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MICHIGAN STATE UNIVERSITY

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DEPARTMENT OF ENTOMOLOGY AND PESTICIDE RESEARCH CENTER

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March 15, 1993

Dr. Wayne Ching
Office of Agriculture
Bureau of Science and Technology
Agency for International Development
Washington, DC 20523

Dear Dr. Ching:

I apologize for not providing you with the final report for aid grant PDC-5542-G-SS-8006. Apparently we were confused on our end on the submission of our second final report. Also we have had several changes of project officers starting when Dr. Benjamin Waite retired and two other subsequent project officers on our two USAID grants. Nonetheless, I am enclosing herein the mid-term report, the final report and two manuscripts that resulted from this work.

I sincerely thank you for your patience and for the support that USAID has provided in the initiation of this project which is beginning to have far reaching effects on environmental quality, food security and the independence of many different people in Asia.

Sincerely,

Mark E. Whalon
Professor

enclosures (3)

rsb

cc: Colleen Sober

APR - 6 1993

Final Report: AID Grant No. PCD-5542-G-SS-8006-00
Identification and Cloning of an Esterase Gene Responsible for Insecticide Resistance in the Brown Planthopper.

by

Mark E. Whalon, Professor
Michgian State Univesity
Department of Entomology and
Pesticide Research Center
East Lansing, MI 48824

The microplate assay that was developed at Michigan State University can be used to detect pesticide resistance in individual brown planthoppers, *Niliparvata lugens*. This test has been expanded and extended to regional cooperators. The cooperators include Dr. Sutrisno, Central Institute for Food Crops, Bogor, Indonesia, 16114; Dr. Weerawooth Katanyukul Hoechst Tailtd, Bangkok, Thailand; Dr. Luong Minh Chau at the Cuulong Delta Rice Research Institute in Cantho, Vietnam. We have also extended the technology to the Chinese at the recent International Congress in Entomology which was held in Beijing, China in June, 1992. M. Whalon provided a one week post congress course with the essentials of the brown planthopper resistance diagnostics system to a group of 30 specialists assemble by the National Academy of Agricultural Sciences.

Since the US Agency for International Development program in Science and Technology did not fund the continuation of this project, Rockefeller Foundation was pleased to pick it up. Subsequently we have developed a 16 member network of scientists from India in the west, the International Rice Research Institute in the east, Gagha Mada University in the south and the National Academy of Natural Science in China and the National Agricultural University in Japan in the north. Our goal is to complete a geographical network of cooperators in the continued study of pesticide resistance in brown planthopper throughout Asia.

The USAID (PST-PDC-5542-G-SS-8006) funded a research associate, Dr. Hugo E. van de Baan, to develop the esterase system and clone the gene which he accomplished. We have subsequently found that this evaluation procedure was too technologically sophisticated for many field application in Southeast Asia. Subsequently, under the same grant we began adapting the biochemical detection process, except in a portable photometer. This technology has proved to be relatively simple and efficiently transferred to educated field personnel in Indonesia and Thailand. For your information, Dr. Hugo van de Baan has gone on to the Ministry of the Environment in The Netherlands where he is now in charge of developing alternative control practices for pesticides that have severe negative environmental consequences. He is still interacting with the laboratory and several of the cooperators that we established under the USAID PST.

Currently, we continue to evaluate DNA of brown planthopper as per the USAID PST grant, but we found only very little binding affinity of the E-4 esterase gene from *Myzus persicae* with resistant brown planthopper DNA extractions. Under the USAID PST we evaluated the sensitivity of this DNA probe methodology, but have not found it to be satisfactory for extension to cooperators in Asia. We did compare non-radioactive DNA detection methods with standard radioactive DNA detection methods using this E-4 DNA probe, but here again the detection systems were difficult to transfer to cooperator labs.

In addition, broadened technology for detecting resistance in brown planthopper which was developed under the USAID PST will be extended this year to 30 visiting scientists involved in the Summer Institute for Resistance Pest Management (Brochure enclosed) which will be held in late July and early August at Michigan State University.

In summary, the project entitled: *Identification and Cloning of an Esterase Gene Responsible for Insecticide Resistance in the Brown Planthopper* under the Program of Science and Technology Cooperation from USAID resulted in two book chapters, a resistance detection system for brown planthopper, and the initiation of a cooperator network for management of resistant brown planthoppers throughout Asia. Although this work is still continuing under Rockefeller Foundation funding, it would not have been possible without the initial support provided by USAID PST.

Yearly!
8.395

MICHIGAN STATE UNIVERSITY

DEPARTMENT OF ENTOMOLOGY/PESTICIDE RESEARCH CENTER

EAST LANSING • MICHIGAN • 48824-1115

July 31, 1989

Dr. Benjamin Waite
Office of Agriculture
Bureau of Science and Technology
Agency for International Development
Washington, D.C. 20523

Dear Benjamin:

Enclosed we are sending you our progress report for the period January-June 1989 of USAID project no. (8.395) 936-5542 entitled "Identification and cloning of an esterase gene responsible for insecticide resistance in the brown planthopper". Enclosed you will also find a travel report of a trip Hugo van de Baan made February/March this year to Indonesia.

I enjoyed talking with you about pesticide resistance and the international situation in developing countries. Hopefully, we will have a more extended interaction at the APS meeting in August. Remember the WRCC-60 Resistance Management meeting is in Salon H of the Richmond Marriott Hotel from 1:30 - 4:30 p.m. on Sunday August 20th. I hope that you will be able to make a poriton of it.

Sincerely yours,

Mark E. Whalon
Professor

Hugo E. van de Baan
Research Associate

APR - 6 1993

PROGRESS REPORT USAID PROJECT NO. (8.395) 936-5542

Period: January - June, 1989

Title:"Identification and cloning of an esterase gene responsible for insecticide resistance in the brown planthopper"

Mark E. Whalon[1], Kasumbogo Untung[2] and Hugo E. van de Baan[1]

Dept. of Entomology, Michigan State University, East Lansing, MI 48824, U.S.A.[1] and Dept. of Entomology, Gadjah Mada University, Yogyakarta 55581B, Indonesia[2].

A microtitre plate assay has been developed at Michigan State University which can be used for the detection of pesticide resistance in individual brown planthopper, *Nilaparvata lugens* (see progress report July - December, 1988). The assay is based on detecting esterase and acetylcholinesterase enzyme activity associated with pesticide resistance.

Hugo E. van de Baan made a trip to Indonesia in the period February 16 - March 28, 1989 (see travel report). The objectives of this trip were:
- Introduce and implement the use of the microtitre plate assay for resistance monitoring in BPH in Indonesia.
- Develop a resistance management program for BPH in Indonesia.
- Coordinate research.

Equipment for the microtitre plate assay was transferred to Gadjah Mada University, Yogyakarta. Personnel was introduced to the background and use of the microtitre plate assay. The assay was adapted for the use in the field by using a portable photometer. Both laboratory evaluation (using an ELISA reader) and field evaluation (using a portable photometer) showed that these techniques are very useful for the detection of resistance in BPH in Indonesia. This technology is relatively simple to use and can therefore easily be used by extension and field personnel.

At Gadjah Mada University, pesticide resistant strains of BPH have been and continue to be selected with pesticides. Selection focusses on the carbamates BPMC, MIPC and the organophosphate phenthoate. Together with a pesticide susceptible strain, these strains will be used as reference strains for comparing resistance levels in field populations of BPH.

In order to evaluate toxicity of pesticides and to obtain resistance levels of various strains and populations of BPH, a laboratory toxicity bioassay has been developed. In this test, BPH are placed in fine-meshed wire cages and dipped in serial dilutions of formulated insecticides. Using this dip test, synergists have also been evaluated, which provide information on the importance of different detoxification enzymes for pesticide resistance.

DNA of BPH has been succesfully extracted, which is being used for the development of sensitive molecular genetic methods to detect pesticide resistance in BPH at an early stage. Non-radioactive DNA detection methods have been evaluated for their use as a tool for detecting resistant gene(s) in BPH. These methods will be compared with standard radioactive DNA detection methods.

The succes of the rice IPM program in Indonesia for the period 1986 - 1989 has been evaluated. Based on this information together with results of our studies, a resistance management program of BPH in Indonesia is being developed. Such a resistance management program will contribute to changing rice pest management towards sustainable IPM in Indonesia.

Literature:

Hugo E. van de Baan, Mark E. Whalon and Kasumbogo Untung. 1989. Monitoring for insecticide resistance in brown planthopper, *Nilaparvata lugens*, in Indonesia. Pesticide Resistance Management Newsletter, vol.1, 2:19

Kasumbogo Untung, Utami Rahardja, Mark E. Whalon and Hugo E. van de Baan. Towards resistance management and sustainable IPM: Rice pest management in Indonesia. In prep.

