

**ECOLOGICAL PHYSIOLOGY OF RICE PLANTS ATTACKED  
BY THE BROWN PLANTHOPPER**

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# ECOLOGICAL PHYSIOLOGY OF RICE PLANTS ATTACKED BY THE BROWN PLANTHOPPER\*

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## Introduction

Insect injury can affect the processes of growth, development and yield formation of a crop, thereby causing a significant yield loss. Murata and Matsushima (1975) state that "(rice) grain yield is determined by a complex chain of developmental processes, which take place in a definite sequence, and a change in any one of these may influence all the following processes". Bardner and Fletcher (1974) hold that an understanding of insect injuries and their effects on yield formation "is provided by the results and theories of crop physiology, especially the techniques of plant growth analysis". However, an integration of entomology and rice plant physiology is still lacking.

We believe that although biological mechanism should be traced to one or more lower level(s) of organization, biological implications ought to be expressed on the basis of higher level(s) of organization. The injury of the brown planthopper (BPH, *Nilaparvata lugens*) to rice plants can be expressed in many ways, depending upon the scale of observation one chooses. In this paper we will review and analyze the effects of the BPH's direct injury to rice plants and subsequent yield loss from the perspective of rice physiology, according to the population, individual, organs and organ systems, and molecular levels. Then, we will depict an overall picture of the pest's injury to the rice plants.

## Injury at the Population and Individual Level

The extent of insect injury to the crop is governed by such qualitative elements as variety of crop, biotype of pest, site of injury, stage of both insect and plant, other environmental factors and cultural practices, etc., and by such quantitative elements as pest population levels, duration of infestation, etc. (Bardner *et al.*, 1974; Chiang, 1973). The magnitude of insect damage is a result of their interactions. In general, damage is proportional to the quantitative element.

The injury of BPH caused a reduction in rice plant's height if infestation took place before the reproductive stage (Fig. 1, Chen *et al.*, 1978). It also caused reduction in plant dry weight (Campang *et al.*, 1974). Heavy injury usually resulted in wilting of the plants – so-called "hopperburn", and in qualitative (e.g. increase in scale-like rice) (Fig. 2, Chen and Cheng, unpublished) and quantitative yield loss (Fig. 3, Chen *et al.*, 1978).

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\*: Scientific review No. 23 of Entomology Division, Plant Protection Center, Taiwan.

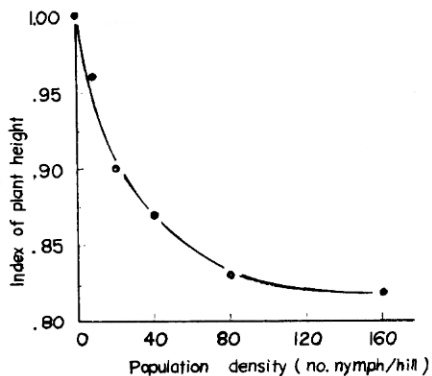


Fig. 1 Relationship between BPH population levels and the height of Tainan No. 5 rice plants infested by planthoppers during the active tillering stage for two weeks.

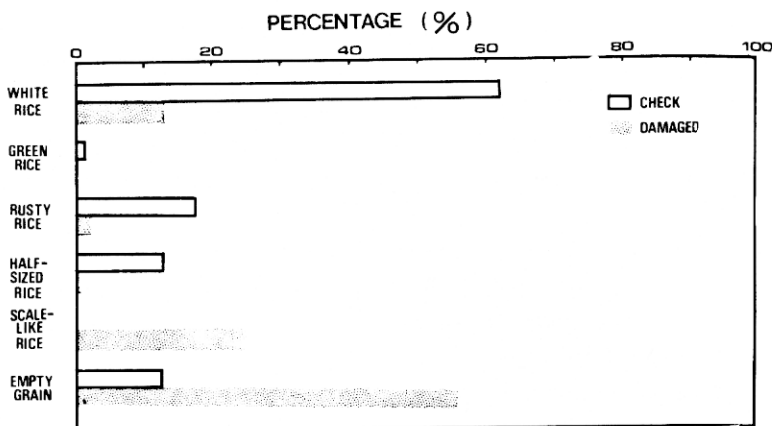


Fig. 2 Comparison of rice quality of Brown plant hopper-damaged grains to those of normal ones.

