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Nonpesticide Methods for Controlling Diseases and Insect Pests

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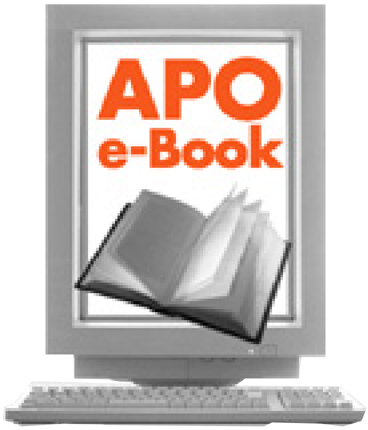

(02-AG-GE-SEM-06) Report of the APO Seminar on Nonpesticide Methods for Controlling Diseases and Insect Pests held in Japan, 10–17 April 2002

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NONPESTICIDE METHODS FOR CONTROLLING DISEASES AND INSECT PESTS

2005
Asian Productivity Organization
Tokyo

Report of the APO Seminar on Nonpesticide Methods for Controlling Diseases and Insect Pests held in Japan, 10-17 April 2002 (02-AG-GE-SEM-06).

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FOREWORD

The effective control of pests such as weeds, insects, and diseases is critical to assuring healthy crops and enhancing agricultural productivity. Various pest control methods have been adopted. One is the use of chemical pesticides, which is still the most common method in many APO member countries because it is cheap and often very effective. The effectiveness of chemical pesticides in protecting crops, however, has masked the negative impacts associated with their use. For farmers, the most serious are the acquisition of pest resistance to the chemicals, secondary pest outbreaks, and health hazards associated with the application of chemicals. For consumers, the main problems are pesticide residues in food and environmental degradation. Because of such concerns, there is a great deal of interest in applying nonpesticide control methods. The success of nonpesticide approaches to controlling crop pests requires concerted efforts by the parties concerned, ranging from increased awareness of the method by farmers, policy shifts on plant protection, to better labeling of agricultural products for traceability and informed consumer choice.

To review the present use of nonpesticide methods for controlling crop pests in member countries, discuss issues and problems in promoting their use, and formulate measures to address them, the APO organized the seminar on "Nonpesticide Methods for Controlling Diseases and Insect Pests". This volume is a compilation of the papers and proceedings of the seminar. I hope that it will serve as a useful reference on the subject in APO member countries and elsewhere.

The APO is grateful to the Government of Japan for hosting the seminar, in particular to the Ministry of Agriculture, Forestry and Fisheries for providing financial and technical assistance, and to the Association for International Cooperation of Agriculture and Forestry for implementing the program. Special thanks are due to Dr. Peter A.C. Ooi for editing the present volume.

Shigeo Takenaka
Secretary-General

Tokyo
August 2005

SUMMARY OF FINDINGS

INTRODUCTION

The Seminar on Nonpesticide Methods for Controlling Diseases and Insect Pests which was organized by the Asian Productivity Organization (APO) and hosted by the Government of Japan was held in Tokyo from 10 to 17 April 2002. The Association for International Cooperation of Agriculture and Forestry (AICAF)* with financial and technical cooperation of the Ministry of Agriculture, Forestry and Fisheries (MAFF) implemented the program. Sixteen participants from 12 member countries and five resources speakers from: FAO Regional Office for Asia and the Pacific, Bangkok; Secretariat of the Pacific Community, Fiji; National Agricultural Research Center, Japan; and National Institute for Agro-Environmental Sciences, Japan, participated in the seminar.

The objectives of the seminar were to: 1) review the present situation in using nonpesticide methods for controlling crop pests in member countries; and 2) identify issues and problems in promoting the use of such nonpesticide methods and formulate measures for addressing such issues and problems.

The seminar consisted of the presentation of resource papers and country papers, workshop sessions and field visits to the Ibaraki prefecture. The topics covered by the resource papers were: 1) Some Nonpesticide Methods for Managing Crop Insect Pests – Present Status, Issues and Strategies; 2) Nonpesticide Methods for Sustainable Crop Disease Management in the Asia-Pacific Region: Present Status, Issues and Strategies; 3) Biological Control of Vegetable Pests with Natural Enemies; 4) Nonpesticide Methods for Managing Crop Weeds in the Asia-Pacific Region – Allelopathic Cover Crops; and 5) Control of Plant Virus Disease by Cross Protection in Japan. While the country papers focused on current status of using nonpesticide methods for controlling crop pests in participating member countries.

In the workshop participants identified the major issues and problems in promoting the use of nonpesticide methods for managing crop pests in the APO member countries; and suggested strategies/ solutions and action plans to address such issues.

The seminar highlights are presented below:

RESOURCE PAPERS

Some Nonpesticide Methods for Managing Crop Insect Pests – Present Status, Issues and Strategies (Dr. Peter A. C. Ooi)

The use of chemical pesticides has been dominating the plant protection since1950s. This parochial approach has led to neglect in the study of alternative pest management methods and increased pest outbreaks in oil palm, rice, vegetable and even tea. However, with advances made in Integrated Pest Management (IPM) in Asia in the last decade, there is growing interest in nonpesticide methods. Two main types of nonpesticide methods are discussed in this paper, namely; biological control and physical and cultural practices. Case studies demonstrated that promoting indigenous and ecological knowledge encouraged development of nonpesticide methods.

The first case study of the diamondback moth demonstrated the need to understand that the insect was an introduced pest. It lacked effective natural control factors. This understanding encouraged the importation of effective biological control agents. Following establishment of parasitoids in the cooler highlands, the impact of the parasitoids can only be realized by crucifer farmers if they stop using chemical insecticides. This realization necessitates a non-formal education approach promoted by the Food and Agriculture Organization (FAO) of the United Nations. This approach is better known as the IPM Farmer Field School (FFS).

* It was reconstituted to the Japan Association for International Collaboration of Agriculture and Forestry (JAICAF) in 2004.

In the second case study, rice farmers discovered that arthropod predators feed on rice insect pests. This knowledge helped farmers conserve these friends of farmers by avoiding use of chemical insecticides in their crop. Even for other types of biological control farmer education helps optimize the impact of these natural enemies.

