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APPROACHES TO THE MANAGEMENT OF THE RICE BROWN PLANTHOPPER IN TAIWAN WITH SPECIAL EMPHASIS ON YIELD LOSS ASSESSMENT*

Chiou-nan Chen
Plant Protection Center, Taiwan

ABSTRACT

This paper reviewed some approaches to the management of the rice brown planthopper in Taiwan. Special emphasis was placed on rice yield loss assessment and its related studies and the determination of multiple economic thresholds (ET) to suit various circumstances in Taiwan. The validity of ET values was appraised by employing two types of analysis. One was a pair-wise comparison between two control strategies in terms of the ratio of incremental profit to incremental cost; the other a profit-maximizing analysis to determine an optimal management intensity at different areas based on different ET's. Finally, a pilot program of economic control of rice pests in Taiwan was described.

INTRODUCTION

The brown planthopper (BPH, *Nilaparvata lugens*) causes severe rice yield loss by direct sucking damage and by transmitting virus diseases to rice plants. It has become a serious threat to rice production throughout Asia since its upsurge as a rice key pest in 1960's(Dyck & Thomas, 1979). In fact, because of its extremely economic importance the International Rice Research Institute has started studies of varietal resistance to the BPH since 1966(Pathak & Khush, 1979). Moreover, at least two symposia have been held in 1970's to solely discuss its biology and control measures (FFTC, 1977; IRRI, 1979).

The BPH is unique in each locality because of its highly dynamic and adaptive nature. This paper only reviews the problems in Taiwan and describes how we develop and implement a management program to solve the problem. Special emphasis will be placed on yield loss assessment, the determination of economic thresholds (ET) and the appraisal of the validity of ET.

PRESENT STATUS OF BPH PROBLEMS IN TAIWAN

BPH mainly damages the 2nd rice crop in the west coast from central to southern parts of Taiwan (Fig.1). Outbreaks in the 1st crop were only recorded in 1966 and 1969

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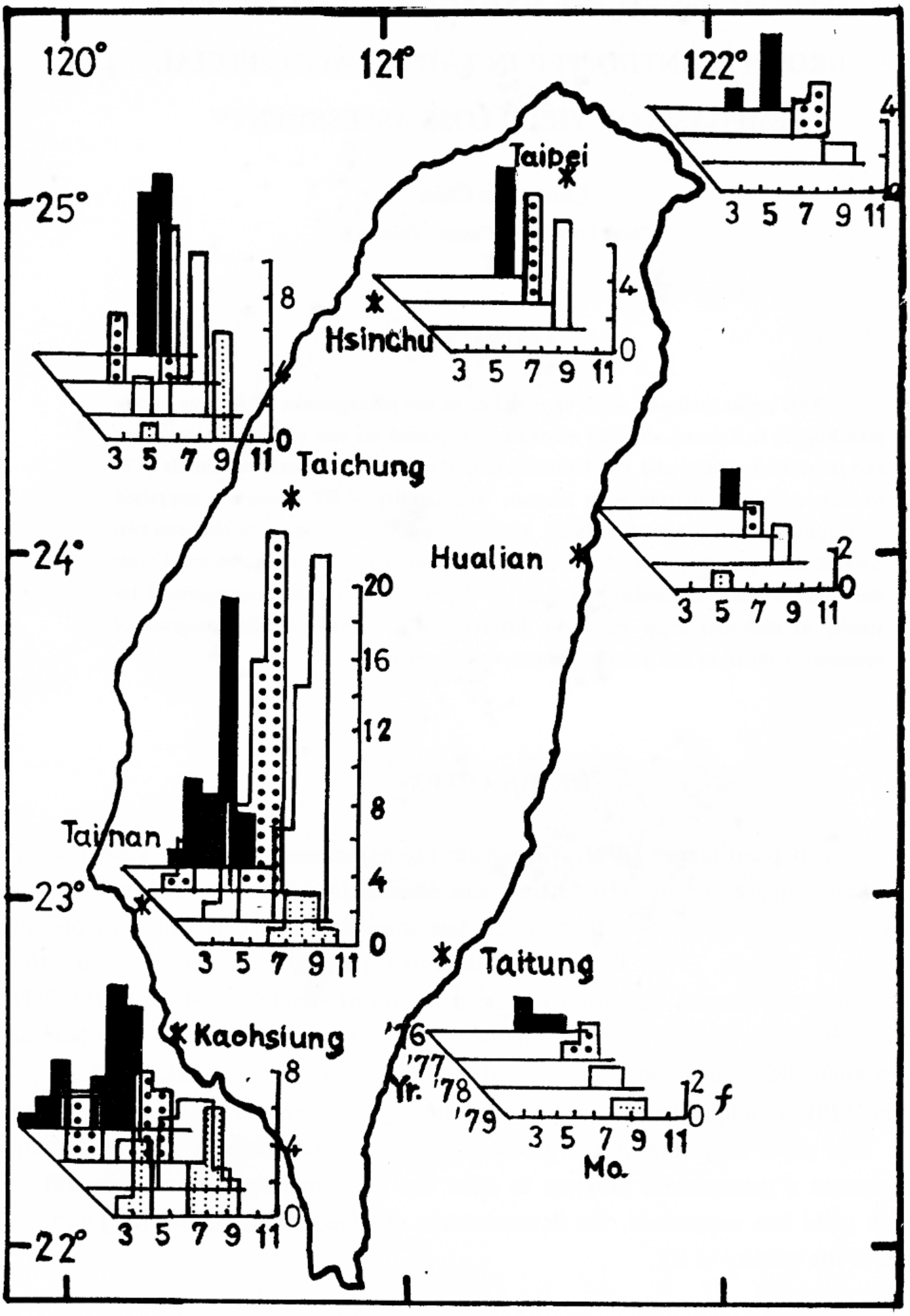

Fig. 1. Frequency of control warnings issued by scouts during 1976–1979 (PDAF 1976–79).