April 26, 1989

Travel report Hugo E. van de Baan

USAID project no. (8.395) 936-5542
Trip Indonesia 2/16 1989 - 3/28 1989

This trip was part of USAID project 936-5542 between Michigan State University and Gadjah Made University, Indonesia, entitled "*Identification and Cloning of Esterase Gene Responsible for Insecticide Resistance in the Brown Planthopper*". Duration of the stay was 4 weeks at the Dept. of Entomology at Gadjah Mada University, Yogyakarta, Indonesia. As outlined in the project, communication between both universities is very important. Therefore, this trip was made at an early stage of the project in order to coordinate research efforts. The specific purpose of this trip was to implement in Indonesia pesticide resistance monitoring techniques in brown planthopper (BPH) which have been developed as part of this project in the laboratory at Michigan State University.

The following accomplishments have been made:

1. Discussions on theory and background of pesticide resistance management and its implication for pest management of BPH in Indonesia.

2. Development of standardized laboratory bioassays (toxicity tests) for the evaluation of pesticides in BPH. A pesticide-dip test was evaluated for BPH as a tool to determine pesticide effectiveness in laboratory selected and field populations of BPH.

3. Evaluation of synergists using the newly developed bioassays in order to elucidate the importance of detoxification enzymes responsible for pesticide resistance in BPH.

4. Discussion of theory and application of biochemical detoxification enzyme assays (microtitre plate assays) for monitoring resistance in BPH and instruction of laboratory techniques involved in enzyme assays.

5. Evaluation of resistance levels of laboratory selected BPH and field collected BPH using microtitre plate assay. Implementation of microtitre plate technique for pesticide resistance management of BPH in Indonesia.

6. Extraction of DNA from BPH. The extracted DNA was brought back to Michigan State University for continuation of research on the molecular genetic aspects of resistance in BPH. This will be used to develop new techniques for early detection of resistance in BPH.

This trip has been succesful in transferring knowledge and technology on pesticide resistance management to Indonesia, and coordinating research efforts between both Universities. Good communication that has been established between Michigan State

University and Gadjah Mada University will ensure optimal continuation of this project and implementation of laboratory findings developed at Michigan State University for pesticide resistance management of BPH in Indonesia.

Hugo E. van de Baan, Research Associate
Pesticide Research Center B-11
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Journal of Economic Entomology
Section: Forum

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TOWARDS RESISTANCE MANAGEMENT AND SUSTAINABLE IPM: RICE PEST MANAGEMENT IN INDONESIA

KASUMBOGO UNTUNG[1], UTAMI RAHARDJA[1], MARK E. WHALON[2] AND HUGO E. VAN DE BAAN[2]

[1]Department of Entomology, Gadjah Mada University, Yogyakarta 55581B, Indonesia and [2]Department of Entomology, Michigan State University, East Lansing, MI 48824

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ABSTRACT In 1983 Indonesia reached rice self-sufficiency through a rice production intensification program based on high inputs of fertilizers and pesticides combined with the use of high yielding rice varieties which were resistant to insect pests. However, the brown planthopper (BPH), Nilaparvata lugens Stal, became a major pest of rice during this period, and outbreaks of BPH between 1984 and 1986 seriously threatened Indonesia's rice self-sufficiency. Major factors that contributed to the increasing problems of BPH were the unjudicious use of pesticides which caused pest resurgence and the development of pesticide resistance, breakdown of host plant resistance, and lack of integration of different pest management tactics. Research demonstrated that natural enemies are able to control BPH in situations where no disruptive pesticides are used, and showed that an IPM program based on the conservation of natural enemies could be effectively implemented if extension personnel and farmers are educated in the basic principles of IPM. In 1986 the Indonesian government banned the use of 57 pesticides for their use on rice and declared IPM the national rice pest management strategy. Although this IPM program is highly effective, BPH will continue to adapt to pesticides and resistant rice varieties used in the current IPM program. Therefore, in order to develop a sustainable rice IPM program, insecticide and host plant resistance management strategies need to be implemented.

KEY WORDS Insecta, *Nilaparvata lugens*, brown planthopper, rice pest management, resistance management, sustainable IPM

IN THE 1970's and 1980's one of the major goals of rice production in Indonesia was to reach self-sufficiency (FAO 1988). Through a rice production intensification program Indonesia became rice self-sufficient by 1983. This was primarily achieved by combining high pesticide and fertilizer input with the use of high yielding rice varieties which were resistant to insect pests (Anonymous 1986, FAO 1988).

The intensification of rice production, however, caused increasing pest problems (Anonymous 1986, FAO 1988, Untung 1988). During this period, the brown planthopper (BPH), Nilaparvata lugens Stal, became a major pest of rice in Indonesia. BPH was first reported as a rice pest in Indonesia in 1969 (Anonymous 1986). Major outbreaks of BPH occurred in the 1970's and 1980's, which caused servere damage and reduction of rice yields nation-wide (Anonymous 1986, FAO 1988, Untung 1988). The increasing severity of BPH outbreaks became a serious problem for rice production in Indonesia and threatened Indonesia's rice self-sufficiency.

Drastic changes in BPH control were a result of these problems. Supported by research conducted in Indonesia on integrated control of BPH and other rice pests, the Indonesian government banned 57 pesticides for their use on rice and declared Integrated Pest Management (IPM) the national pest control strategy for rice (Presidential Decree 3, 1986).

This paper discusses the factors that caused BPH to become a major pest of rice in Indonesia, the changes in control strategies that turned ineffective control into a highly effective management system, and future directions for sustainable IPM of BPH and other rice pests. The Indonesian experience can serve as a model of changing pest management towards sustainable IPM for other agroecosystems in developing and developed countries.

BPH becomes a major rice pest

In Asia more than 28 species of insects have been reported as major pests of rice (Kiritani 1979). In Indonesia alone, 8 species have been identified as major insect pests of rice (Table 1). Besides insects, mammals such as rats and wild pigs, and diseases such as ragged stunt, bushy stunt, and tungro can also seriously damage rice. The pest complex of rice is dynamic resulting from the alteration of the environmental conditions, pest control strategies, cultural practices, seasonal variation, etc., to which insects are able to adapt. A dramatic example of such an adaptation to 'new' environmental conditions is the change in pest status of N. lugens in Indonesia and other areas in Asia in the past 20 years (Kiritani 1979, Dyck & Thomas 1979, Anonymous 1986). This insect causes direct damage to rice by feeding on the rice plants, and high populations of BPH can cause a total yield loss due to 'hopperburn' (Sogawa 1982). BPH is also a vector of ragged stunt, a virus, and bushy stunt, a mycoplasma, and these diseases frequently follow BPH outbreaks (Sogawa 1982).

The importance of BPH as a pest of rice was first reported in Indonesia in 1969, when it started to cause incidental economic damage, but BPH did not become a serious pest until the 1974/1975 cropping season (Anonymous 1986). Populations of BPH drastically increased in the 1970's and early 1980's as shown in Table 2. Losses in rice yield due to BPH damage in this period were estimated to 300-500 thousands tons of milled rice annually and from the period 1977 to 1979 alone, over 2 million hectares of rice were lost (Anonymous 1986, FAO 1988). Major outbreaks occurred again in 1984 through 1986, during which period BPH caused severe damage and reduction of rice yields nation-wide (Anonymous 1986, Untung 1988).

Strategies for controlling BPH in the 1970's and early 1980's depended mainly on the use of insecticides and BPH resistant rice varieties, although some cultural practices were suggested to overcome the BPH problem (Oka 1979, Anomous 1986). Pesticide induced resurgence, pesticide resistance, breakdown of hostplant resistance and the lack of integration of different pest management tactics caused BPH to become a major pest.

Rice pest management: Past control strategies

Cultural practices. In the early 1970's, the rice production intensification program in Indonesia did not encounter problems with BPH. At a limited scale, increased rice production was accomplished according to 5 principles of integrated crop protection known as the 'Panca Usaha'. The Panca Usaha included the use of improved varieties, sound water management, sound cultural practices, rational use of feritilizers, and appropriate pest control measures implemented through extension personnel (Anonymous 1986). When the rice production intensification program was implemented on a larger scale in Indonesia, the principles of the Panca Usaha eroded, resulting in BPH population build-up and eventually outbreaks. The following cultural factors contributed to the increased problems with BPH (Oka 1979, Anonymous 1986):

1. Lack of crop rotation: rice was continously planted twice or three times a year, without rotation with other non-host annuals, resulting in a continous food source for BPH.