From the standpoint of yield reduction, it is clear that rice plants respond to the pest's injury differently at various plant stages. Injury taking place during late booting to anthesis (Fig. 3, 45-59 DAT) – i.e. vegetative growth phase, and then by milking to doughy grain stage (75-89 DAT) – i.e. ripening phase (Chen *et al.*, 1978).

These observations will be further explained using both growth analysis (GA) and yield components analysis of rice plants infested by the BPH.

### Injury at the Level of Organs and Organ Systems

#### Growth Analysis

Crop growth analysis (GA) is the quantitative analysis of photosynthetic production measured by the production of dry matter during the growth and development of the crop (Watson, 1952). The principles and techniques of GA have been well established (Evans, 1972; Radford, 1967; Sésták *et al.*, 1971; Watson, 1952). It has become one of the standard methods in crop ecophysiology. However, as pointed out by Bardner and Fletcher (1974) the "entomologists

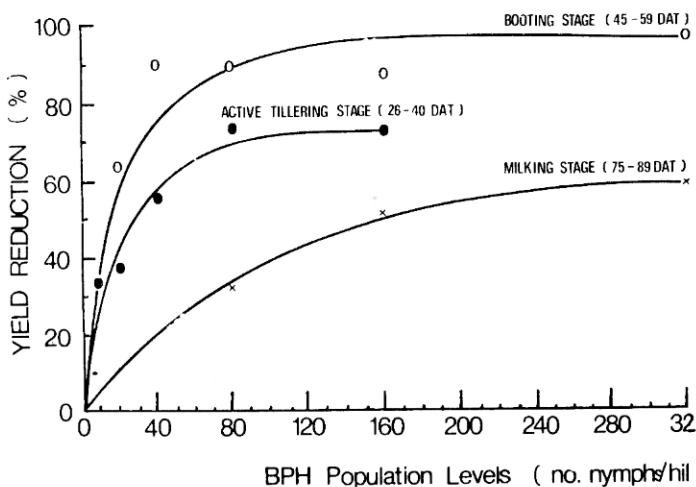


Fig. 3. BPH density in relation to rice yield reduction of Tainan No. 5 rice plant infested for two weeks. (Redrawn from Fig. 8 of Chen and Cheng, 1978) ;(DAT= days after transplanting).

have been slow to make use of these ideas and techniques”.

The primary parameters in GA are the dry weight of whole plants and/or of their parts and the leaf area. From these basic data, the growth characteristics such as leaf area index (LAI), leaf area ratio (LAR), relative leaf growth rate (RLGR), crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR = ULR, unit leaf rate), *etc.*, are derived (Evans, 1972; Sésták *et al.*, 1971).

A preliminary GA of rice plants attacked by the BPH has revealed that attacked plants usually had significant drop in  $\overline{RLGR}$ ,  $\overline{NAR}$ ,  $\overline{CGR}$  and  $\overline{RGR}$  as compared to uninfested plants (Fig. 4, Chen and Cheng, unpublished). This drop was most significant for plants attacked during late booting to maximum heading stage (57-72 DAT). This clearly supports the previous finding that the rice plants are most sensitive to the pest's attack during that period.