The third case of using nonpesticide methods for managing crop insect pests was reported by a group of rice farmers in the district of Indramayu, West Java, Indonesia. By learning that the white stem borer aestivates during a prolonged drought period and such diapause is broken by the onset of rainy season, farmers were able to plan an avoidance strategy. They learned to monitor the time of peak flight and only plant rice after that period. This would prevent pest outbreaks and avoid the development of secondary pest outbreaks following use of chemical insecticides.

In the case of the cocoa pod borer in Southeast Asia, farmers need to understand that the cocoa moth lays eggs on the fruit surface. The larvae burrow into the fruit often resulting in unmarketable pods. Farmers learned that wrapping young fruits in clear plastic sleeves prevented laying of eggs and hence, the pod damage. This method is very effective when integrated with ecological harvesting. A most effective method to manage the fruit and shoot borer of brinjal in Bangladesh is to regularly remove and destroy all infested fruits and shoots. Above examples point to the need to:

* adopt a more ecological approach towards pest management
* educate farmers about the agro-ecosystem using a non-formal education approach
* encourage farmers to discover non-chemical methods of pest management
* develop a more environmentally sound policy for insect pest management.

Nonpesticide Methods for Sustainable Crop Disease Management in the Asia-Pacific Region: Present Status, Issues and Strategies (Dr. D. G. Hunter)

The Asia-Pacific region is faced with the need to increase agricultural productivity dramatically in order to feed a rapidly growing population. This will not be achieved by increasing the area under production because of constraints of land and water. In the past crop productivity increases have been achieved through the addition of chemical inputs. Dramatic advances in pest management were made using chemical pesticides. However, increased awareness of the adverse environmental, ecological and health impacts of pesticide methods means that new nonpesticide approaches will be required to achieve pest management and to contribute to increased crop productivity.

This paper examines the use of nonpesticide methods for crop disease management. It takes the position that an effective quarantine service is the building block for nonpesticide crop disease management. This can greatly reduce the number of disease problems that a country or region must deal with. The Pacific is rather fortuitous in this context given the natural barriers to plant and disease movement that exist. However, there is much that can be done to strengthen national quarantine services and this is highlighted. The range of other appropriate nonpesticide approaches – pathogen-free planting material, cultural practices, biological control and host plant resistance – are reviewed in depth and the success of methods in the Asia-Pacific region highlighted. Constraints to future development and success are discussed. Finally, the role and impact of biotechnology in the region is discussed.

Some countries of the region have put in place frameworks for the development and application of biotechnology and there is some evidence to indicate that they are beginning to reap the benefits of this. The impact of biotechnology in other countries has been considerably less and there are a number of technical, environmental and socioeconomic issues that need to be addressed if this is to be changed. It is stressed that no one approach will offer a solution rather a range of options need to be considered and integrated in order to achieve sustainable management of crop diseases.

Biological Control of Vegetable Pests with Natural Enemies (Dr. Eizi Yano)

Use of natural enemies or biological control is essential in integrated pest management (IPM) of vegetables pests. Augmentative release of natural enemies is the key technology in IPM of greenhouse pests. On the other hand, conservation of indigenous natural enemies is crucial in IPM of vegetable pests in the field. Since chemical control of pests in greenhouses is not easy and is always accompanied by the risk of development of resistance to pesticides, biological control has been developed as an alternative control measure in western countries. More recently biological control is also expected to become the basic system of pest control in Japan for safe and laborsaving crop production in greenhouses.

Ten arthropod natural enemy species have become available for commercial use in greenhouses in 2002. Imported species such as *Phytoseiulus persimilis* and *Encarsia formosa* have been commercialized first, followed by commercial use of indigenous species. Indigenous *Orius* spp. are expected as promising biological control agents for thrips control. Extreme temperature conditions in greenhouses, delay in release, effect of chemicals and low level of tolerance of pest damage for some crops are major limiting factors in use of natural enemies in commercial greenhouses.

Cultural control measures, such as field hygiene or prevention of pest immigration, are fundamental for effective control of pests. Since the number of available natural enemies for biological control is limited and the technical development of the use of other natural enemies is still at preliminary stage, integrated use of natural enemies and other control measures is essential for commercial application. Suitable crops for integrated control using natural enemies can be assumed to be the crops attacked by a small number of serious pests, the crops for which a low level of pest damage is tolerable, and the crops requiring insect pollinators. Tomato, strawberry and sweet pepper are three good crops for developing integrated control in Japan.

Recently some trials have been carried out to develop IPM of vegetables in the field. These are based on conservation of indigenous polyphagous predators using selective pesticides. As a case study, conservation of *Orius sauteri* to control *Thrips palmi* on eggplants in the field is explained. After evaluating the suppressive potential of *O. sauteri* against *T. palmi* with insecticidal check methods, usefulness of a selective pesticide, pyriproxyfen, for integrated use with *O. sauteri* was demonstrated. An IPM system for all major pests of eggplants in the field was developed later by using several selective pesticides or using non-selective pesticides in a selective way. Conservation of surrounding vegetations as reservoirs of *Orius* spp. is also emphasized.

Nonpesticide Methods for Managing Crop Weeds in the Asia-Pacific Region
– Allelopathic Cover Crops (Dr. Yoshiharu Fujii)

Abandoned paddy fields (APF) are increasing in number because of the increasing aging farmers and industrialization in Japan. Number of APF has reached nearly 5 percent, including fallow fields regulated by the government for overproduction of rice. These fields tend to grow many weeds and many fields have been allowed to grow weed-trees cover on the surface of land. The land recovery is difficult and requires much investment to restore to the original paddy fields.

Our group is engaged in a search for allelopathic plants in order to determine allelopathy and its mechanism. In the course of this study, we developed some new methods to discriminate and identify allelopathy from other competitive factors such as nutrients, light and water. We have reported allelopathy in velvet bean (*Mucuna pruriens* var. *utili*), hairy vetch (*Vicia villosa*), medicinal plants and others.

Cover crops with allelopathic activity are recommended for nonpesticide weed control. Hairy vetch for temperate region and velvet bean for tropical and subtropical regions are the most practical allelopathic crops. Other allelopathic plants with natural bioactive chemicals were also recommended for the future use.