2. staggered planting: synchronous planting of rice allowed for more easily management of BPH with a short fallow period. However, the general pattern of rice cultivation resulted in all growth stages within a small area, thus providing BPH a continous food source.

3. use of fertilizers: increased rice production through increases in nitrogen fertilizers also triggers an increased ovipositional response in BPH, which led to dramatic population increases (Oka 1979).

4. use of non-resistant varieties: Although the Indonesian government made resistant varieties available, many farmers planted old varieties with better taste and economic return (see below). Susceptible varieties provided an easy accesible food source and rapid BPH population build-up.

Pesticides. During the rice production intensification program in Indonesia, pesticides were subsidized by the government, in order to make them readily available at a low price for farmers. As a result, there has been a tremendous increase in the use of insecticides for rice pest control, from 1,000 tons in 1970 up to 15,000 tons in 1985 (Helmi 1983, Repetto 1985, Fig. 1). By 1986 more than 60 insecticides were registered for control of insects in rice in Indonesia (Helmi 1983). Despite this dramatic increase of pesticide use in rice, problems with insect control became more serious (Anonymous 1986, FAO 1988, Untung 1988, Fig. 2). Two major factors contributing to the failure of chemical control of BPH have been the resurgence of BPH after pesticide applications and the development of insecticide resistance.

Resurgence, a significant increase in the BPH population after insecticide treatment, was observed in Indonesia since 1979 as well as elsewhere in Southeast Asia

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(Chiu 1979, Heinrichs & Mochida 1984, Anonymous 1986, FAO 1988, Untung 1988). Laboratory and field studies at the International Rice Research Institute (IRRI), Los Banos, Philippines, demonstrated a sublethal reproductive stimulation in females (Chelliah et al. 1980). This phenomenon combined with selective removal of natural enemies, caused resurgence of BPH (Heinrichs et al. 1982). Increased feeding rate, reduction in the length of the nymphal stages, and increased adult longevity, are additional factors that may contribute to resurgence (Chelliah & Heinrichs 1980, Heinrichs & Mochida 1984).

Studies on the effect of insecticides on populations of BPH and natural enemies on central Java supported the IRRI resurgence research (Rahardja 1982, Surjana 1982, Untung 1988). All the major groups of insecticides (carbamates, organophosphates, and pyrethroids) caused BPH resurgence, although some compounds seemed to be more harmful than others. For example, fenitrothion, diazinon, deltamethrin, chlorpyrifos, dimethoate, phenthoate, and dichlorvos caused high levels of BPH resurgence, whereas monocrotophos, carbofuran, MIPC (2-sec-Butylphenyl-N-methylcarbamate), and BPMC (2-Isopropyl-phenyl-N-methylcarbamate) caused lower levels of resurgence (Untung 1988). The degree of resurgence was also inversely correlated with the rice host plant resistance levels. Among the natural enemies studied, the mirid _Cyrtorhinus lividipennis_ (Reuter) was most sensitive to the insecticides tested, whereas the spider

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Lycosa pseudoannulata (Boes. et Str. ?? spell out) and the parasites *Oligoshita* sp., *Anagrus* sp., and *Gonatocerus* sp. were less sensitive. In the insecticide treated plots, BPH caused damage to the rice plants, whereas in untreated plots BPH populations did not reach damaging levels, which was attributed to the high populations of natural enemies observed (Untung 1988).

These studies indicated that the use of broad-spectrum insecticides eliminated natural enemies of BPH, allowing the pest to reach damaging levels. Thus, BPH were effectively controlled by natural enemies if no disruptive insecticides were used in the rice agroecosystem. Similar results were observed in Malaysia (Ooi 1980), Japan (Fukuoka 1985), and in the Philippines (Kenmore 1980, Kenmore et al. 1984).

The excessive use of insecticides during the rice production intensification program caused an unnecessary high selection pressure on populations of BPH, and the development of insecticide resistance resulted. In other areas of Asia, BPH has also developed insecticide resistance to a variety of compounds. Organophosphate, carbamate and pyrethroid resistance has been reported in BPH from Taiwan and Japan (Sun et al. 1984, Dai & Sun 1984, Kilin et al. 1981, Endo et al. 1988). Organochlorine, organophosphate and carbamate resistance has been reported in BPH populations from China (Tang et al. 1988), and BPH from the Philippines showed resistance to a variety of carbamates (Heinrichs 1978, Fabellar & Mochida 1985).

In Indonesia similar patterns have been observed. Populations of BPH from central Java were reported to be resistant to organophosphates, carbamates and pyrethroids (Chang & Whalon 1987). Sutrisno (1989) observed resistance to organophosphates, carbamates and pyrethroids in populations of BPH from 7 different locations on Java. Resistance levels were related to patterns of pesticide use. Populations from Bandung and Cianjun, which had not been intensively exposed to pesticides, were relatively susceptible to organophosphates and carbamates. Populations from Banyumus and Banyuwangi had been exposed to carbamates and showed carbamate resistance, whereas populations from Bantul and Sleman exposed to organophosphates and carbamates showed resistance to both groups of compounds.

Studies on the biochemistry of resistance showed that esterases are of major importance in resistance to organophosphates and some carbamates in BPH from the Philippines, Taiwan, and Japan (Tranter & van Emden 1984, Chung & Sun 1983, Endo et al. 1988). Altered cholinesterase may also be involved in carbamate resistance. Similar results have been observed in BPH from Indonesia. Chang & Whalon (1987) reported the importance of esterases conferring organophosphate, carbamate, and pyrethroid resistance in BPH collected from central Java. Sutrisno (1989) reported the importance of insensitive cholinesterase in BPMC and MIPC resistant BPH, and the importance of aliesterase in organophosphate resistant strains.

Resistant rice varieties. In order to overcome the problems of insecticide resistance in BPH, more effort was put into the propagation and distribution of BPH-resistant rice varieties in Indonesia. As early as 1967, varieties resistant to BPH had been identified at IRRI (Pathak et al. 1969). Since then, new BPH-resistant varieties have been selected, and through genetic analysis, 4 genes for resistance were identified. Two dominant genes, Bph 1 and Bph 3, and two recessive genes, bph 2 and bph 4 were characterized (Athwal et al. 1970, Lakshinaruyana & Khush 1977). These genes formed the genetic basis for breeding improved varieties resistant to BPH, and IRRI promoted these resistant varieties as the principle method of BPH control in Asia (IRRI 1979). IR26 (Bph 1 gene) was the first resistant variety broadly released from IRRI in 1973 (Pathak & Khush 1979).

In Indonesia, IR26 and other varieties containing the Bph 1 gene were introduced in 1977-1978 (Untung 1988, Table 3). Since 1979, various resistant varieties containing the bph 2 gene have been introduced. In Indonesia, BPH resistant varieties containing the bph 2 gene have also been developed (Table 3). These moderately resistant varieties, Krueng Aceh, Cisadane, and Cipunegara, were more popular among farmers than the IRRI varieties, because of their high production, better taste, and higher economic return (FAO 1988, Untung 1988).

Initially, BPH-resistant varieties were not affected by BPH. However, within 2 years of extensive planting, damage by BPH on IR26 were reported in the Philippines (Feuer 1976). Outbreaks of BPH on varieties with the Bph1 gene were also reported in other areas in Asia following extensive planting (Khush 1979). Succesful control of these BPH outbreaks was obtained through the introduction of varieties with the bph 2 gene. However, after 6 years, resistance to IR36 and related varieties was broken in the Philippines (Peralta et al. 1983).

Similar trends of hostplant resistance breakdown were observed in Indonesia. Hostplant resistance to varieties containing the Bph 1 gene did not last for more than 2 cropping seasons (less than 1 year), after their introduction in 1977-1978 (FAO 1988). After 1979 BPH outbreaks could be controlled by the introduction of varieties containing the bph 2 gene, such as IR36 and Cisadane (Untung 1988). However, this narrow base of resistance made the rice production system vulnerable to BPH outbreaks. The acreage of rice fields damaged by BPH increased from 19,000 ha in 1984 to 60,000 ha in 1986 (Untung 1988).

The ability to breakdown host plant resistance has been related to the development of 'biotypes' (Pathak & Saxena 1980). At IRRI, laboratory cultures of individuals obtained from field populations and selected on host plants containing different resistant genes led to the development of strains capable of surviving host plant resistance, hence the biotype designations. Although some authors speculate that the occurence of biotypes in the field may even eventually lead to sympatric speciation (Saxena & Barrion 1985), other workers conclude that biotypes are simple genetic variants rapidly selected with no mating barriers (Claridge & Den Hollander 1980). The latter is probably the case, given the extensive migratory behavior of BPH throughout southeast Asia (Kisimoto 1979).