It was noted that infested plants showed negative  $\overline{RLGR}$  sooner than uninfested ones, indicating an acceleration of leaf withering in the attacked plants (fig. 4A). The  $\overline{NAR}$  which indicates the photosynthetic efficiency of the plants, only dropped significantly after heading (Fig. 4B). The BPH's injury seemed to exert less effect on the  $\overline{NAR}$  before heading. Furthermore, it is interesting to note that during the milking stage (76-90 DAT) the  $\overline{NAR}$  in uninfested plants increased remarkably. This could have been to either a decrease in leaf area with a resultant better light penetration, or/and a stimulation in photosynthesis due to the translocation of assimilated energy to panicles (see comments by Dr. Murata in Discussion).

Since the efficiency of dry matter production is related to  $\overline{NAR}$  and leaf area – the expression being  $CGR = NAR \times LAI$  and  $RGR = NAR \times LAR$  (Watson, 1952) – both CGR and RGR of attacked plants were consequently affected. Again, it was noted that attacked plants showed significantly lower  $\overline{CGR}$  and  $\overline{RGR}$  than uninfested ones after late booting (Fig. 4C and D). Wu *et al.* (1975) reported that energy reserves before heading only account for 14% of grain yield and those after heading 86% for Tainan No. 5 variety. We would expect that a

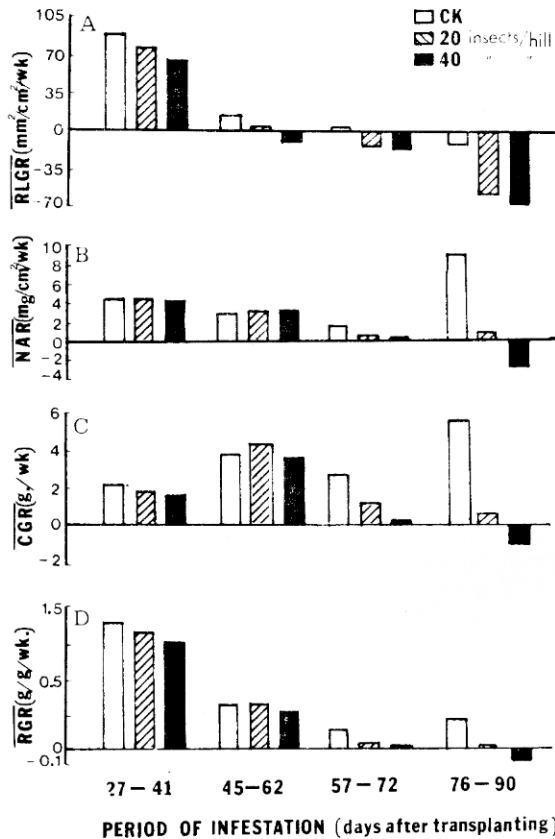


Fig. 4 Comparison of growth characteristics between BPH infested rice plants (Tainan No. 5) and uninfested ones (Chen & Cheng, unpublished).

drop in  $\overline{\text{CGR}}$  or  $\overline{\text{RGR}}$  during heading would drastically influence the yield. This will be supported by its influence on the yield components to be discussed later.

It should be noted that the exact relationship of decreased photosynthesis to decreased yield is still unknown and it is the photosynthates of the whole cropping season rather than the photosynthate in any discrete period that are significantly related to grain yield (Boyer, 1976). Accordingly, a dynamic study which follows the photosynthesis during the entire growing season is of supreme importance if such a relationship is to be revealed.

### Yield Components Analysis

The major rice yield components are the number of bearing tillers (i.e. panicles) per unit area, the number of grains per panicle, percentage of ripened grains, and the mean weight of a grain (Matsushima, 1960). Variation in the value of each components will result in variation in grain yield. The BPH's effect on the rice yield will be analyzed in terms of major yield components affected.

It has been shown that rice plants infested by the BPH before maximum tillering (i.e.

during vegetative phase) usually have fewer panicles per unit area (Fig. 5) and lower mean grain weight (Fig. 6). Plants attacked during booting to heading (i.e. during reproductive phase) have fewer grains per panicle and lower percentage of ripened grains (Fig. 7), and lower grain weight (Fig. 6). Plants injured after anthesis (i.e. during ripening phase) mainly have lower percentage of ripened grains (Fig. 7) and lower grain weight (Fig. 6, Bae *et al.*, 1970; Chen *et al.*, 1978).