1. ***Introduction of Hairy Vetch for Temperate Region in Asia***

Allelopathic cover crops are the most promising application of allelopathy to weed control in abandoned fields, now increasing to 5-10 percent of the cultivated fields in Japan. To access the allelopathic activity, new procedure for the specific bioassay referred to as the "Plant Box Method" and the "Sandwich Method" was developed. Using these methods, the candidates for cover crops were evaluated. Leguminous cover crops such as hairy vetch (*Vicia villosa*), and gramineous cover crops such as oats (*Avena sativa*), rye (*Secale cereale*), certain cultivars of wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) were found promising. From the screening by bioassay, 39 species were selected for field tests. Fall-sown cover crops are effective when compared to spring-sown cover crops. The promising candidates were fall-sown cover crops such as hairy vetch, rye, wheat, oat, grass pea, and mustard. Especially, hairy vetch was most promising for the weed control in abandoned fields because of its ability to die off during summer season to make thick straw-like mulch. Recently we isolated a potent allelochemical from hairy vetch, and it was cyanamide, a well-known chemical fertilizer with insecticidal, fungicidal and herbicidal activity. This is the first finding of cyanamide from nature.

2. ***Introduction of Velvet Bean for Tropical and Subtropical Regions***

Among the 65 plants tested for allelopathic properties, velvet bean (*Mucuna pruriens* var. *utilis*) was found to be the most promising. It is recognized that this tropical legume grown for green manure, has a special ability to smother weeds. The field test showed that test plots containing velvet bean had the smallest weed population compared to that of tomato, egg plant, upland rice and fallow conditions. High Performance Liquid Chromatography (HPLC), and seed germination and seedling growth bioassays showed that the growth inhibiting substance was L-3,4-dihydroxyphenylalanine (L-DOPA). L-DOPA is a well-known precursor of neurotransmiter dopamine, and an intermediate of many alkaloids. This study revealed that velvet bean leaves and roots contained large amount of L-DOPA (about 1 percent of the fresh weight). L-DOPA suppressed the growth of some broad leaf weeds, while little effect was observed on grass. It was concluded that in addition to its usefulness as a green manure, velvet bean could be utilized as an allelopathic crop to control weeds.

Control of Plant Virus Disease by Cross Protection in Japan (Dr. Shinya Tsuda)

Cross protection means that plants infected with one strain of a plant virus are protected from effects caused by a related strain of the same virus. If the first virus is mild and the second virus is severe, plants manually infected with the first virus can be protected from more severe effect by the second strain. Thus, cross protection in plants is similar to the vaccination widely used against human or animal infectious diseases, but the mechanism of protection will be totally different between the two.

In Japan, much work has been done in order to select or to produce safe and efficient attenuated viruses. Several attenuated viruses, such as L11A, are currently used in real fields. Well-characterized attenuated viruses do not give harmful influence to the ecosystem nor cause environmental pollution. We consider that well-selected attenuated virus is one of the safe and effective tools for environmentally sustainable agriculture. This report introduces the present status, problems and future prospects on control of plant virus disease using attenuated virus in Japan.

1. ***Current Status on Research Work for Attenuated Virus in Japan***

Numerous attenuated viruses have been reported since 1991. For practical use of attenuated viruses with ease, we consider that attenuated viruses would have to satisfy the following conditions:

i. Attenuated viruses cause very mild symptoms and very little reduction in yield and quality of the target crop, if any.
ii. Throughout the growing period, mutation back to a virulent type will not occur and protection level will not decrease.
iii. By mixed infection with the attenuated virus and other virus/es, plant will not be damaged worse.
iv. An easy and efficient inoculation method must be established.

If a newly isolated attenuated virus satisfies all of these conditions, it will be in a large-scale use immediately with ease. Methods for obtaining and improving attenuated viruses are divided into four categories.

i. The search for naturally occurring mild strains.
ii. Treatment of virulent strains by high or low temperature, treatment with mutagens such as nitrous acid, or with ultraviolet.
iii. Exchange of RNA component(s) between distinct two strains so as to produce a mild strain or to restrict its host range.
iv. Addition of satellite RNA (sat-RNA) or defective interfering RNA (DI-RNA) to virulent strains so as to be attenuated.

2. ***Current Status in Field Application of Attenuated Virus***

In Japan, five viruses of four major vegetables and one important group of fruit are successfully and efficiently controlled by attenuated viruses. They are symptomless mutants of tomato mosaic virus (ToMV), tobacco mosaic virus (TMV), cucumber green mottle mosaic virus (CGMMV), soybean mosaic virus (SMV) and citrus tristeza virus (CTV). At present original inoculums of attenuated viruses are distributed through non-profit making organizations such as prefectural experimental station in all cases after confirming absence of virulent strains.

3. ***Problems and Future Prospects of Biological Control Using Attenuated Viruses***

Well-selected attenuated viruses already under practical application are efficient for control of virus diseases of crops in Japan, and will cause only very little damage to surrounding plant, insect and animals, if any. Until now, no claims have been raised on attenuated viruses in Japan.

Attenuated viruses already in a large-scale use have at least one of the two features. One is a rather restricted host range, and another is non-transmissibility by vectors (aphids, nematodes, fungi, etc.) So far not so many attenuated viruses are under practical use even in Japan. The barriers for wider application and more viruses will be as follows:

i. One attenuated virus is normally applicable to only one crop.
ii. Selection of effective attenuated virus is elaborated and tedious, since no established simple schematic procedures have been found. Therefore, isolation of good attenuated virus depends on luck.
iii. Attenuated virus is not protected under patent, so far no private company will keen to isolated attenuated viruses.

Recent prominent advance in biotechnology on plant virology will introduce new schematic procedures for isolation of useful attenuated virus. Transgenic plants carrying cDNA of a coat protein gene of a virus with an appropriate promoter bare resistance to the virus. Transgenic plants harboring cDNA of sat-RNA also become resistant to the helper virus. In the future, attenuated virus will become an immediate remedy to the sudden outbreak of detrimental plant virus, while transgenic plant will become a long-time lasting remedy to it.

In Japan, attenuated viruses are now in demand for protection of vegetative propagated virus-free plants (sweet potato, yam, taro and bulbous flowers). By inoculation of attenuated viruses to such plants prior to release to the open field, virus-free plants can be protected from the shock of virus infection. Without this inoculation, plants will be damaged and will deteriorate within a few years.