Apparently, BPH quickly adapts to selection pressure exerted by either pesticides or host plant resistance, and this adaptation process is similar. As resistant individuals are selected for, their survival ensures the expression of resistant genes in the next generation. If selection is continued the resistant gene(s) become(s) fixed in the population. From these experiences, more rice researchers are concluding that control of BPH solely based on the use of pesticides or resistant rice varieties will not be effective in the long term.

Presidential decree: overcoming the BPH crisis

Based on the findings that natural enemies can effectively control BPH if no disruptive insecticides are used, pilot studies were conducted to implement pest control based on the conservation of natural enemies. This IPM strategy emphasized the use of insecticides only when needed and the use of locally acceptable resistant rice varieties. An important aspect of this study was the training of extension personnel and farmers to diagnose and monitor pest problems in the field and to make decisions accordingly. In 1986 farmers using the IPM approach applied 1.9 insecticide applications per rice crop, whereras farmers using standard control measures applied insecticides 4.5 times per crop (FAO 1988). Farmers using IPM methods produced on average 6.3 tons/ha compared with 6.1 tons/ha by farmers using standard control strategies. Results of these pilot studies demonstrated the feasibility of the IPM approach for larger areas of rice production in Indonesia.

In the mid 1980's the acreage of rice fields damaged by BPH increased from 19,000 ha in 1984, to 22,000 ha in 1985, and 60,000 ha in 1986 (Untung 1988). Because of the increase in damage caused by BPH and the availibity of the IPM alternative, the Indonesian Government declared on 5 November 1986 by Presidential Decree 3 (Inpres 3/1986) IPM the national pest control strategy for rice. The Presidential Decree emphasized that insecticides should only be used when control thresholds in effect were reached thus mandating a monitoring strategy. The decree banned the use of 57 insecticides on rice because of their implication in BPH resurgence. Only four compounds were allowed for rice pest management, the carbamates MIPC, BPMC, and carbofuran and the insect growth regulator Applaud[r] (buprofezin). The use of BPH resistant rice varieties was also required. An appropriate cropping system, including synchronous planting, rotation with non-rice crops, and a considerable free rice crop period was recommended. In order to implement this program, the Presidential Decree stated that extension personnel and farmers should be trained to conduct IPM of BPH.

Presidential Decree 3 resulted in effectively controlling BPH and improving rice pest management in Indonesia. The number of insecticide applications dropped from 4.5/ha in 1986 to 0.5/ha in 1988 (FAO 1988). The rice yield increased from 6 tons/ha in 1986 to 7.5 tons/ha in 1988 (Fig. 3). This resulted in a reduction of insecticide costs to the farmers of 7,500 rupiah/ha in 1986 to only 2,200 rupiah/ha in 1988, even though insecticides were more expensive due to a reduction in government subsidy compared with 1986. Throughout the introduction of IPM in Indonesia, an extensive training program of field personnel, extension workers and farmers was put in place. The current goal of the Indonesian government is to educate 2.5 million farmers and extension workers in IPM by 1994.

Resistance management: The transition state

Resistance management: a strategy within IPM. Integrated pest management has been defined as a pest

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management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes the best set of strategies, tactics, and tools to maintain pest populations at levels below those causing economic injury, while minimizing the socioeconomic and environmental effects of pest control. Although IPM proposes the use of a variety of techniques in an ecologically sound manner, most IPM programs generally depend mainly on the use of pesticides as the major population suppression strategy. Because of the major role of pesticides in IPM and the increasing problems of pesticide resistance in arthropods (Georghiou 1986), pesticide resistance management is becoming an important strategy within the IPM philosophy (National Academy of Sciences 1986). The objective of resistance management is to delay, prevent or reverse the development of resistance in pest species to pesticides, and if possible, to promote resistance development in natural enemies (Dover and Croft 1984, National Academy of Sciences 1986). Genetic, reproductive and behavioral/ecological factors influence the rate of resistance development (Georghiou & Taylor 1977a, Georghiou & Taylor 1977b, Georghiou 1983) and are the key to resistance management. Resistance management tactics should be aimed at reducing resistant allele frequencies, reducing resistance dominance, and minimizing the fitness of resistant genotypes (Leeper et al. 1986), resulting in the maintainance of pesticide susceptibility. Any resistance management tactic may stem resistance by itself, but the integration of multiple measures is usually needed for sustainable results (Dover & Croft 1984).

An important requirement for any succesful resistance management program is the ability to detect resistance in a population at a sufficiently early stage to reduce selection pressure. Through resistance monitoring one attempts to measure changes in the frequency or degree of resistance in time and space in pest species (National Academy of Sciences 1986). Resistance monitoring is therefore essential for the evaluation of strategies, validation of tactics, and implementation of an ongoing IPM program.

The concepts of resistance management also apply to host plant resistance, in which one wants to prolong the resistance of the host plant to the insect, by delaying, or preventing the ability of the insect to breakdown the host plant's resistance. Plant genes for resistance act as a mechanism of selection pressure on variable field populations leading to a shift in population characteristics and finally resulting in the breakdown of resistance by selection of BPH biotypes (Gallun et al. 1975, Gallagher 1988). The analogy between selection pressure by an insecticide leading to a change in population characteristics resulting in the failure of the chemical and the breakdown of host plant resistance is obvious.

Resistance management of BPH in Indonesia. The current IPM strategy for BPH in Indonesia emphasizes the importance of natural enemies and the use of more selective pesticides for BPH control, thereby reducing the selection pressure by pesticides. However, the availibility of only four insecticides for the control of BPH and this species' propensity to quickly develop insecticide resistance, requires the application of resistance management as a strategy within IPM to sustain BPH control in Indonesia. As discussed above, monitoring for resistance is the key implementation step for a succesful resistance management program. However, resistance in BPH in Indonesia has been mainly observed through field failure of insecticides (Sutrisno 1989). Therefore, the development of resistance monitoring techniques was the initial step in the resistance management of BPH.

Laboratory bioassays have been developed and are currently being implemented to evaluate the toxicity of insecticides under standardized conditions for laboratory and field populations of BPH (unpublished data or Table 4?). In these tests, BPH were placed in fine-meshed wire screen cages, dipped in serial dilutions of formulated insecticides, and mortality determined after 48 hrs. The disadvantages of this assay were that only one insecticide could be tested per insect, large numbers of insects were required, and the assay was time consuming. Because of the importance of esterases and acetylcholinesterases for resistance in BPH in Indonesia (see above, Chang and Whalon 1987, Sutrisno 1989), microplate assays for the detection of esterase and acetylcholinesterase activity and inhibition in individual insects (Sawicki et al. 1976, Brogdon et al. 1988) were evaluated for detection of resistant BPH (unpublished data or Table 4?). A field resistance monitoring kit was also being evaluated using a portable photometer, which allows for the detection of resistance levels in populations of BPH in the field. These biochemical tests provided information about resistance frequencies within populations, required fewer insects, and were more sensitive and less time consuming than morbidity bioassays. This technology was simple and was easily transferred to relatively untrained field personnel.

In the future, the availibility of resistance monitoring techniques may allow for effective resistance management of BPH in Indonesia. The following tactics supported by laboratory data and/or field experience have been generally considered useful in managing resistance in arthropods (National Academy of Sciences 1986) and will be evaluated for BPH: local rather than areawide pesticide applications; treatments only when the economic threshold is reached; use of less persistent pesticides; mixtures, rotations or mosaics of pesticide applications of the carbamates MIPC, BPMC, carbofuran and the growth regulator, buprofezin; use of synergists; use of selective compounds to protect natural enemies and use of pesticide resistant natural enemies; introduction of new toxophores with alternate sites of action.

Regarding the host plant resistance management program, monitoring for the ability to breakdown the resistances of different resistant varieties in field populations of BPH under standardized conditions will be an essential component. Tactics that may reduce the speed at which BPH will break down host plant resistance are the following: resistant host plant rotation, i.e. rotation of different resistant genes; more local than areawide planting of a certain resistant variety, i.e. host plant mosaic; introduction of new convential selected resistant genes (laboratory biotypes of BPH may be useful for genetic screening of new resistant varieties). Biotechnology also offers the possibility of creating new resistant varieties, but there is no reason a priori to assume that these exotic genes could not be overcome by BPH biotypes.