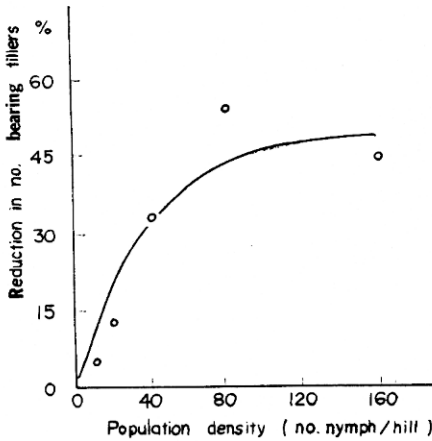


Fig. 5. Relationship between BPH population levels and the rate of reduction in the number of effective tillers of Tainan No. 5 rice plants infested during the active tillering stage for two weeks.

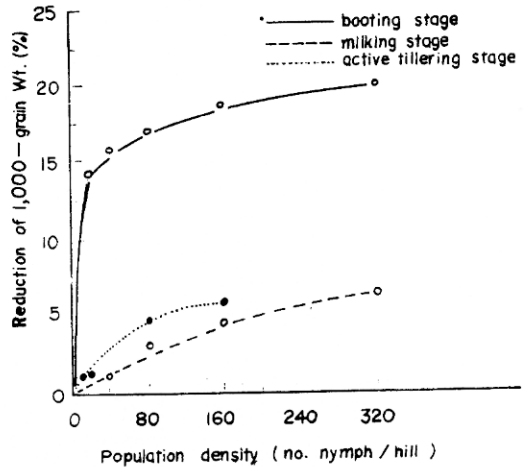


Fig. 6. Effect of BPH population levels on the weight of 1,000-grain of Tainan No. 5 rice plants infested by the BPH for two weeks.

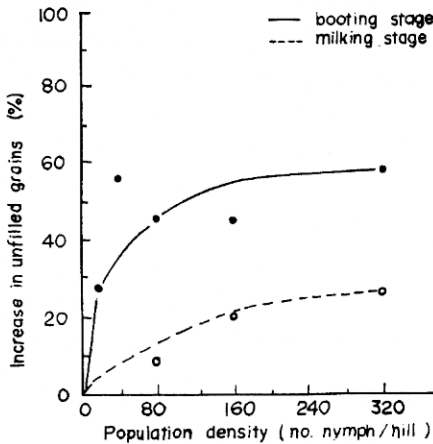


Fig. 7. Relationship between BPH population levels and the percent increase of unfilled grains of Tainan No. 5 rice plants infested during the booting and milkling stages for two weeks.

There differences in physiological sensitivity of rice plants at different stages can be further explained in terms of the time gap between the time of attack and the critical period when rice plants are most sensitive to attack – i.e. from late booting to heading – as shown in

Fig. 8 (Chen *et al.*, 1978). It was noted that with a greater the time gap from critical period to infestation period the higher was the tolerance of rice plants to BPH injury and the lower was the yield loss.