(Hsieh 1977), while in the 2nd crop they occurred in 1962(Tao, 1963), '66, '67, '69, '74 and '75(Hsieh, 1977)(Fig 2). In normal years the infested area was between 12 to 20% of the total paddy fields; while in outbreak years it was about 23 to 31% of the total cropping area (Fig. 2). Control warnings were usually issued in August, September and October(PDAF, 1976–79) (Fig. 1),which covered the period from booting to soft dough grain stages of rice plant.

Rice protection in Taiwan has been greatly strengthened by the establishment of an island-wide field surveillance network since 1966. In this network 47 scouts are stationed at major rice growing regions to do regular monitoring and surveillance of pest situation, including the BPH, in the field. Based upon scout's experience and pest's control thresholds, warnings are issued and released by posters in village or through newspapers, TV and radio broadcasts so that pest may be controlled in time eigher individually or collectively (Yen & Chen, 1977).

By integrating resistant variety, e.g. Chianung Shen 11, cultural practices, e.g. burning of stubbles to destroy BPH and disease inoculum, and chemical control, BPH in Taiwan is pretty much under control in recent years. Its resistance to pesticides is not significant and has been monitoring closely. (Ku, Wang & Hung, 1977).

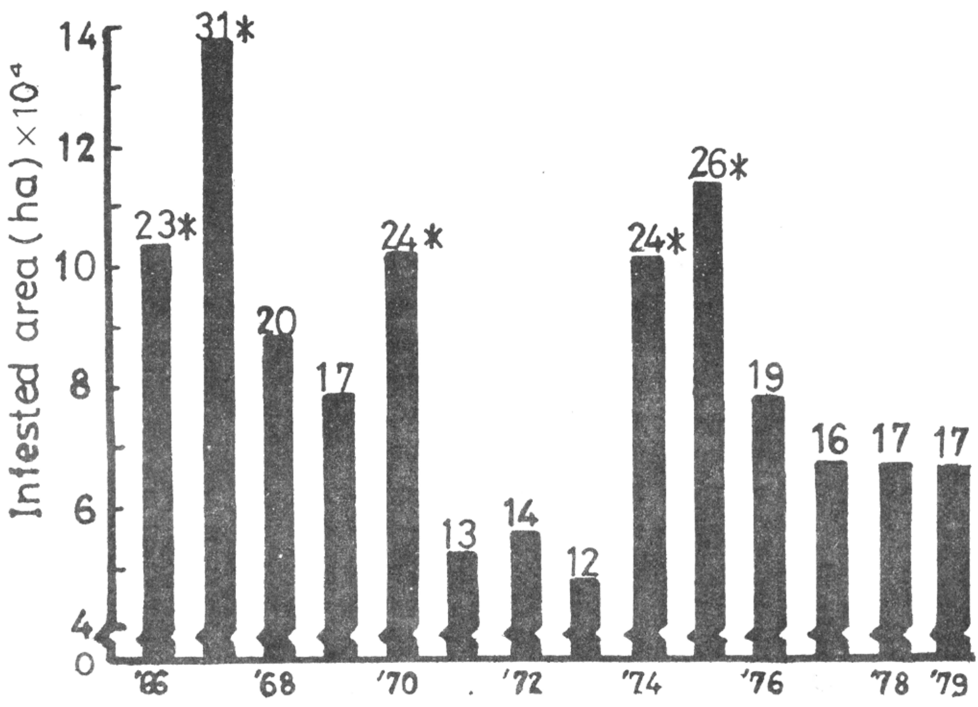

Fig. 2. Recent outbreaks (*) of the brown planthopper in the 2nd rice crop in Taiwan (Number on the top of each histogram indicates percentage of the total cropping area) (Hsieh 1977, PDAF 1976–79).

ASSESSMENT AND PROCESSES OF RICE YIELD LOSS CAUSED BY BPH

Sampling technique to estimate field insect population density, the establishment of economic thresholds to justify control measures, and insect population dynamics are three foundations to the development of an insect pest management (IPM) program (Gonzalez, 1970). This is more clearly depicted by Iwao (In Kiritani, 1972) in a conceptual model of a systems approach to develop an IPM program. Such an approach has been pretty much adopted to develop the BPH management program in Taiwan.

The study of insect injury in relation to crop yield loss is basic to the establishment of economic threshold level (Smith, 1969; Southwood & Norton, 1972; Stern, 1973). In doing researches on yield loss assessment factors influencing insect damage to crop plants should be aware of. These include pest factors such as species or biotype, behavior, stage, age distribution, dispersion, population level and duration of infestation; crop plant factors such as variety, stage and site of injury etc. and other factors e.g. weather, cultural practices, inter-and intra-species competition, and natural enemies (Bardner & Fletcher, 1974; Chiang, 1973; Smith, 1967, 1969; Strickland & Bardner, 1967).

Rice yield loss in relation to population levels of BPH has been studied in Taiwan by caging and artificial infestation at various stages of rice plant with a fixed infestation period (Chen & Cheng, 1978; Cheng, 1979) and by chemical treatment (Cheng, 1979). Results showed that responses of rice plants to BPH infestation differed at different stages. The booting stage was the most sensitive stage, followed by the milking, the maximum tillering and the soft dough stage. The yield loss threshold level was 2-3 BPH/hill during reproductive and ripening stage and 4 at maximum tillering stage. Yield loss was proportional to BPH population levels (Fig. 3). Damage to grain quality was also very significant. An increase in empty and partially filled grains was often resulted (Fig. 4).