Sustainable rice IPM: Future goal

The primary element of sustainability is the cycling of resources, a self perpetuating system which keeps itself within the boundaries of self-sufficiency. An example of such an agricultural system is natural farming in which no fertilizers and pesticides are used. In Japan for more than 20 years a rice/barley/clover succession has been succesfully grown without tillage, weeding, and use of fertilizers and pesticides (Fukuoka 1985). Although succesful under specific conditions at a small scale, natural farming may not be a realistic approach for rice growing in Indonesia as yet, because of the increasing demands of higher yields in order to feed an increasing population and the current practices of rice production.

Rice production in Indonesia will continue to be based on high-input intensive farming. As part of the current IPM program, the use of insecticides as well as resistant rice varieties will therefore continue, thus selection pressure will occur and BPH populations will adapt. However, it is hoped that the integration of insecticide and host plant resistance management strategies will result in stable control of BPH in Indonesia. Because, BPH is a highly adaptive species, we believe that continuous monitoring and strategy alteration will be necessary for BPH management. In our view, resistance management is therefore, an essential strategy within a sustainable IPM approach to BPH management.

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Table 1. Importance of insect pests of rice in Indonesia for the period 1979-1983 (Anonymous 1986).

importance	species	cummulative weight of infestation intensity[1]
1	brown planthopper *Nilaparvata lugens*	29,750,729
2	rice stemborer *Chilo suppressalis*, *Tryporyza incertulas* other species ??	11,302,015
3	leaf roller *Cnaphalocrois medinalis* right species ??	6,770,431
4	rice bug *Leptocoriza acuta*	5,116,308
5	army worm *Spodoptera mauritia* right species ??	4,142,039
6	rice gall midge *Orseolia oryzae*	1,427,661
7	stink bug species ??	1,017,403
8	green stink bug species ??	353,530

[1] $\frac{\text{area infested x intensity}}{\text{area infested}}$

what does this mean??
area infested in ha?
intensity ??

What is meant by cummulative weight of infestation intensity?

What about diseases and their importance ??

Table 2. Area of rice (ha) infested by brown planthopper, *Nilaparvata lugens*, in Indonesia for the period 1974-1986 (Anonymous 1986).

year	infested area (ha)
1974	321,480
1975	576,680
1976	454,590
1977	713,185
1978	319,987
1979	744,436
1980	79,361
1981	38,279
1982	61,699
1983	128, 591
1984	19,917
1985	42,419
1986	60,000

What about data from 1987-1989 ??

Table 3. Introduction of various resistant rice varieties in Indonesia since 1977.

variety	resistant gene	year released
IR 26	Bph 1	1977
IR 36	bph 2	1979
IR 38	bph 2	1979
IR 42	bph 2	1979
Krueng Aceh	bph 2	1981
Cisadane	bph 2	1981
others ??		

Information complete ?? Get more data, and fill in after 1981.

Do we have data yet for this table ? If so, include. Otherwise we will refer in the text to unpublished data.

Table 4. Resistance levels and related esterase activity of field and laboratory selected populations of brown planthopper, *Nilaparvata lugens* from Indonesia.

population	compound selected	LD_{50}	R-level	esterase activity
susceptible				
lab strains				
field populations				

Figure 1. Consumption (metric tons) of pesticides in rice in Indonesia for the period 1970-1985.

Which data to use?
According to World Resources Institute:

year	metric tons
1970	1000
1974	1500
1979	7150
1984	15000

According to Helmi, head pesticide division, Ministry of Agriculture, Indonesia:

year	metric tons
1978	4018
1979	4144
1980	6413
1985	15000

U

Figure 2. Number of pesticide applications and percentage pest damage in rice in Indonesia for the period 1966-1980 (After ?? what is the source ??).

Figure 3. Insecticide use (number of applications/season) before the introduction of IPM (1986) and after the introduction of IPM (1987/88) (FAO 1988).

Running title: Untung et al.: Sustainable rice IPM in Indonesia

Section: Forum

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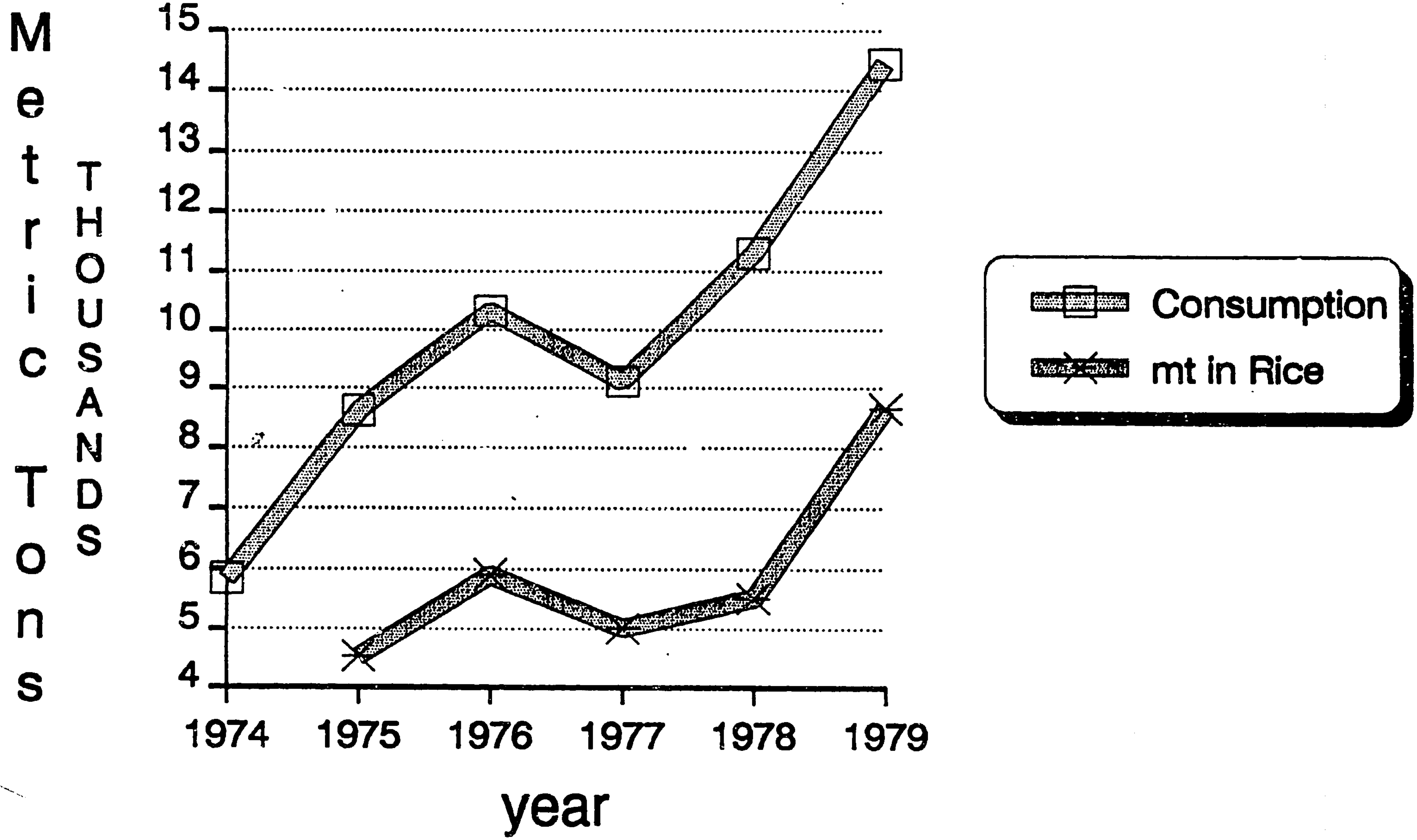
mestic Consumption of Pesticides