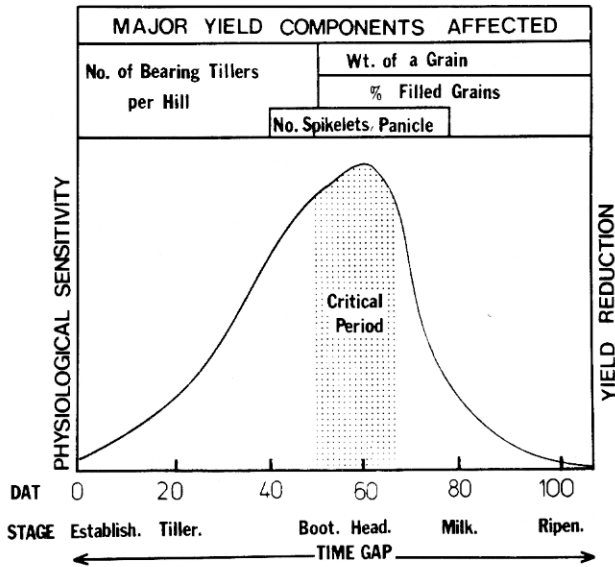


Fig. 8 Relationships between rice stages being attacked by the BPH, the physiological sensitivity of plant, major yield components affected and the yield reduction with the incorporation of time gap concept. (revised from Chen and Cheng, 1978).

Results from growth analysis and yield components analysis can be unified. During vegetative phase the assimilated energy is utilized to form tillers and leaves (Ishizuka, 1971). A drastic reduction in dry matter production (Fig. 4) will cause a reduction in the number of bearing tillers (Fig. 5) and in fewer reserves being translocated to ears later on, thus causing the grain to weight less (Fig. 6). Once the plants advance to reproductive phase the number of bearing tillers is much less affected. But because during this phase the flower organ and “yield container” are being formed (Ishizuka, 1971), a significant reduction in photosynthates could drastically affect the number of grains per panicle, percentage of ripened grains (Fig. 7) and the weight of a grain (Fig. 6). This, in turn, caused the most severe damage to yield loss (Fig. 3). During ripening phase the plants are in vigorous translocation of assimilates to fill the “container” (Ishizuka, 1971), so that a reduction in photosynthate will cause marked drop in the percentage of ripened grains (Fig. 7) and the mean weight of a grain (Fig. 6). The drain of the plant sap by the pest creates a leak which diverts some assimilates away from being translocated to “metabolic sinks” at different rice stages and reduces crop yield by affecting the yield components.

### Injury at the Molecular Level

Responses of the rice plants infested by the BPH have been traced to the molecular level. Chemical and biochemical data in this regard have been obtained by various researchers without,

however, showing their relevance to plant physiological process. (Cagampang *et al.*, 1974; Mita, 1959; Sogawa, 1972)

A significant drop in water content (Cagampang *et al.*, 1974; Mita, 1959), chlorophyll (Figs. 9 & 10, Cagampang *et al.*, 1974) and culm starch (Mita, 1959) with a marked increase in free amino acids (Cagampang *et al.*, 1974; Sogawa, 1971) (Fig. 11), fructose and glucose (Sogawa, 1972), and iron content (Fig. 12, Mita, 1959) in the infested rice plants have been documented.

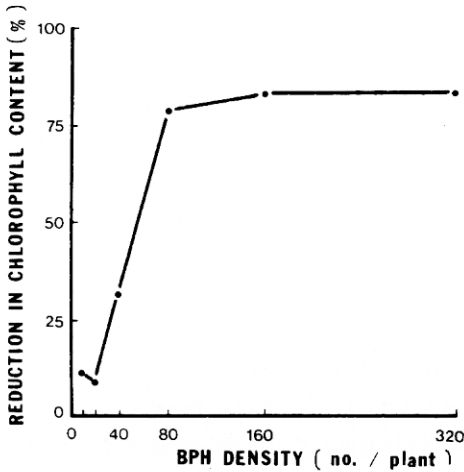


Fig. 9. BPH density vs. chlorophyll content reduction in leaf blades of 7-wk old TN1 rice plants infested by the BPH for 1 week. (From Cagampang *et al.* 1974).