COUNTRY PAPERS

The participants were given guidelines to prepare their country papers and these included:

* discuss current status of using nonpesticide methods for controlling crop pests
* explain government policies and programs on use of nonpesticide methods
* give a brief account of issues and problems in using nonpesticide methods
* suggest measures for effective and efficient use of nonpesticide methods.

This summary reviews the contents of the papers circulated during the seminar together with the presentations made in the light of the above guidelines.

Bangladesh (Md. Salequr Rahman)

Agriculture contributes about 30 percent of the country’s GDP. Rice crop covers about 80 percent of cultivable land. One of the major constraints to increasing agricultural production in Bangladesh is insect pests, diseases, rodents and other vertebrate pests that cause serious yield loss (estimated at 10-15 percent). In Bangladesh, chemical control has been the primary method of pest control. Use of chemical pesticides was increasing up to 1999. Due to negative impacts of chemical pesticides, at present Department of Agricultural Extension, under the Ministry of Agriculture, Government of Bangladesh, and different donor agencies are supporting to disseminate nonpesticide methods to farmers for controlling insect pests and diseases. However, still only 1.85 percent of farmers in Bangladesh use nonpesticide method. These include action of biological control agents, use of tolerant varieties, use of physical/mechanical methods and microbial agents. Success of Farmer Field School (FFS) in educating farmers in Bangladesh to conserve natural enemies in rice was also highlighted. Some of the problems are listed in Annex. Suggested measures for effective use of nonpesticide method are also given.

Republic of China (Dr. Tze-chung Huang)

With improvement of social and economic situation, food safety, animal and plant health, environmental protection and conservation have become great concern of the general public and important indicators of the quality of living. Taiwan has warm and humid climate that is suitable for occurrence of plant insect pests and diseases. Farmers in Taiwan are used to controlling plant pests with pesticides that might result in problems of chemical residues, pesticide resistance and environmental pollution. To minimize negative effects caused by the use of chemical pesticides, plant protection institutions have been undertaking intensive research and extension of nonpesticide methods since early 1970s. The top authority of plant protection, Council of Agriculture (COA) has set the development and extension of nonpesticide method as a national strategic plan since 1984. Being aware of the significance of nonpesticide method, Bureau of Animal and Plant Health Inspection and Quarantine (BAPHIQ), established in 1998, has put great emphasis on supporting and coordinating research and extension projects on promoting such methods. Over the past few years, awareness of nonpesticide method has been promoted, and many techniques have been brought into extensive application resulting in satisfactory outcomes. Such methods include action of biological control agents (classical, inundative and conservation) for arthropod pest management and a variety of nonpesticide method for plant disease control. To continue to promote application of nonpesticide method, some important issues to be further addressed are: integration of nonpesticide method into practical IPM models to make farmers willing to adopt, formulation of nonpesticide agents in commercial production to produce them at low cost and high efficacy, and influence of nonpesticide method (especially imported biological control agents or the agents that are genetically engineered) on ecosystem.

India (1) (Dr. Carl O. Rangad)

The presentation focused on present status of different nonpesticide methods, and success stories regarding the use of nonpesticide method. India produces 201.6 million mt of food from an area of 124 million ha with a productivity of 1,625 kg/ha. Pests and diseases are causing huge damage to various crops. Normally farmers depend on chemical pesticides for controlling insect pests and diseases. Use of chemical pesticides has led to many environmental and health hazards apart from resistance developed by the pests against the chemical pesticides. Several nonpesticide method such as mechanical, physical, and cultural control measures employed to control insect pests and diseases are discussed. Other nonpesticide method included varieties resistant/tolerant to pests, biological control methods and transgenic plants. The paper highlights many success stories in nonpesticide method. Issues, problems and suggestions to promote nonpesticide method are consolidated with the second presentation from India in Annex.

India (2) (K. J. Devendrappa)

The presentation focused on government policies and programs, issues and problems in nonpesticide method and suggestions for promotion of nonpesticide method in India. Plant protection activities in the States and Union Territories mainly fall under the purview of the States/Union Territories. However, Central Government has an advisory role including training apart from being directly responsible for plant quarantine and the locust control. IPM in India is funded by the Central and State Governments, and international organizations such as FAO, UNDP, ADB-CABI (Commonwealth Agriculture Bureau International). Nonpesticide method is an inbuilt component of crop improvement research and its various disciplines are incorporated in the crop research institutes as well as All India Coordinated Improvement Projects of the Indian Council of Agricultural Research (ICAR). In addition a National Center for Integrated Pest Management along with regional centers all over the countries has been established. Similarly a Project Directorate of Biological Control has been created. The Department of Biotechnology is also providing financial assistance to various organizations for developing and producing biopesticides, biogas, etc. Traditionally pest control was dominated by chemical pest control. However, the Government of India has tried to introduce other alternative methods such as setting up of biocontrol laboratories all over the country in the light of adverse externalities associated with use of pesticides. The State governments have intensified their efforts to popularize IPM through demonstrations and training of the extension personnel and farmers. The Central Government, ICAR and State agricultural universities are extending technical assistance. Issues, problems and suggestions to promote nonpesticide method are consolidated with the first presentation from India in Annex.

Indonesia (1) (Sugeng Hartadi)

Pest infestation is the main risk in the promotion of food production in Indonesia. Many insect pests and diseases damage the crops, especially main staple food crops such as rice, soybean and maize. Intensive use of chemical pesticides during the promotion of food production program was encouraged in 1960s and 1970s. To overcome negative effects of such use of chemical pesticides, Government of Indonesia has decided to implement an environmentally sound IPM technology. National policies to strengthen the nonpesticide method for controlling pests have been decided in terms of promoting the crop protection system. Successful implementation of IPM in Indonesia resulting from the development of extensive infrastructure and institutions was discussed. Implementation of nonpesticide method was described for insect pests and diseases and included use of pest-resistant varieties, enforcement of even cropping pattern and growing season regulation, crop and varietal rotation, mechanical methods and biological control. Main constraints in promoting nonpesticide method for controlling crop pests include resistance breakdown of the variety, complicated procedure of biological agent application, inadequate coordination among all the stakeholders, slow effect of biological agent, inadequate supply of healthy seed and seedings, among others. To overcome various constraints empowerment of crop protection system as a whole was suggested. Some constraints in promoting nonpesticide method as well as the solution to the problems are summarized in Annex.