Indonsesia 1974 - 1979



ıdonesia: Rice Crop Damage and Frequency of Pest Control

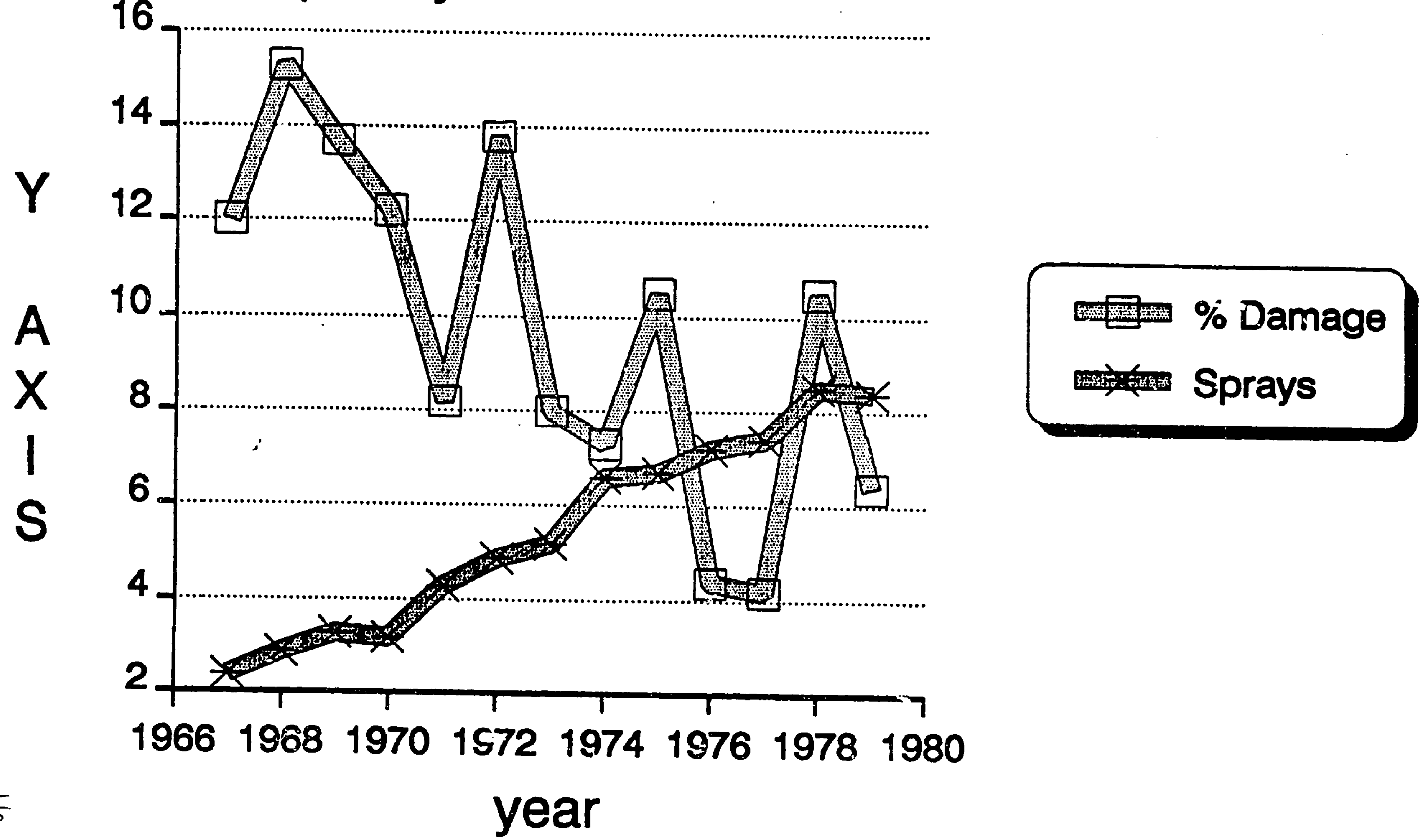
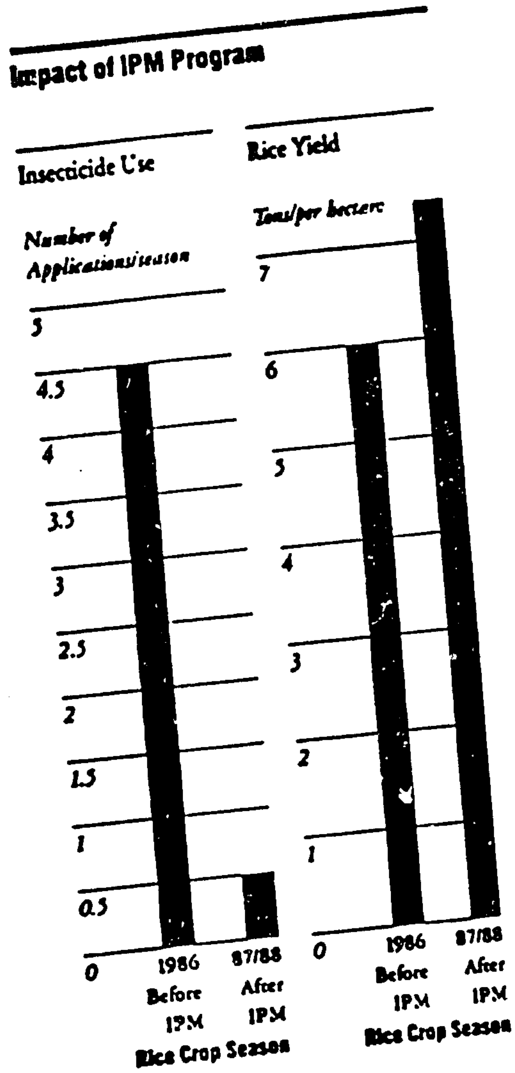


Fig. _


Impact of IPM Program
Insecticide Use
Number of Applications/season
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1986 Before IPM
87/88 After IPM
Rice Crop Season
Rice Yield
Tons/per hectare
7
6
5
4
3
2
1
0
1986 Before IPM
87/88 After IPM
Rice Crop Season

8395

RESISTANCE MANAGEMENT OF BROWN PLANTHOPPER, NILAPARVATA LUGENS, IN INDONESIA

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ABSTRACT

In the 1970's and early 1980's, during rice production intensification in Indonesia, the brown planthopper, Nilaparvata lugens Stal, became a major pest of rice and seriously threatened Indonesia's rice self-sufficiency. Factors that contributed to the increasing problems of brown planthopper were: injudicious use of pesticides which caused pest resurgence, the elimination of natural enemies and the development of resistance; breakdown of host plant resistance, and; lack of integration of different pest management tactics. In 1986, because of the increasing problems with brown planthopper, the Indonesian government declared Integrated Pest Management (IPM) the national rice pest management strategy and banned 57 pesticides for their use on rice based on expert advice. Although this IPM program is highly effective, brown planthopper will continue to adapt to pesticides and resistant rice varieties used in the current IPM program. Therefore, in order to develop a sustainable rice IPM program, pesticide and host plant resistance management strategies need to be implemented.

THE BROWN PLANTHOPPER PROBLEM

In the 1970's and early 1980's one of the major goals of rice production in Indonesia was to reach self-sufficiency [1]. Through a rice production intensification program Indonesia became rice self-sufficient by 1983. This was primarily achieved by combining high pesticide and fertilizer input with the use of high yielding rice varieties that were resistant to insect pests [1,2].

The intensification of rice production, however, caused increasing pest problems [1,2,3]. During this period, the brown planthopper, Nilaparvata lugens Stal, became a major pest of rice in Indonesia. This insect causes both direct damage to rice by feeding on the rice plants, causing 'hopperburn', and indirect damage by transmitting grassy stunt, a mycoplasma [4]. The brown planthopper was first reported as a rice pest in Indonesia in 1969, and in subsequent years there was a dramatic increase in brown planthopper populations and losses in rice yield due to damage caused by this insect [2, see Fig. 1]. From the period 1977 to 1979 alone, over 2 million hectares of rice were lost due to brown planthopper damage [1,2]. Since 1979 damage caused by brown planthopper decreased, however, brown planthopper outbreaks in 1984 and 1986 reduced rice yields nation-wide [2,3].

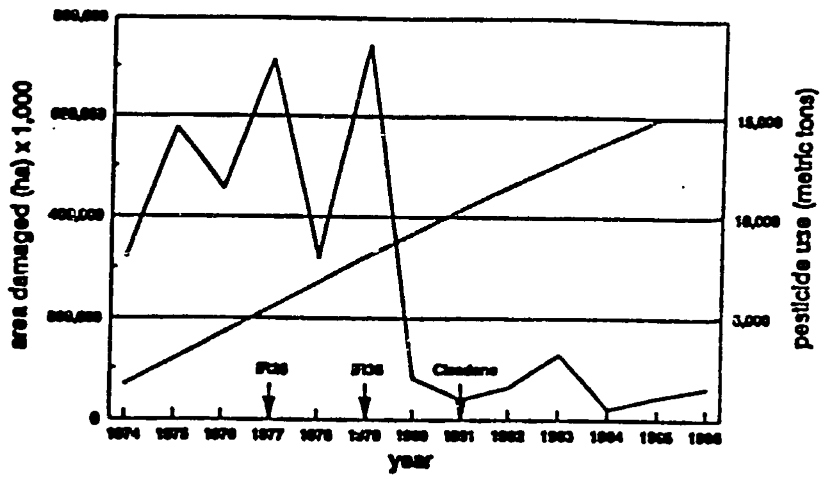

Figure 1. Economic damage caused by brown planthopper, N. lugens, (—) and the use of pesticides (—) and release of resistant rice varieties (IR26, IR36, Cisadane) for its control in Indonesia.