The processes of yield loss could be explained in the light of yield component and crop growth analysis (Chen & Cheng, 1978, 1979). It has been shown that rice plants infested by BPH before maximum tillering (i.e. during vegetative phase) usually have fewer panicles per unit area (Fig. 5-a), and lower mean grain weight(Fig. 5-c). Plants attacked during booting to heading (i.e. during reproductive phase) have fewer grains per panicle, lower percentage of ripened grains (Fig. 5-b) and lower grain weight (Fig. 5-c).

Growth analysis of rice plants attacked by BPH has revealed that injured plants usually have a significant drop in relative leaf growth rate $\overline{(\text{RLGR})}$, net assimilation rate $\overline{(\text{NAR})}$, crop growth rate $\overline{(\text{CGR})}$ and relative growth rate $\overline{(\text{RGR})}$, as compared to uninfested plants (Fig. 6). This drop was most significant in plants attacked during late booting to maximum heading stage (ca. 57–72 DAT), which is clearly depicted in Fig. 7 as the plant's critical period in terms of physiological sensitivity to BPH attack. It is noted in Fig. 3 that rice plants at maximum tillering stage showed high tolerance to BPH infestation. This is clearly indicated by the higher $\overline{\text{RGR}}$ (Fig. 6) of the rice plants and hence a higher capability to compensate for BPH injury.

It is concluded that because during vegetative stage the assimilated energy is mostly utilized to form tillers and leaves, a reduction in dry matter production will cause a de-

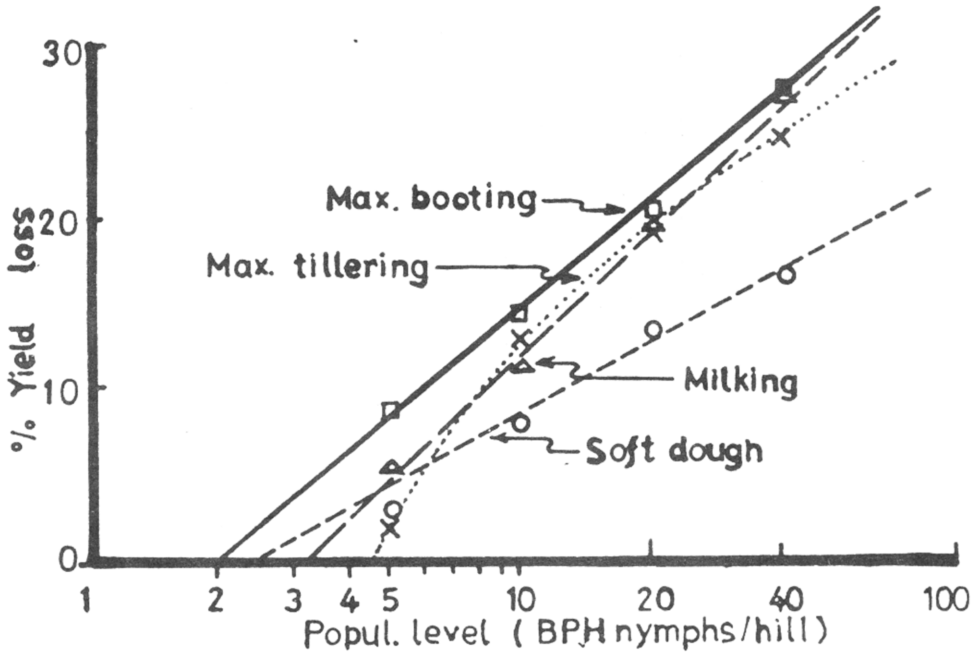

Fig. 3. Population levels of BPH vs. rice yield loss. (Re-drawn from Cheng, 1979).

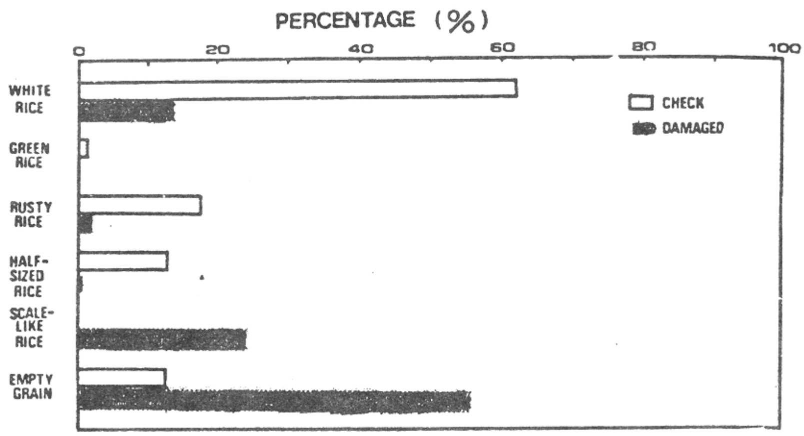

Fig. 4. Comparison of rice quality between BPH-damaged and normal grains (Chen & Cheng, 1979).

crease in the number of bearing tillers and in less reserves to be translocated to panicles later on, thus causing the grain to weigh less. 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, a significant decrease in photo-