Indonesia (2) (Sutarto Alimoeso)

Biological control methods used by farmers in Malang, East Java were described. Problems encountered in implementing nonpesticide method included the perceptions of slow action, nonpesticide method being not practical and unable to meet demands of consumers for blemish free produce. Aggressive promotion of chemical pesticides by big chemical companies was also highlighted. Mr. Hartadi however did not prepare the country paper for circulation.

Islamic Republic of Iran (Dr. Gholam A. Abdollahi)

More than 18.5 million ha of land is under arable farming, nearly 12 million ha are under forests, and approximately 90 million ha are rangeland. Farmers produce a variety of food, forage and horticultural crops. Different pests cause huge damage to the crops (sometimes up to 30 percent). To address national issues in plant protection comprehensively and effectively, Government of Iran established the Plant Pests and Diseases Research Institute (PPDRI) in 1974 by merging several units in the provinces. The PPDRI operates under the auspicious of the Agricultural Research, Education and Extension Organization of the Iranian Ministry of Agriculture. Use of chemical pesticides for controlling crop pests is common. For instance, still aerial spray of chemical pesticides is practiced in Iran. In response to the international developments and serious consideration of safe agricultural production, national program on “Optimizing the Usage of Pesticides and Fertilizers” (OUPF) was started in 1995 that led to substantial reduction in use of the chemical pesticides. Similarly strategic IPM projects under PPDRI aim at enhancing productivity of several crops in an eco-friendly and sustainable manner during the next five years. Objectives and tasks of the PPDRI as well as of OUPF and IPM projects are discussed. The need to convince policymakers to support IPM activities that involves farmers was emphasized.

Malaysia (Dr. Mohd Norowi Hamid, Mohd Roff Mohd Noor and Lo Nyok Piang)

Agriculture sector remains an important part of the Malaysian economy. A large proportion of crop yield is lost because of pest infestations. Several methods of pest control have been adopted to minimize such crop losses. Most common method to control crop pests is use of chemical pesticides that has led to two main problems of pesticide residues in food and the hazardous to applicators. Nowadays common priority areas in plant protection research are development of resistant varieties and biological control. The government has formulated various policies to encourage the adoption of nonpesticide methods to manage pest infestation. Nonpesticide method used to control insect pests, plant disease and weeds are described. Paper also highlights success stories on nonpesticide method use. Main issues and challenges in use of nonpesticide method include lack of appreciation for using nonpesticide method, inadequate biological and ecological research, lack of proper observation, and over-dependence on chemical pesticides. For crop protectionist, it is a challenge to develop sustainable ways of managing crop pests. Paper also suggests the future directions for promoting use of nonpesticide method for controlling crop pests. Some problems and suggested future directions are summarized in Annex.

Mongolia (Davaasambuu Undarmaa)

Mongolia is characterized by long, severe winter seasons and short cropping period that makes crop production difficult. Crop production is very young in Mongolia and is characterized by low productivity. Another main constraint to crop production is huge damage caused by insect pest, disease and rodent infestation. To minimize such damage chemical pesticides imported from other countries are in common use. Recently it has been realized that chemical methods alone are unable to control increasing infestation by crop pests as well as they are expensive and have negative impact on users and environment. Therefore, various nonpesticide methods such as physical, mechanical, cultural and biological control are introduced. Mongolian agriculture is poised to move forward in using nonpesticide method to achieve sustainability in agriculture but for implementation of some nonpesticide methods such as biological control it lacks the modern technology and know-how.

Pakistan (Dr. Abdul Khaliq)

Agriculture contributes about 25 percent of the national GDP in Pakistan. Agriculture is characterized by low productivity of various crops. One of the most important constraints in enhancing crop productivity is the huge crop damage caused by insect pests, diseases and weeds. Use of chemical pesticides is common to control pests especially in crops such as cotton, a major cash crop of Pakistan. The development of resistance in *Helicoverpa armigera* and *Bemisia tabaci*, the important cotton pests, is posing a serious threat to the cotton growers in Pakistan. The situation warrants a shift from chemical to nonpesticide methods of pest control such as cultural, mechanical, physical and biological. These nonpesticide methods are discussed. Besides nonpesticide methods for plant diseases and weeds are described. Biological control of some insect pests has been proved very successful in sugarcane, another cash crop of Pakistan. The public sector is trying to establish the IPM strategies for control of pests through research and motivating the farmers. Some existing legislative measures to suppress pest population through nonpesticide method are removal of crop stubbles in case of sugarcane, cotton, rice, maize, etc. to kill the hibernating larvae. Moreover farmers are not allowed to sow rice nursery before 20 May and transplant that after 7 August. Major issues/problems in promoting use of nonpesticide method for managing crop pests are: lack of education and training on nonpesticide method application; pesticide residues in food products; little or no access of small farmers to IPM technologies; low efficacy and higher prices of biopesticides as compared to pesticides; and lack of awareness among consumers on benefits of green products, among others. Some issues, problems and suggestions to promote nonpesticide method are summarized in Annex.

Philippines (Dr. Pio A. Javier, Rizaldy G. Bayot and Flor V. Bariuan)

About 30 percent of Filipino farmers use nonpesticide methods (NPMs) such as biological, cultural and physical methods for controlling crop pests. Conservation of respective existing natural enemy population is the best strategy to reduce pest population in rice and corn ecosystems of Philippines. Different NPM for weed management in rice and corn are also discussed. Similarly NPMs for managing insect pests in crucifers and mango and for controlling plant diseases in onion and other vegetables are highlighted. Problems associated with the use of NPM for controlling pests include specificity and delayed action of biological control agents, stringent requirements for classical biological control, laborious and time-consuming cultural methods, high cost of labor, etc. Promotion of NPM would require strong government support in the form of capacity building, premium prices for pesticide-free products, etc. Some of the problems faced and suggested solutions to promote NPM are given in Annex.