Strategies for controlling brown planthopper in the 1970's and early 1980's depended mainly on the use of brown planthopper resistant rice varieties and insecticides, although the use of some cultural practices were suggested to overcome the brown planthopper problem [2,5, see Fig. 1]. However, the unilateral dependence on resistant rice varieties and insecticides, to which brown planthopper was able to adapt, and the lack of integration of different pest management strategies caused brown planthopper to become a major pest in this period. The following factors contributed to the increasing brown planthopper problem;

1) Inappropriate cultural practices: the lack of crop rotation and staggered planting provided a continuous food source for brown planthopper [2,5]. Nitrogen fertilizers trigger ovipositional response in brown planthopper, and increased use of fertilizers

during the rice production intensification program led to dramatic population increases [5]. Although resistant rice varieties were available, many farmers planted old, brown planthopper-susceptible, varieties because of better taste.

2) Pesticides: three major factors contributing to the failure of chemical control have been the resurgence of brown planthopper after insecticide applications, the elimination of natural enemies of brown planthopper due to broad spectrum chemicals, and the development of insecticide resistance in brown planthopper. Resurgence, a significant increase in brown planthopper populations after insecticide treatment, was observed in Indonesia since 1979 as well as elsewhere in Southeast Asia [1,2,3,6,7]. Studies on the effect of insecticides on populations of brown planthopper on central Java indicated that all the major groups of insecticides (carbamates, organophosphates, and pyrethroids) caused brown planthopper resurgence [3,8]. These studies also indicated that the use of broad-spectrum insecticides eliminated natural enemies of brown planthopper, allowing the pest to reach damaging levels. Brown planthoppers were effectively controlled by natural enemies if no disruptive insecticides were used. The excessive use of insecticides during the rice production intensification program caused high selection pressure on brown planthopper populations, resulting in the development of insecticide resistance. Populations of brown planthopper from Java were reported to be resistant to organophosphates, carbamates, and pyrethroids [9,10], and resistance levels were related to patterns of insecticide use [10].

3) Breakdown of host plant resistance: in order to overcome the increasing problems with brown planthopper, more effort was put into the propagation and distribution of brown planthopper-resistant rice varieties in Indonesia. As early as 1967, varieties resistant to brown planthopper had been identified at the International Rice Research Institute, Los Banos, Phillipines [11]. In Indonesia, IR26 and other resistant varieties containing the Bph 1 gene, were introduced in 1977-1978 [3, see Fig. 1]. However, host plant resistance was easily broken down by brown planthopper, and resistance to these varieties did not last for more than 2 cropping seasons (less than one year), after their introduction [1]. After 1979, brown planthopper outbreaks could be controlled by the introduction of varieties containing the bph 2 gene, such as IR36 and Cisadane [3]. However, this narrow base of host plant resistance made the rice production system vulnerable to brown planthopper outbreaks. The acreage of rice fields damaged by brown planthopper increased from 19,000 ha in 1984 to 60,000 ha in 1986 [3, see Fig. 1]. The ability to breakdown host plant resistance has been related to the development of 'biotypes', based on the observations that laboratory cultures of brown planthopper obtained from field populations and selected on host plants containing different resistant genes led to the development of strains capable of

surviving host plant resistance [12]. Although some authors speculate that the occurence of biotypes in the field may even eventually lead to sympatric speciation [13], other workers conclude that biotypes are simple genetic variants rapidly selected with no mating barriers [14,15]. The ability of brown planthopper to quickly breakdown host plant resistance as well as to develop resistance to insecticides indicates that this insect is highly adaptive to selection pressure exerted through different means on the population. Researchers start to realize that control of brown planthopper solely based on the use of pesticides or resistant varieties will not be effective in the long term.

INTEGRATED PEST MANAGEMENT OF BROWN PLANTHOPPER

Based on the findings that natural enemies can effectively control brown planthopper if no disruptive insecticides are used, pilot studies were conducted in the early 1980's to implement pest control based on the conservation of natural enemies as part of a new Integrated Pest Management approach [2,3,8]. Integrated Pest Management (IPM) is a philosophy of pest control that utilizes the "best set" of management strategies, tactics and tools to limit pests below an economic threshold with mimimum environmental and socioeconomic impacts [16]. Various tools, tactics, and strategies were developed and evaluated in order to implement a more sustainable rice production system (see Fig. 2). The rice IPM strategy emphasized the use of insecticides only when needed and the use of locally acceptable resistant rice varieties. An important aspect of this program was the training of extension personnel and farmers to diagnose and monitor pest problems in the field and to make decisions accordingly. Results of these pilot studies demonstrated the feasibility of the IPM approach for larger areas of rice production in Indonesia.

Because of the increase in damage caused by brown planthopper in the mid 1980's (see Fig. 1) and the availibility of an IPM alternative, the Indonesian Government declared on November 5, 1986, by Presidential Decree 3 (Inpress 3/1986) IPM the national pest control strategy for rice [1,2]. The Indonesian legislation was based on expert advice from the Indonesian (Gadjah Mada University, Yogyakarta, and Central Research Institute for Agriculture, Bogor) and international (International Rice Research Institute and Food and Agricultural Organization, Phillippines) rice research community. The Presidential Decree emphasized that insecticides should only be used when control thresholds in effect were reached (5 brown planthoppers/tiller), thus mandating a monitoring strategy. The decree banned the use of 57 insecticides on rice because of their implication on brown planthopper resurgence. Only four compounds

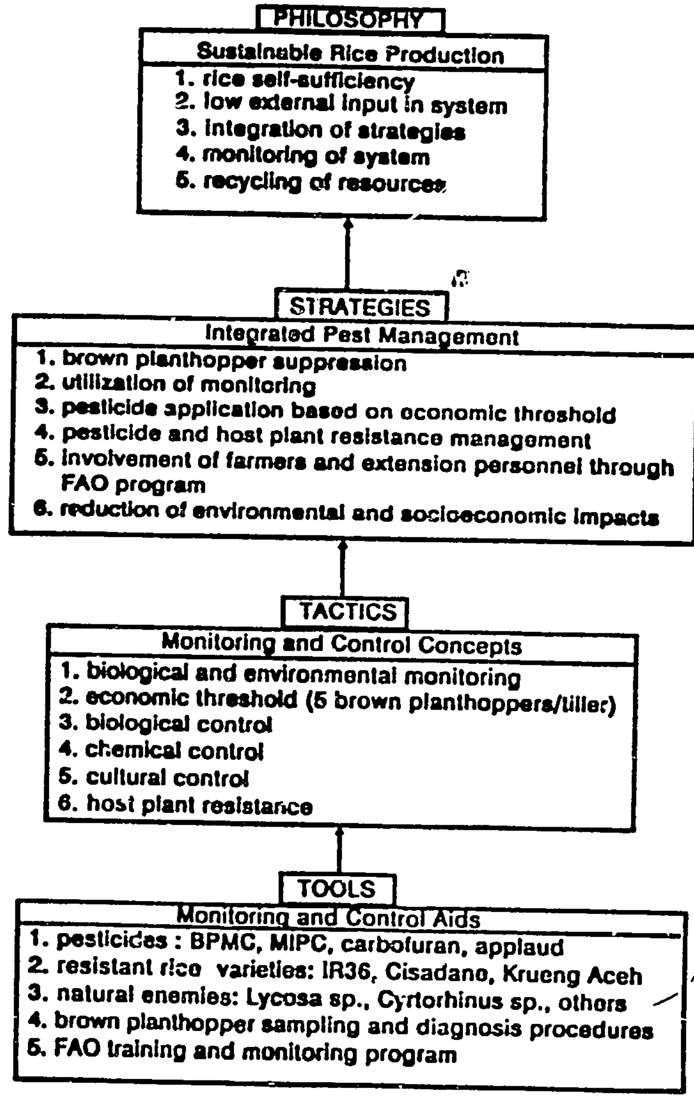

Figure 2. Tools, tactics, strategies, and philosophy of Integrated Pest Management of brown planthopper, *N. lugens*, in Indonesia.

were allowed for rice pest management, the carbamates MIPC, BPMC, and carbofuran and the insect growth regulator buprofuzin (Applaud^R). The use of brown planthopper resistant rice varieties was also required. An appropriate cropping system, including synchronous planting, rotation with non-rice crops, and a considerable free rice crop period was recommended. In order to implement this program, the Presidential Decree stated that extension personnel and farmers should be trained to conduct IPM of brown planthopper.