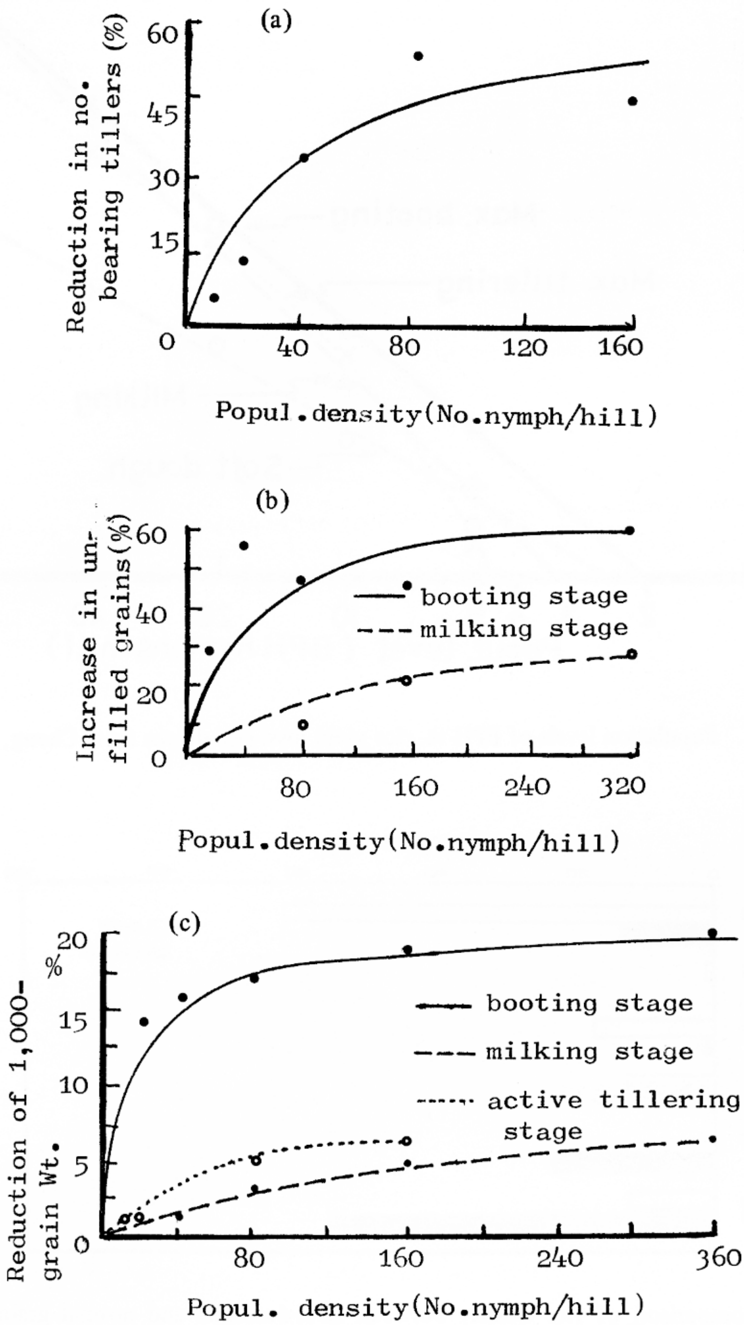

Fig. 5. Effects of BPH injury on rice yield components. (a) Reduction in number of bearing tillers at active tillering stage; (b) Increase in unfilled grains during booting and milking stage; (c) Reduction of 1,000–grain weight at different stages (Chen & Cheng, 1979).

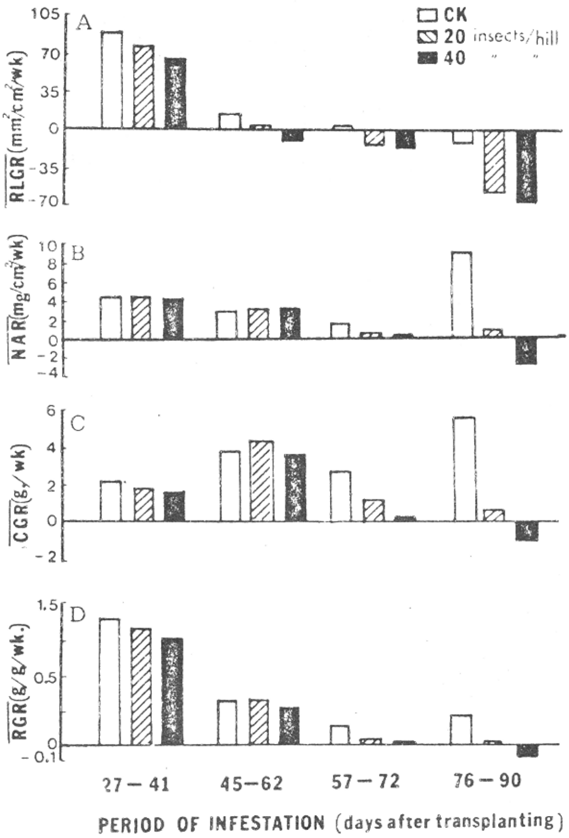

Fig. 6. Growth analysis of rice plants injured by BPH at various rice stages (Chen & Cheng, 1979).

synthates can severely affect the number of grains per panicle, percentage of ripened grains and weight of a grain. Consequently, a severe damage is resulted. During ripening phase the plants are vigorously translocating assimilates to fill the "container", so that a reduction in photosynthates will cause marked drop in percentage of ripened grains and the mean weight of a grain. Apparently, the drain of the plant sap by BPH feeding creates an extra "sink" to compete assimilates with normal "metabolic sinks" at different rice stages and reduces crop yield by affecting the yield components (Chen & Cheng, 1979).

DETERMINATION OF THE ECONOMIC THRESHOLDS OF BPH

In addition to data on pest levels vs. damage relationship, such variables as control cost, expected crop yield, predicted sale price, control efficiency, and pest survival rate etc. are needed in order to determine the economic threshold (Chiang, 1973, 1979; Southwood & Norton, 1973; Stone & Pedigo, 1972). Moreover, various ET's will be needed to suit the circumstances of individual farmers in peasant agriculture (Farrington, 1977). By taking these into consideration and utilizing a model proposed by Chiang (1979), we have established the economic thresholds of BPH in Taiwan.

