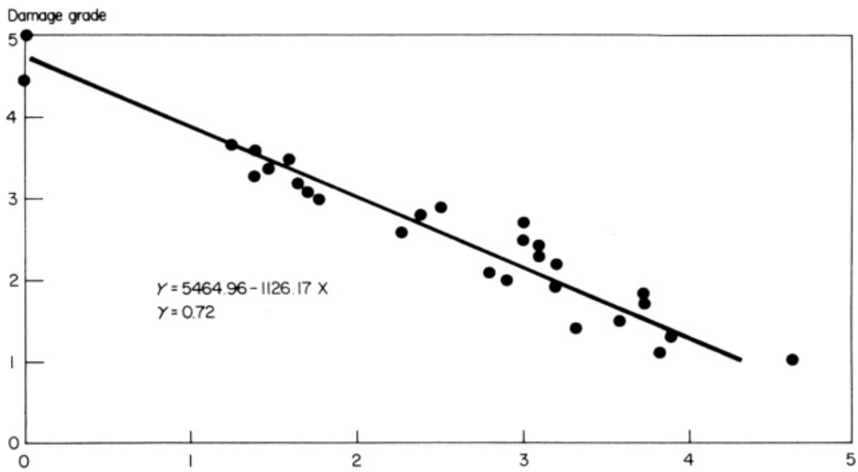
Crops that have suffered different degrees of damage

Rice entomologists commonly assess yield loss on the basis of degree of damage caused by the BPH. According to Nomura (1949), the lodging percentage of infested plants is used as a basis for assessing grain reduction due to the BPH. Plants with 100, 80, and 60% lodging had grain yields reduced by more than 80, 70, and 50%, respectively. Unhealthy-looking plants infested with a large number of planthoppers suffered from 20 to 30% yield loss.

Gifu Statistics and Survey Office in Japan (1966) and Suenaga and Nomura (1970) based five grades of damage on the appearance of infested plants. The worst infestation caused about 80% yield loss; slight infestation caused about 10% yield reduction (Table 4). Using those damage categories, a regression line, Y = 5465 – 1126X, was developed for assessing yield loss resulting from the BPH infestation. It indicates that every one-grade increase in damage results in a yield loss of about 1.1 t/ha or 20% of total production (Fig. 9). Similarly, rice loss is also estimated by using an index calculated from the following equation :

$$\text{Damage index} = \frac{[(1A + 2B + 3C + 4D)/4T]\ 100}{T \times 4}$$

where A indicates the number of tillers with the upper two leaves undamaged and the rest withered; B, the number of tillers with all except the flag leaf withered; C, the number of tillers with all leaves withered but with panicles still alive; D, the number of tillers with leaves, stems, and panicles all withered; and T, the total number of infested tillers. The percentage of yield loss in each



9. Relationship between the damage grade (see Table 4) and rice grain yield (Cheng 1976a).

damage index is calculated in Table 5. With this procedure, the damage indexes recorded in Taiwan in the first and second rice crops of 1975 were 5.9 and 15.3, and those of 1976 were 2.4 and 6.3, respectively (Department of Agriculture and Forestry, Taiwan 1974, 1975).

Nomura (1951) also tried to assess yield loss on the basis of the percentage of dead panicles, degree of panicle damage, and degrees of lodging of infested plants (Table 6). The yield loss is expressed with a multiple-regression equation:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3$$

where X_1 is percentage of panicles dead. X_2 is degree of panicle damage, and X_3

Table 5. Relationship between damage index and yield loss (%). Department of Agriculture and Forestry, Taiwan 1972.

Damage index [a]	Yield loss (%)
10	10
20	20
30	25
40	35
50	40
60	50
70	55
80	60
90	65
100	70

[a]Damage index = [(1*A* + 2*B* + 3*C* + 4*D*)/4T]100; A. tillers (no.) with 2 upper leaves undamaged, all other leaves withered; *B*. tillers (no.) with all leaves withered except flag leaves, *C*. tillers (no) all leaves withered, panicles alive; *D*, tillers (no.) with leaves, stems, and panicles all withered; *T*. total no. of infested tillers.

Table 6. Relationship between plant damage caused by brown planthopper and rice loss (Nornura 1951).