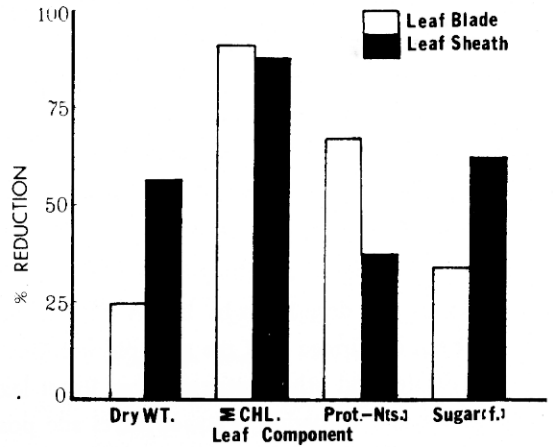


Fig. 10 Reduction of leaf components of 8 - wk - old TN1 plants infested with 80 adult BPH for 8 days. (From Tables 2 & 3 of Cagampang *et al.* 1974), Σ CHL. = Total chlorophyll; Port.-N(s) = Soluble protein-N, Sugar (f.) = free sugars.

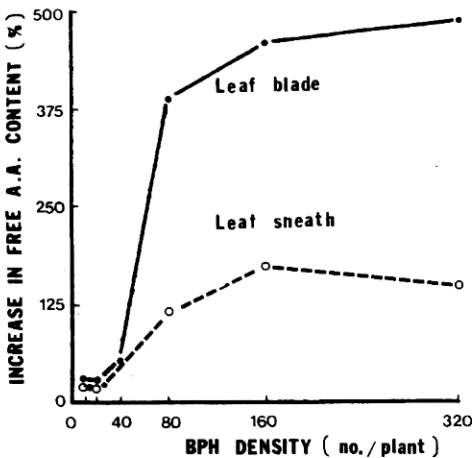


Fig. 11 BPH density vs. increase in free A.A. content in leaves of 7 - wk old NT1 plants attacked by the BPH for 1 week (From Table 4 of Cagampang *et al.* 1974).

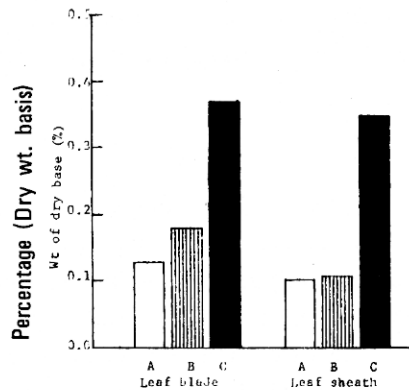


Fig. 12 Iron content in leaves of BPH-infested and uninfested rice plants (Original from Mita 1959). A: Uninfested plants. B: Plants at periphery of a hopperburn patch. C: Plants in the center of a hopperburn patch.

Although the information is still too fragmented, a possible explanation is given below. When one considers the remarkable amount of plant sap removed by the BPH and its simultaneous excretion of large quantities of sugars and amino acids in the honeydew it is no surprise that the attacked plants will decrease in content of water, soluble proteins, free sugars and even starch. The increase in free amino acid possibly indicates an accumulation of amino acid because of a breakdown of existing proteins or reduction in the rate of new protein synthesis. Since asparagine can stimulate sucking activity of the BPH (Sogawa, 1972), a marked increase in this amino acid (Cagampang *et al.*, 1974) is of special biological significance. This means that the feeding activity will be reinforced as infestation persists.

A decrease in chlorophyll content could be brought about by an acceleration of leaf senescence and withering (Fig. 4A). Because photosynthetic activity is directly proportional to content of water, soluble protein-N and chlorophyll in leaf (Boyer, 1976; Murata, 1969), a drop in these will reduce the photosynthetic efficiency (Fig. 4B) and hence decrease the amount of photosynthetic production (Fig. 4C & D).