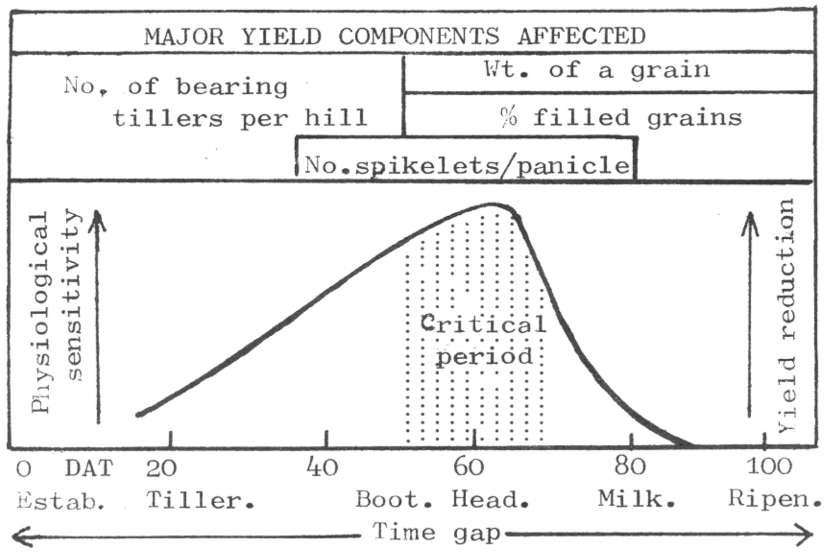

Fig. 7. A diagram showing relations among time of BPH attack, physiological sensitivity, yield components affected and rice yield reduction (Chen & Cheng, 1979).

During the 2nd cropping season 3-4 pesticidal applications are usually needed to control BPH. The control cost, including pesticides and labor, varied from 2500 to 6000 N.T.$ per hectare (ca. 36 N.T.$ = 1 U.S.$). The rice sale price varied from 8 to 12 N.T.$ per Kg. Control efficiency varied from 60 to 90%, assuming 80% as an average. The expected rice yield varied from 2500Kg/ha to 5500Kg/ha, with an average of 4000Kg/ha. Accordingly, the BPH economic thresholds in terms of number of BPH excluding 1st and 2nd instar nymphs per hill per week before ($\hat{Y}_1$) and after heading ($\hat{Y}_2$) was $\hat{Y}_1 = 5.06 + 0.0015X_1 - 0.61X_2$ and $\hat{Y}_2 = 12.18 + 0.0054X_1 - 2.17X_2$, as shown in Fig. 8., where X_1 is control cost and X_2, rice sale price. It is noted that the higher the control cost the higher will be the ET, whereas the higher the rice price the lower the ET. For instance, if the rice price is 12 N.T.$/Kg, the ET before heading at the control cost of 3500, 4000 and 5000 N.T.$/ha will be 3.5, 4.0 and 4.5 nymphs per hill, respectively. And if the control cost is 3500 N.T.$, the ET before heading at the rice price of 8, 10, 12 and 14 N.T.$/Kg is 5.0, 4.0, 3.5 and 3.0, respectively. ET values after heading in most cases are about doubled. Since ET is so dynamic its application should be flexible. Monitoring of BPH population must be made from 40 to 80 days after transplanting, which covers the duration from active tillering to milking stage of rice plant. Early index of ET could be obtained if the survival rate from 1st and 2nd instar to 3rd-5th instar nymph is known in the near future.

FIELD SAMPLING TECHNIQUE AND SEQUENTIAL DECISION SAMPLING

In order to know if field BPH population reaches ET level to justify control action, simple random sampling by direct sight counting has been recommended. And 30 to 50