Dead panicles[a] (%)	Panicle damage[b]	Lodging[c]	Grain loss (%)
100	70	50	80
100	50	40	70
70	50	40	65
70	40	30	55
50	40	30	50
50	20	20	40
30	20	20	30
10	10	10	20
5	5	5	15

[a]$\frac{\text{No. dead panicles} \times 100}{\text{Total no. panicles}}$ [b]Damage index: 0 = no damage; 100 = panicles and grains 100% empty; damage index/all panicles investigated. [c]0 = plants stand upright; 100 = –panicle ends touch the ground.

is degree of lodging of the infested plants. Nomura calculated the yield loss due to the BPH according to the following equation:

$$Y = 10.898 + 0.126X_1 + 0.470X_2 + 0.306X_3.$$

The method mentioned above is generally believed to be adaptable to those areas where the BPH infestations occur mainly after heading. Yield loss caused by the BPH before the heading stage could be assessed through the methods used for assessing yield loss from whitebacked planthopper infestation (Gifu Statistics and Survey Office 1966).

ECONOMIC INJURY LEVEL FOR THE BPH

The economic injury level (EIL) is the lowest population density that will cause injury sufficient to justify artificial control measures (Stern et al 1959). It is a basic criterion for economic control. However, it must be recognized that the EIL is a dynamic parameter, varying with a number of factors. For a given plant variety and a particular geographical area, the EIL changes with a change in (1) the market value of the crop; (2) the cost of artificial control measures; and (3) the environmental factors, such as tolerance of the plant and feeding of the insect (Michael and Pedigo 1974; Pedigo 1972).

Recently several rice entomologists have attempted to determine the EIL for the BPH. They usually caged pests at constant densities on potted plants at various stages of growth for certain periods, or applied insecticides to check insect populations when the target populations reached certain population levels. As pointed out, the relationship between insect population levels and rice yield losses varies greatly depending on the stage at which the plant is infested and the rice variety used. Before an accurate EIL was developed, a crude control threshold based on observations and experience had been proposed as

Table 7. Relation of brown planthopper population densities to grain yield and net return. Chiayi Agriculture Experiment Station, Taiwan, 1976, 2nd crop.

Insect population[a]	Tainan 5			TN1		
	Insecticide application (kg/ha)	Grain yield (t/ha)	Net return (NT $/ha x 1000)	Insecticide application (kg/ha)	Grain yield (t/ha)	Net return (NT $/ha x 1000[b])
Weekly spray	12	5168	44 43	12	6170	49.79
10/hill	2	4370	47.76	3	5298	51.88
20/hill	2	4222	46.05	3	5187	50.72
40/hill	1	4091	45.80	2	4938	49.53
80/hill	0	3834	44.09	1	4607	47.12
160/hill	0	3672	42.23	0	4089	49.93

[a] Treated with 75% Orthene W.P. at 0.8 kg/ha when the number of insects per hill reached its target population level. [b] Net return: value of rough rice minus cost of insecticide and of its application. Cost, 11.5 NT $/kg for Tainan 5 rice and 10 5 NT $/kg for TN1 rice Cost for application: 450 NT $/ha, 75% Orthene W.P. 800 NT $/ha.

a rough guideline for practical pest control operations (Yen and Chen 1976). In the Philippines (Custodio et al 1974) the recommended threshold is 1 adult, hill up to 20 days after transplanting (DT); 10 nymphs/hill from 20 to 40 DT, and 20 adults or nymphs/hill thereafter. About 20 and 25 planthoppers/hill, a generally accepted threshold in several tropical countries, seems to be too high to minimize yield loss, because grain yield in plots that reached the EIL were reduced at 15–20% (Cheng 1976b: Table 7). Available data indicated the control threshold for the BPH should be about 10 insectsihill.

In Japan, the economic threshold for the BPH has also been determined by predicting whether the insect population would be able to reach a “tolerance-density” or cause loss by reaching the “tolerance-level of damage”, so that the BPH could be controlled before the population passed the “tolerance-density’’ level. Sugino (1975) calculated population levels for the first generation of the planthoppers that he considered could cause a yield loss greater than the “tolerance-level of damage” (3.5% of total grain production) during later generations. Those population levels are reached when (1) the number of insects in the generation preceding the one that has the highest population peak in from 2 to 5/hill, (2) when the highest number of insects/hill is about 5 during the second generation after immigration (first 10 days of August), or (3) when the number of brachypterous female adults reaches 0.25–0.33/hill in the second generation after immigration (first 10 days of August). Kulshreshtha and Kalode (1976) suggested that the threshold of economic injury for the insect up to 70 days after planting, based on the growth pattern of populations of the BPH in India, is between 2 and 5 nymphs and adults per hill.

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