Furthermore, the decrease in leaf water and leaf iron is a manifestation of the deterioration of physiological activity of the root system (Mita, 1959). This could be caused by the plugging of the sieve tubes by the "stylet sheaths" of the planthopper (Sogawa *et al.*, 1977). It has been confirmed that the root physiological activity is often dependent on the supply of carbohydrates and other nutrients from lower leaves (Murata *et al.*, 1975; Tanaka, 1958). The senescence and withering of lower leaves and possible plugging of the sieve tubes will cause a shortage of energy supply in the root system and a disorder of physiological activities. This, in turn, will cause a decline in the oxidizing ability of the root (Lai *et al.*, 1976). Consequently, the mobile ferrous iron ( $\text{Fe}^{++}$ ) is readily absorbed into the root system and then translocated to other plant tissues (Okajima, 1975). An unusual increase of iron content has been detected in those heavily injured plants in the center of a hopperburn patch (Mita, 1959). Such an explanation, however, requires further investigation.

Weakening of the physiological activity of the root system will cause a decrease in water and nutrient absorption. This will intensify the withering processes and bring about a further reduction in photosynthetic activity (Murata *et al.*, 1975).

### Concluding Remarks

In general, we agree with the scheme of possible interaction between BPH feeding and the development of hopperburn symptoms in rice plants proposed by Sogawa and Cheng (1977). However, from this review and our unpublished data we would like to revise their scheme with more detailed information as shown in Fig. 13.

It is clear from that a bioenergetic study might be initiated to bridge the gap between growth analysis and yield components analysis. We need much more concrete data to support the processes in the right hand part of the scheme, especially the pest's injury to the root system.