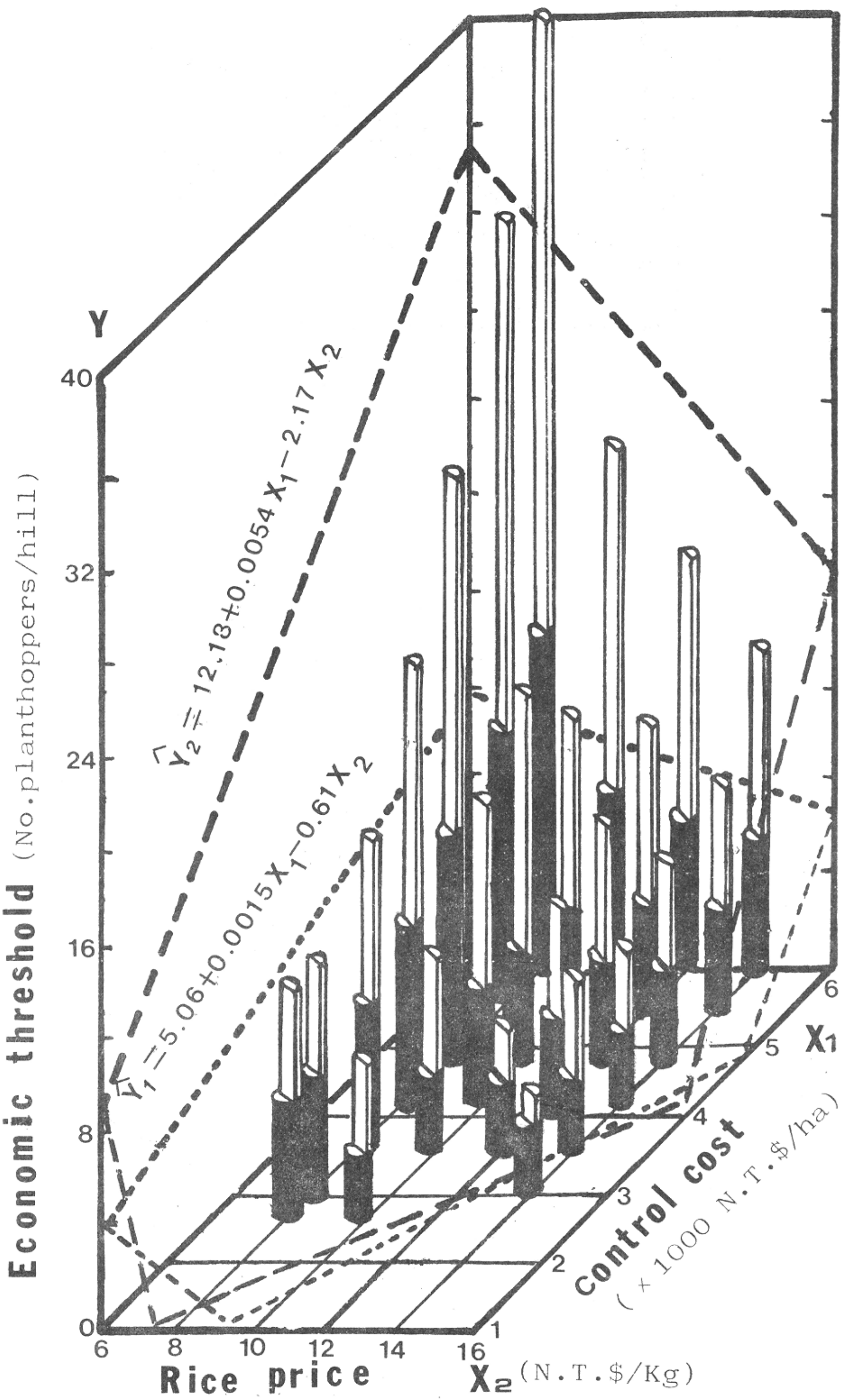

Fig. 8. Economic thresholds of BPH in relation to control cost and rice unit price in Taiwan (Based on data in Cheng, 1979).

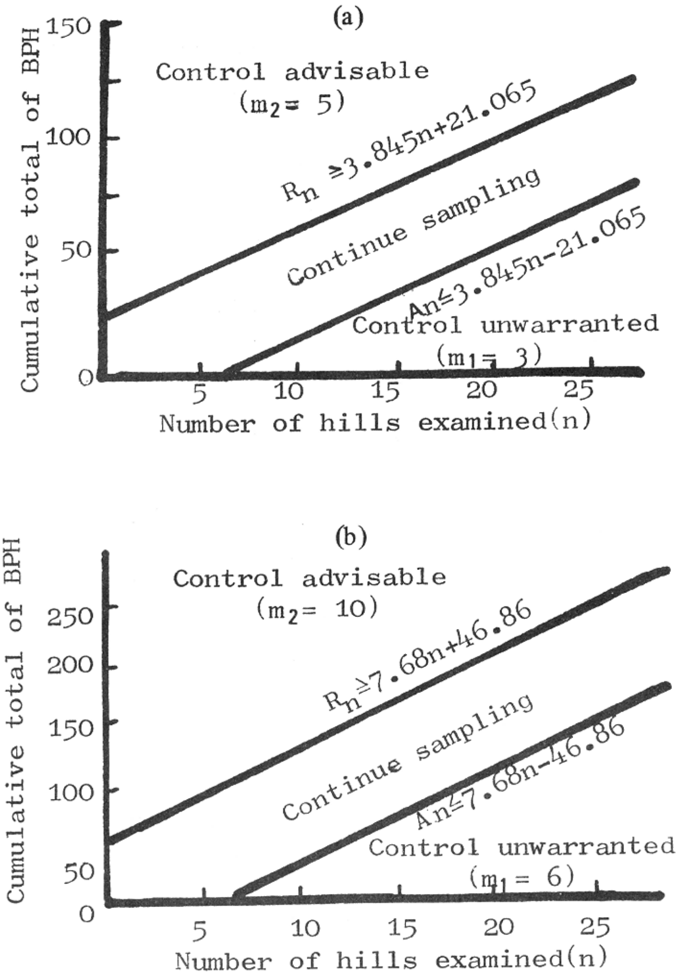

Fig. 9. A sequential decision graph for sampling the brown planthopper in Taiwan. (Revised from Chen, 1979). (a) to be used before heading; (b) to be used after heading.

hills is suggested for field sampling to secure the 20% precision level (Table 1) (Chen, 1977). However, because the dispersion pattern of BPH was not stable, varying between negative binomial distribution and Thomas series, the sampling plan based on negative binomial distribution is to be revised (Lin & Chen, 1979).

The application of ET is most efficient when a sequential sampling plan is devised. Decision of the necessity of control is reached as soon as the cumulative total of BPH falls in either "control advisable" zone or "control unwarranted" zone. A revised sequential sampling plan is shown in Fig. 9 to replace the one developed in 1976 (Chen, 1976). However, its validity needs to be tested before implementation.