Sri Lanka (1) (Dr. Fazal Sultanbawa)

Agriculture accounts for 20 percent of GDP in Sri Lanka. Paddy, tea, rubber and coconut are the major crops grown on an area of 1.2 million ha. Several nonpesticide methods for insect pest, plant disease and weed control are practiced in Sri Lanka. For insect pest control, some of the nonpesticide method used include biological, pheromone traps, light traps, organic repellants, and pest-resistant varieties. Success stories on use of biological agents to control coconut pests, insect-proof nets to control pests of high-value crops such as flowers and seeds, pheromone traps to control fruit fly in mango, among others are discussed. Major constraint in introduction of biological control agents is sole dependence on government institutions that are too slow to meet the growing demand of commercial agriculture for import of suitable biological agents from other countries. Various nonpesticide methods for managing plant diseases (resistant varieties, control of vectors by sticky-yellow polythene strips, aphid-proof netting, solarization) and weeds (polythene mulches, cover crops, mechanical weeders) have been used successfully in different crops. The role of private sector involved in plant protection with special reference to nonpesticide method for managing crop pests was also explained.

Sri Lanka (2) (Dr. C. Kudagamage)

Pests are considered as one of the main constraints to increase productivity of agricultural crops in Sri Lanka. Often pesticides are used as the first line of defense for managing agricultural pests. Several research and development efforts have been undertaken in the past several decades to promote NPMs in Sri Lanka. The most successful NPM is exploitation of plant resistance in rice. However, development of biotypes and lack of screening techniques for identification of resistance are major constraints to utilization of varietal resistance. Paper also explains successful stories about use of NPM for managing pests in tea and coconut. Use of plant products as water extracts, decoction and smoke and cultural methods for controlling pests is also mentioned. Government policy statement is that dependence on chemical fertilizers and agrochemicals will be reduced through adoption of measures such as IPM and other agronomic practices. Some of the issues/constraints to promote use of NPM include lack of information on NPM, poor institutional coordination, inadequate number of extension workers, lack of agricultural support services, less availability of materials needed for NPM, conditioning of farmers by the commercial pesticide companies to use chemical pesticides, etc. In order to promote NPM, institutionalization of IPM as the basis of national plant protection policy was suggested. His suggestions from promotion of NPM are also summarized in Annex.

Thailand (1) (Dr. Turnjit Satayavirut)

Several nonpesticide methods including mechanical, physical, cultural, good sanitation practices, biological and crop varieties resistant to pests are practicable for controlling certain insect pests. The need of IPM is emphasized. Some success stories pertaining to use of nonpesticide method for controlling pests of super sweet corn, fruits, vegetables and sugarcane are mentioned. Biological control technology using predators, parasites, microbial organisms and nematode to control pests have been very useful for transferable technology and specific examples are cited. The government policy is to develop human resources and implement alternative agriculture. The government strategy is directed to restructure agricultural production and quality improvement. Some issues/problems in promoting use of nonpesticide method include: how to determine agricultural products free of pesticide?; how to convince producers to use complicated nonpesticide method in place of simple chemical pesticides?; how government sector can compete with the commercial pesticide sector?; how to increase participation of farmers in use of nonpesticide method?; less clear policy and planning; and how to enhance government support? Effective and efficient use of nonpesticide method comprising resistant variety, botanical insecticides and biological control tactics for controlling insect pests in Thailand was suggested. Some of the problems faced and suggested solutions to promote nonpesticide method are summarized in Annex.

Thailand (2) (Dr. Wiwat Suasa-ard)

The paper discusses current activities on the use of natural enemies for controlling insect pests and weeds in Thailand. A milestone toward biological control activities was establishment of the National Biological Control Research Center (NBCRC) at Kasetsart University operating under joint venture with the National Research Council of Thailand in 1971 but NBCRC became operational in 1975 and is the only center devoted to biological control in Thailand. Several success stories of using biological control of insect pests in rice, sugarcane, corn, cotton, soybean and fruit trees are mentioned. Paper also discusses achievements of NBCRC at national, regional and international level. Some biological control agents of weeds are also mentioned. Though a lot of work on biological control of crop pests has been done in Thailand, yet further efforts are needed to develop the biological control activities to a usable and practical level. Further progress in biological control will need more emphasis on conservation and augmentation because most of the problems are caused by endemic pest species, evaluation and development of potential and promising biological control agents, and close cooperation and collaboration among various institutions at national, regional and international level.

Vietnam (Dr. Pham Van Bien)

Agriculture sector in Vietnam contributes major share of the national economy. Since the start of renovation process in 1989 agriculture has made remarkable progress. In Mekong Delta rice is grown on more than 50 percent of the cultivated area. Other crops grown in the upland areas during the rainy season are corn, sugarcane, vegetables, and orchards and fruit trees. In the Mekong River Delta rice field rats have been the chronic pets. Application of pesticides has been the most common approach to control pests. To minimize use of chemical pesticides and promote nonpesticide methods for controlling pests in agricultural production national programs and foreign collaborated programs have been initiated. Such programs led to some success stories in use of nonpesticide method for controlling insect pests and diseases in Vietnam. Main issues included production of effective biological control agents, and application of biotechnology to agriculture in a sensible way, among others.

ISSUES RELATING TO THE UNDERSTANDING OF NONPESTICIDE METHODS

Several confusions emerged from the country paper presentations. This led to interesting discussions of the following issues:

Are Pheromones/Attractants Part of NPM?

a) In some cases, pesticides are used to kill trapped insects.
b) When used as a monitoring tool, it justified use of pesticides to control pests.
c) Disruption methods using pheromones are not well worked out and may not be sustainable.

Are Botanical and Microbial Pesticides Nonpesticides?

a) Botanical extracts, by their nature, are poisons and hence should be considered as pesticides.
b) Even commercial *Bacillus thuringiensis* (sold as endotoxins) should be considered as a biological pesticide.
c) However, nuclear polyhedrosis virus, *Trichoderma* and similar organisms work because they are self-replicating and hence are not considered as pesticides.
d) If we examine the term "nonpesticide methods" it is inconsistent to include botanical or biological pesticides as nonpesticides.