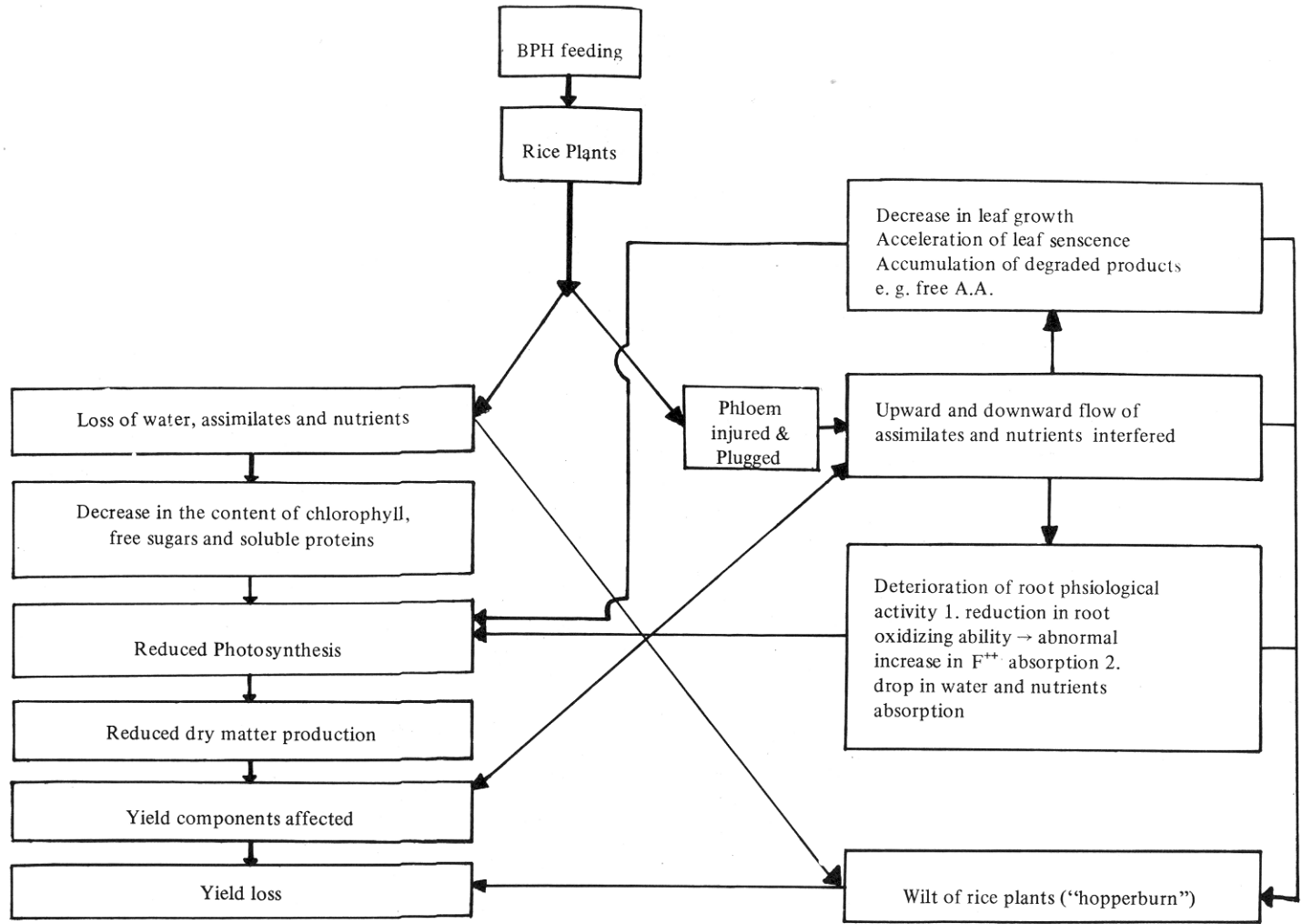


Fig. 13 Possible processes of "hopperburn" and yield loss of rice plants attacked by the brown planthopper.

## Acknowledgement

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### Comment and Discussion

- Dr. Y. Murata: I am much impressed by your presentation. Your presentation is a beautiful combination of entomology and plant physiology. I want to make two comments. One is: You mentioned the increase in NAR in milking stage in the normal plant, and the cause is, I think, based on two. The first is, after heading, the leaf area index decreases severely, and light condition becomes better. This is the cause. The other is: At heading an increase in photosynthetic activity is usually observed. According to my own data obtained 20 years ago, I observed this fact. Considering that CGR is also increased at this stage, it must be due to the second reason, that is, due to the physiological acceleration of photosynthetic activity at this stage. The second comment is: According to your results, the insect-attacked leaves become low in chlorophyll content and also in soluble protein content. These may result in the decrease in photosynthetic activity. However, according to our recent results, the photosynthetic activity is most likely to be limited by the key enzyme of Calvin cycle, RuDPCarboxylase. In your results there is greater decrease in soluble proteins than chlorophyll. So, in this case, the main limiting factor may be the decrease in this key enzyme.
- Dr. C. N. Chen: Thank you. Could you also comment on the unusual increase in the iron content? Are there some kind of iron containing enzymes in leaves?
- Dr. Y. Murata: Excuse me, I myself would like to ask you this question.
- Dr. C. N. Chen: That is a result obtained by a Japanese worker, Mida, in 1959. I don't know how to explain that.
- Dr. K. H. Houg: You mentioned that the most severe damage is done at the early growth stage, is this right?
- Dr. C. N. Chen: No. The most severe damage is done at the booting stage.

Dr. K. H. Houg: Could this be due to the increase in the population during the later stage?

Dr. C. N. Chen: No. In this case we maintained the population level during the infestation period, and thereafter removed them. Our interest was to indentify the physiological tolerance as to the insect damage.

Dr. K. H. Houg: You mentioned that due to the insect damage, the soluble nitrogen content decreased while the soluble amino acid content increased. How do you explain this, because the soluble amino acids appear to be the main parts of the soluble nitrogen compounds.

Dr. C. N. Chen: No. It is the soluble protein fraction that is reduced and the soluble amino acid content is increased. The total soluble nitrogen content remained the same.

Dr. K. H. Houg: You mentioned that the iron content is increased, could this be due to the drying up of the leaves, the dry matter content is reduced, and as the result the iron content is increased relatively.

Dr. C. N. Chen: I would think so, but I don't know how the Japanese worker, Mida, would explain this. I am not so sure about this.