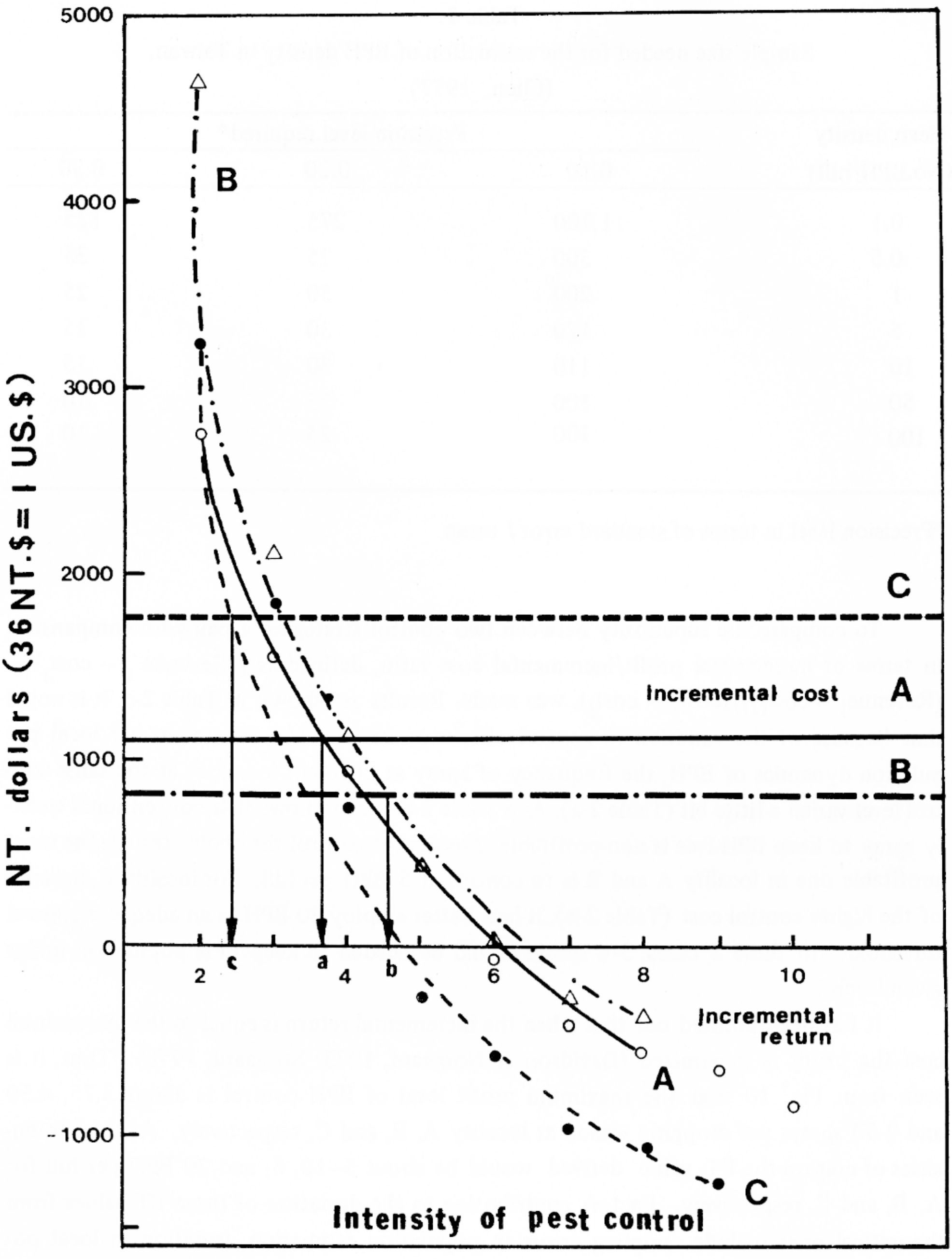

Fig. 10. Incremental cost and incremental return at different intensities of BPH control in Taiwan. (Based on data in Cheng, 1979).

APPRAISAL OF VALIDITY OF ET

Field test of ET values has been done by Cheng (1979). His data are now re-analyzed from economic point of view.

Table 1.
Sample size needed for the estimation of BPH density in Taiwan.
(Chen, 1977)

Mean density (No.BPH/hill)	Precision level required*		
	0.10	0.20	0.30
0.1	1,100	275	125
0.5	300	75	35
1	200	50	25
5	120	30	15
10	110	30	15
50	100	25	10
100	100	25	10

*Precision level in terms of standard error / mean

To compare the superiority between two control strategies, a pair-wise comparision in terms of incremental profit/incremental cost ratio, defined as $[(\text{Revenue}_i - \text{cost}_i) - (\text{Revenue}_j - \text{cost}_j)]/(\text{cost}_i - \text{cost}_j)$, was made. Results are shown in Table 2-c. It is noted that because of the variation in control efficiency of chemical treatment and local population dynamics of BPH, the frequency of spray at different localities at the same control level varied a little bit (Table 2-a). And Table 2-c clearly shows that conventional weekly spray to keep BPH-free is non-profitable. Among the control thresholds tested, the most profitable one in locality A and B is to control at 5 BPH per hill. For locality C, because of the higher control cost (Table 2-b), it had better employ 20 BPH as an adequate control threshold. In these 3 cases, 3-4 sprays would be needed to keep BPH population under given levels.

It has been pointed out that when the incremental return is equal to the incremental cost the profit is maximized (Davidson & Norgaard, 1973; Norgaard, 1976). Thus, it is seen from Fig. 10 that the maximum profit level of BPH control is about 3.75, 4.50 and 2.50 sprays per cropping season at locality A, B, and C, respectively. At these intensities of control the ET value derived would be about 5–10, 5, and 20 BPH per hill for A, B, and C, respectively. Factors contributing to the deviation of these ET values from theoretical ones include sampling errors in population estimation, variation in local population dynamics of BPH, aggregated distribution of BPH in nature in contrast to homogenous one in artificial yield loss assessment, and the influence of weather on pest-plant interactions. Nevertheless, this experiment did demonstrate the feasibility of 3–4 sprays currently recommended during 2nd cropping season in Taiwan.

A PILOT PROGRAM OF RICE ECONOMIC PEST CONTROL

Because farmers usually encounter insects and diseases in paddy fields at the same

Table 2.

Comparison between control strategies tested to manage BPH populations in Taiwan.
(Based on data in Cheng, 1979).

(a). Frequency of spray

Locality	Control threshold (BPH/hill) 0	5	10	20	40
A	10	4.25	3.25	3	2
B	8	3.75	2.5	1.5	1
C	9	4	3	2.5	2

(b). Pesticides used and control cost

A–– 40% Hokbal E.C. 1.51/ha , 1080NT$/ha/appl.
B–– 50% MIPC W.P. 1.2 Kg/ha , 880 NT$/ha/appl.
C–– 40.64% Carbofuran F. 1.5 1/ha, 1740 NT$/ha/appl.

(c). Pair-wise comparison by incremental profit/incremental cost ratio.