Presidential Decree 3 resulted in effectively controlling brown planthopper and improving rice pest management in Indonesia. The number of insecticide applications dropped from 4.5/ha in 1986 to 0.5/ha in 1988 [1]. This resulted in a reduction of insecticide costs to the farmers from 7,500 rupiah/ha in 1986 to only 2,200 rupiah/ha in 1988, even though insecticides were more expensive due to a reduction in government subsidy compared with 1986. The rice yield increased from 6 tons/ha in 1986 to 7.5 tons/ha in 1988. Throughout the introduction of IPM in Indonesia, an extensive training program of field personnel, extension workers and farmers was put in place.

RESISTANCE MANAGEMENT OF BROWN PLANTHOPPER

Although the current rice IPM program in Indonesia emphasizes the integration of various tools for pest control, resistant rice varieties as well as insecticides remain important components of the overall IPM strategy. The availibility of only 4 insecticides (MIPC, BPMC, carbofuran, and buprofezin) and 3 major brown planthopper-resistant rice varieties (IR36, Krueng Aceh, and Cisadane) for brown planthopper control, imposes a substantial selection pressure on populations of this pest. Because of the propensity of brown planthopper to quickly adapt to selection pressure exerted on populations by resistant host plants or insecticides, as indicated by strains of brown planthopper able to breakdown host plant resistance or to develop insecticide resistance, the application of resistance management is necessary. We define resistance management as a strategy within an IPM system that seeks to limit the selection for resistance alleles to major population suppression strategies such as host plant resistance and insecticides. Through resistance management one seeks to prolong the life of a pesticide or resistant host plant variety by preventing, delaying or reverting resistance development to the pesticide or ability to breakdown host plant resistance by the pest. The goal of resistance management is to implement a sustainable IPM system which allows for long term control of a pest or pest complex. Because of the importance of managing resistance in brown planthopper for overall pest control in rice, a strategy of resistance management of brown planthopper has

been developed as an initial step to implement a resistance management program in Indonesia. Figure 3 shows the different tools, tactics, and strategies of such a resistance management program.

Pesticide resistance management

An important requirement for a resistance management program is the ability to detect resistance in a population at a sufficiently early stage to reduce selection pressure. Through resistance monitoring one attempts to measure changes in the frequency or degree of resistance in time and space in a pest species. Resistance monitoring is therefore essential for the evaluation of strategies, validation of tactics, and implementation of an ongoing IPM program.

Insecticide resistance in brown planthopper in Indonesia has been mainly observed through field failure of insecticides [10]. Because of the importance of detecting resistance at an early stage, resistance monitoring techniques have been currently developed as initial steps in resistance management of brown planthopper. Toxicity bioassays, including topical application of insects, dipping of insects, and exposing insects to insecticide residues seem appropriate assays for evaluating the efficacy of pesticides. However, disadvantages of such toxicity bioassays are that only one insecticide can be tested per insect, relatively large numbers of insects are needed, and results are only known after 24 or 48 hrs. More recently biochemical assays have been developed for various insects such as aphids and mosquitoes in which the activity of detoxification enzymes can be measured in individual insects which is an indication of resistance to a certain insecticide [17,18]. Advantages of such biochemical tests are that they provide information about resistance frequencies within populations, require fewer insects, and are more sensitive and less time consuming than toxicity bioassays [19]. Studies on the biochemistry of resistance in brown planthopper from Java showed that esterases are important in conferring resistance to organophosphates, carbamates, and pyrethroids [9,10]. Therefore, biochemical assays were developed for the detection of esterase activity in individual brown planthoppers, using either a microtitre plate assay and an ELISA reader or a portable photometer set-up. The latter allows for the detection of resistance levels in populations of brown planthopper in the field. These biochemical assays are simple and easily transferred to relatively intrained field personnel and seem useful tools for resistance monitoring.

The availability of resistance monitoring techniques may allow for effective resistance management of brown planthopper in Indonesia in the future. The following strategies supported by laboratory data and/or field experience have been generally considered useful in managing resistance in arthropods [20] and will be evaluated for brown planthopper during the development and implementation of a

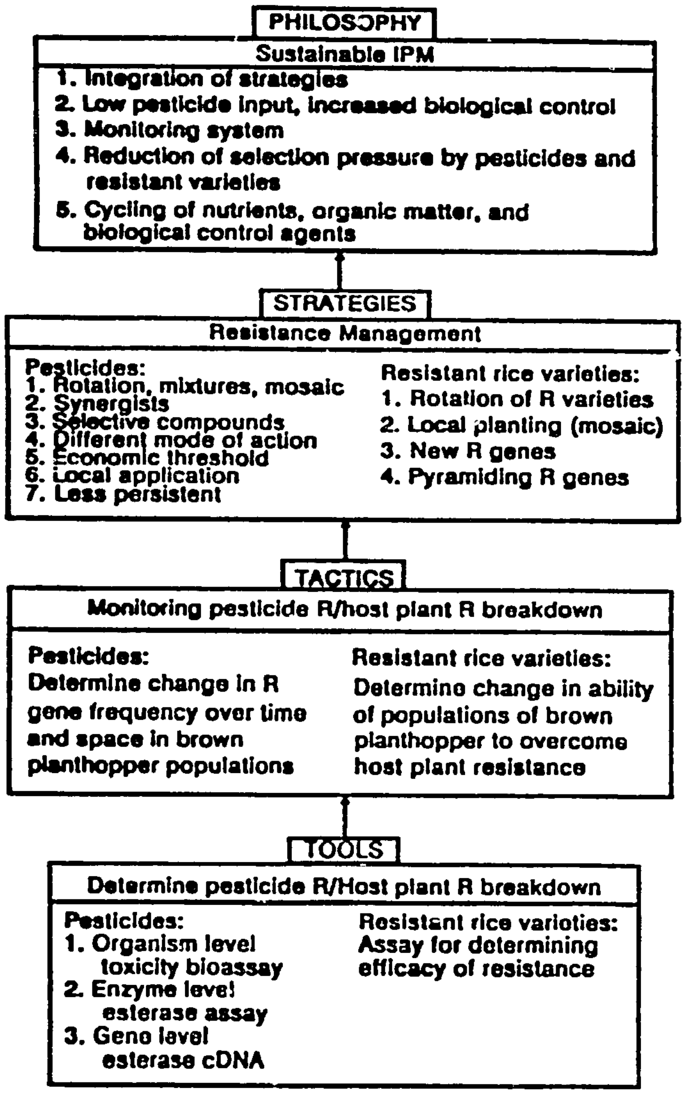

Figure 3. Tools, tactics, strategies, and philosophy of Resistance Management of brown planthopper, N. lugens, in Indonesia.

resistance management program: local rather than areawide insecticide applications; treatments only when the economic threshold is reached; use of less persistent insecticides; mixtures, rotations or mosaics of applications of the carbamates MIPC, BPMC, carbofuran and the insect growth regulator buprofezin; use of synergists; use of selective compounds to protect natural enemies; use of compounds with different mode of action.

Host plant resistance management

Regarding host plant resistance management, monitoring for the ability to breakdown the resistances of different resistant varieties in field populations of brown planthopper under standardized conditions will be an essential component. Strategies that may reduce the speed at which brown planthopper will break down host plant resistance are the following: rotation of resistant varieties, i.e. rotation of different resistant genes; more local than areawide planting of a certain resistant variety, i.e. host plant mosaic; pyramiding existing resistant genes from different varieties into a new variety; introduction of new convential selected resistant genes (laboratory biotypes of brown planthopper may be useful for genetic screening of new resistant varieties). Biotechnology also offers the possibility of creating new resistant varieties, but there is no reason a priori to assume that these exotic genes could not be overcome by brown planthopper biotypes.

Future perspectives

Because of the great demand for rice, rice production in Indonesia will continue to be based on high-input intensive farming. As part of the current IPM program, the use of insecticides as well as resistant rice varieties will therefore continue, thus selection pressure will continue and brown planthopper populations will eventually adapt. However, it is hoped that the integration of insecticide and host plant resistance management strategies will result in stable control of brown planthopper in Indonesia. Because, brown planthopper is a highly adaptive species, we believe that continuous monitoring and strategy alteration will be necessary for brown planthopper management. In our view, resistance management is therefore an essential strategy within a sustainable IPM approach to brown planthopper management.

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