Can Minimum Tillage Using Herbicides Like Paraquat Be Considered NPM?

a) This is really a straightforward issue and use of a herbicide (which is a pesticide) is not an NPM even if it conserves earwigs.
b) This issue probably arose due to confusion between NPM and IPM. NPM may be integrated into IPM and should not replace IPM even if NPMs overlap with the same values associated with IPM.

WORKSHOP OUTPUT

Objectives

A workshop was conducted to: 1) identify issues and problems in using NPMs for controlling crop pests in member countries; 2) suggest strategies/solutions for addressing such issues and problems; and 3) develop action plan/s for the suggested strategies/solutions. To encourage more frank discussion and better sharing of views and experience, the participants were divided into two groups as follows:

Group I: Bangladesh, India (2), Islamic Rep. of Iran, Pakistan and Sri Lanka (2)
Chairperson: Mr. K. J. Devendrappa
Rapporteur: Dr. A. F. Sultanbawa
Facilitator: Dr. Peter A. C. Ooi

Group II: Rep. of China, Indonesia (2), Malaysia, Mongolia, Philippines Thailand (2) and Vietnam
Chairperson: Mr. Sutarto Alimoeso
Rapporteur: Dr. Pio A. Javier
Facilitator: Dr. Danny G. Hunter

The outputs of two groups were presented in a plenary session and were summarized as follows:

Group I

Background – Dependence on chemical pesticides leads to the following issues:

1. Residues
2. Resistance to chemicals
3. Ecological impacts/imbalances
4. Environment pollution
5. Costs – cost of alternatives like NPM, indirect (health) costs.

Problems	Strategies/Solutions/Action Plans
1. Lack of farmer organizations/groups	Encourage formation of such farmer groups
2. Lack of knowledge – of researcher, extension worker, policymakers, implementer (farmer)	Collect all information, conduct applied, multidisciplinary field research, socio-anthropological research, education programs for extension workers, policymakers and farmers.
3. Inadequate research on disease, weed and insect pest control	More NPM research is needed on disease, weed and insect pest control.
4. Slow acting	Promote NPM as a sustained activity aimed at creating ecological balance and minimizing outbreaks/epidemics.
5. Low availability of NPM products and difficulty production	Government support. Private sector production with quality control.
6. Strong pesticide industry lobby	Tax pesticide trade. Publicize instances of abuse. Stronger registration requirements for pesticides.
7. Poor communication between research and extension institutions, and farmers	Stronger linkages between research, extension and farmer.

Group II (see next page)

FIELD VISITS

For field studies participants visited the following facilities in Ibaraki prefecture.

1. Ibaraki Agricultural Center – Kashima Agricultural Research Station (15 April 2002)
2. Japan agricultural cooperatives – Shiosai Group of Farmers (15 April 2002)
3. Ibaraki Agricultural Center – Plant Biotechnological Center (16 April 2002)
4. Ibaraki Agricultural Center – Horticultural Research Institute (16 April 2002).

Group II

Group	Issues and Problems	Strategies and Solutions	Action Plans
Technical	1. Lack of knowledge and policies 2. Cannot compete with pesticide in terms of effectiveness and cost 3. NPM is too cumbersome 4. NPM is slow acting	– Collaboration and networking – Basic and applied research – Education (researcher) – Develop feasible management strategy for cropping systems	– Basic research (needs support from government) – Networking – Evaluation of the impact of NPM (exotic organism, GMO*)
Socioeconomic	1. Lack of farmers' organization 2. High labor and cost/shortage 3. Farmers reluctant to learn 4. Conflicting NPM recommenda-tions, i.e., weeds vs. diseases 5. Lack of incentive on the pro-duction of pesticide-free crops 6. Insufficient consumer education 7. Lack of involvement of social scientist	– Organize farmers into groups through improving their education/awareness – Offer premium to pesticide-free products – Motivate farmers for education by enhancing awareness – Promotion of agro eco-tourism – Premium prices for pesticide-free products – Stakeholder education – Involve social scientist in research and development on NPM	– Collaboration with NGOs in the implementation of NPM – Establish FFSs – Launch pilot projects – Launch campaign to educate and to create awareness of benefits of NPM among all stakeholders
Policy	Lack of government support (financial/policies)	Develop policies and provide financial support	Restriction/law enforcement on the use of pesticides

Note: * Genetically modified organisms.

A brief on each of the above field visits is as follow:

Ibaraki Agricultural Center – Kashima Agricultural Research Station

Mr. Matsumoto Yukie, Deputy Director of Kashima Agricultural Research Station (KARS) welcomed the participants. The KARS is one of the three Horticultural Research Stations of the Ibaraki prefecture. It was established 65 years ago. Its total staff strength is seven. The KARS is specialized in research on green pepper and some other horticultural crops for cultivation on sandy soils. The station is engaged in five research areas, viz. vegetable management on sand, insect pests of vegetables growing on sand, floriculture, variety development in vegetables and flowering plants, and cultivation of fruit trees. Traditional green pepper varieties were very susceptible to many diseases including viral, and farmers were using methyl bromide to suppress the viral diseases. However, recently the KARS has developed a new variety called "*Kasimamidori*" through a hybrid cross. However, variety is still on trial basis and is not grown on commercial scale. Main characteristics of "*Kasimamidori*" are its high resistance to PMMoV, its yield is comparable to standard varieties and its fruit quality is similar to that of the traditional green pepper varieties highly susceptible to viral diseases. Hopefully development of "*Kasimamidori*" will help minimizing use of chemicals such as methyl bromide and will enable farmers to grow green pepper in the fields infected with PMMoV virus. The participants were able to visit greenhouse facility of the KARS where the varieties are still evolved through conventional breeding. The participants enjoyed very much their visit and appreciated the greenhouse research facilities of the station.