CT*	20			10			5			0		
	A	B	C	A	B	C	A	B	C	A	B	C
40	0.8	4.8	4. 2	1.8	3.5	2.6	1.9	3.7	1.4	0.1	1.2	(–)
20				0.2	2.9	0.9	2.7	3.5	0.4	(–)	0.9	(–)
10							2.0	3.9	0.2	(–)	0.6	(–)
5											(–)	(–)

*Control threshold

Table 3.

Frequency of treatments in supervised and farmer's plots.

Year	Supervised plots	Farmers' plots	Difference
1976	4.4	5.0	0.6
1977	3.7	4.5	0.8
1978	3.5	4.2	0.7

Table 4. Opinion polling concerning farmers' reaction to a pilot program of rice economic pest control (n = 1477).

	Farmer's reaction (%)					
	Decrease		No change		Increase	
	'77	'78	'77	'78	'77	'78
Control freq.	56	75	14	14	30	11
Cost	70	84	11	9	19	7
Yield	4	2	11	20	85	78

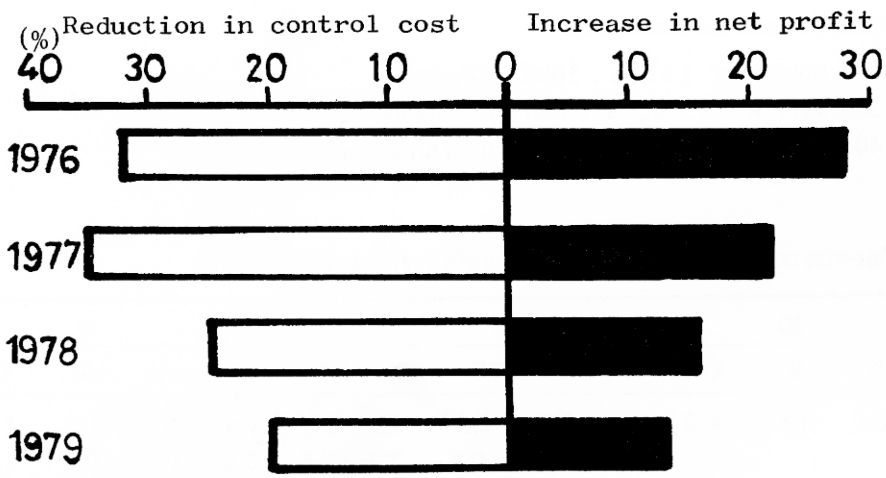

Fig. 11. Reduction in control cost and increase in net profit in a pilot program of rice economic pest control conducted in Taiwan.

time, a pilot program was initiated by government extension workers since 1976 to implement a supervised economic pest control in rice. Comparisons were made between supervised plots and farmers' plots (Tyan, 1980). Although the total hectareage involved was only 6756 ha (ca. 1.3% of total paddy fields) in 1979, the townships involved rapidly increased from 3% in 1970 to 35% of total rice growing townships in 1979. This program has demonstrated success and efficiency as far as implementation of rice protection technology is concerned.

In supervised plots the control necessity was based on close in-season field surveillance and control thresholds of major pests, including rice blast, sheath blight and the BPH, conducted by field scouts. The scouts are regular staff in extension sector hired by the government. They also supervise on choice of pesticides and control techniques.

These supervised plots also served as demonstration fields to be visited by other farmers. After harvest farmers, extension workers and researchers would get together in a meeting. And the farmers, who were supervised by extension workers,talked about their experiences and profit gained in monetary terms.

Statistics showed that in surpervised plots about one application of pesticides was saved (Table 3), control cost significantly reduced, and the net profit increased (Fig. 11). In an opinion polling made in 1978, 70% farmers said their control technique has been much improved; 75% said they made less sprays and cost less than before and 78% reported increase in yield (Table 4). Furthermore, 69% farmers evaluated this program as very profitable and only 2% considered it as no profit at all.

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台灣水稻褐飛蝨管理之研究途徑

陳秋男

台灣植物保護中心

本文討論水稻褐飛蝨管理之一些研究途徑，特別強調產量損失評估的基礎研究及應用問題。文中首先介紹褐飛蝨在台灣過去在一、二期稻作發生的情形（圖1及2），及目前管治現狀。接著討論作物損失評估研究的考慮事項。褐飛蝨爲害水稻可造成質與量的損失，其損失程度在各水稻生育期雖有差異，但一般均隨飛蝨密度的升高而增加（圖3及4）。此損失之過程可從其對水稻產量構成因子的影響及水稻生長分析來解釋（圖5及6），而有關水稻受害之生理生態反應則綜合以圖7的模式圖來說明。

本文進而討論訂定害蟲經濟防治基準的主要考慮事項，並導出水稻抽穗以前褐飛蝨的防治基準爲 $\hat{Y}_1 = 5.06 + 0.0015X_1 - 0.61X_2$；抽穗後爲 $\hat{Y}_2 = 12.18 + 0.0054X_1 - 2.17X_2$，式中 X_1 爲防治費用，X_2 爲稻穀價格（圖8）。接著介紹田間取樣方法（表1）以便估計其密度是否達到防治基準。並修訂逐次取樣方程式（圖9），以使防治與否的決定更加省時、省力。

文中更嘗試兩種新的分析方法來評價防治基準的可靠性，以確立其推廣價值。其一乃利用（多得的利潤）/（多加的費用）之比來比較兩種防治基準之優劣（表2）。另一乃根據最大利潤分析法（圖10）—卽當多得的報酬與多加的費用等値時，此時投資所得的利潤最大—來確定防治基準是否恰當。由此兩種分析，確證本省所訂褐飛蝨防治基準符合經濟原則。

最後介紹把經濟防治基準及取樣方法納入推廣體系的水稻病蟲害經濟防治先導計畫，及其示範成效（表3及圖11）與農民良好反應（表4）。由此可知，近年來本省水稻病蟲害防治，確實有可靠的研究基礎。