Japan Agricultural Cooperatives - Shiosai Production Group, Kamisu

Participants visited one of the greenhouse facilities for green pepper cultivation in Kamisu area. The greenhouse facility belongs to Shiosai Production Group (SPG) of the Japanese JAs. Mr. Ishigami, head of the production group welcomed the participants. There are 204 members of the SPG. Major concerns of the SPG are how to grow green pepper without chemical use? To minimize use of chemical pesticides the group is using biological control agents and various types of traps. At present the SPG is growing green pepper on 50 ha covered under greenhouses with annual production of 5250 tones worth 1.50 billion yens. Major insect pest of green pepper is thrip that is controlled by using a combination of natural enemies such as *Orius laevigatus* and chemical pesticides. However, use of chemical pesticides has decreased by at least 3 times due to use of the natural enemies. Farmers' main concern is high cost of biological control of pests and decreasing price of green pepper in the market. It was told that one plant of green pepper could produce up to 370 fruits per season. The participants were delighted to see very healthy crop of green pepper in greenhouse and appreciated hard work of the farmer. Later participant also enjoyed very much traveling from Kamisu to Mito by road running along the coast and through the rural area where most of the fields for paddy plantation were under preparation.

Ibaraki Agricultural Center-Plant Biotechnology Institute, Iwama-cho

Mr. Otsuka, Administrator, Plant Biotechnology Institute (PBI) welcomed the participants and briefed them on research facilities and achievements of PBI. The institute was established in 1992. Main focus of the institute is production of new varieties. PBI has four labs, viz. Lab of Crop Biotechnology, Lab of Vegetable Biotechnology, Lab of Fruits and Ornamental Biotechnology and Lab of Biological Control. The institute is conducting research mainly on rice, Chinese cabbage and melons, the major crops of Ibaraki Prefecture. Main achievement of the PBI is control of root knots or club root, a common disease of Chinese cabbage in the Ibaraki Prefecture, with the endophyte *Heteroconium chaetospira*. This NPM of controlling root knots or club root is the first discovery in the world and Institute got patent from USA for its technology just one day ago. Though main focus of the institute was development of new varieties through using biotechnology but institute focus seems to be shifting to biological control of insect pests and diseases due to increasing concern of the general public on safety of the GMOs and conservation of environment. Another reason for such shift is that use of methyl bromide that is utilized commonly to sterilize soil and control plant diseases will be banned in 2005 and farmers will need some alternate methods of insect pest and disease control especially NPM.

Ibaraki Agricultural Center – Horticultural Research Institute, Iwama-cho

Mr. Nagatsuka Hisashi, Chief of Insect Pest Unit, Horticultural Research Institute welcomed the participants and briefed them on research activities of the Insect Pest Unit (IPU) of the Institute. He pointed out that traditionally farmers of the area were using chemical pesticides to control insect pests and diseases but now local farmers have to find NPMs for this purpose due to growing concern of the general public on use of chemical pesticides. The IPU research activities could be classified into chemical pesticide use, low chemical pesticide use and IPM. Now the IPU is aiming at IPM strategy for controlling insect pests and diseases. He explained various options for NPM such as crop selection, cultural, physical, biological, etc. He share his experience in using various physical methods developed/refined at the Institute such as perfect solar heat sterilization, simple solar heat sterilization, steam sterilization and polyethylene sheet cover to control various soil-borne fungal and bacterial diseases, as well as light reflection sheet, pheromones and pheromones-cum-cohesive tape to control insect pests. He also briefed on common insect pests of the area and natural enemies for controlling such pests. Lastly he stated that Center was providing guidance to the farmers for biological and other NPM for crop pest control but high cost of biological control is the major constraint. Thus farmers are compelled to use some chemical pesticides along with the biological control.

CONCLUSIONS

1. Recognizing the externalities associated with chemical pesticides, such as environmental degradation, human health hazards, pests becoming resistant to pesticides, secondary pest outbreaks and uneconomic and unsustainable production, as well as in view of growing interest among farmers for using NPMs, and further recognizing the need to improve farm productivity on sustainable basis to enhance farm incomes, the participants at the seminar concluded that it is imperative to promote use of NPMs in agriculture.
2. The participants suggested that NPMs should be used whenever possible and should be an integral part of an overall ecological IPM program.
3. The seminar recommended that further government support would be needed to strengthen multidisciplinary basic and applied research on NPMs for promoting application of such methods in an IPM program.
4. Since use of NPMs for controlling crop pests may be more costly and cumbersome than that of chemical pesticides, participants recommended that a sound mechanism should be established to provide premium prices for the pesticide-free products.
5. The participants recommended that farmers be educated and trained to build up their skills and knowledge of NPMs. To promote use of NPMs in agriculture an IPM FFS approach was strongly recommended. The seminar generally agreed that getting farmers to organize themselves into groups would easily follow the education and awareness process. This process should be supported by government policies to promote research into demand-driven NPMs, to enhance awareness of benefits of NPMs among all stakeholders, to promote greater linkages between farmers, extension workers and researchers and to strengthen regulation on use of chemical pesticides to discourage their use. These activities should be complemented by the NGOs, Civil Society Organizations (CSO) and other public-based groups including consumer associations.
6. The participants agreed that further cooperation and coordination among the national/regional/international organizations will be inevitable for launching an effective movement to minimize the use of chemical pesticides while maximizing the use of NPMs to ensure food quality assurance in the region.

1. SOME NONPESTICIDE METHODS FOR MANAGING CROP INSECT PESTS – PRESENT STATUS, ISSUES AND STRATEGIES

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INTRODUCTION

In the last few decades, plant protection has been dominated by reliance on pesticide methods. However, evidence from oil palm (Wood, 1964), tea (Wood, 1973), rice (Kenmore, *et al*., 1984; and Ooi, 1986) and crucifer crops (Ooi and Sudderuddin, 1978; and Ooi, 1985) provided clear evidence that reliance on chemical insecticides led to pest outbreaks. Indeed, contrary to popular beliefs, chemical insecticides often cause pest outbreaks and have to be avoided or at least minimized (Ooi, 1986). The reliance on chemical insecticides often meant that efforts on investigation of nonpesticide methods were usually neglected.

While not as common as chemical insecticides, nonpesticide methods are present and ecological studies have led to better understanding and even application. Nonpesticide methods include crop varieties that are tolerant to insect damage but this will not be discussed in great depth in this paper. The impact of crop resistance is often complicated by the impact of existing natural enemies, a phenomenon often referred to as natural biological control.

This paper will focus on two types of nonpesticide methods that farmers can engage in, namely; biological control and physical and cultural practices. It is difficult to include the use of attractants as a nonpesticide method as often the use of pheromones/attractants is associated with use of pesticides to kill off the trapped insects. In the case of using rotting meat to attract the rice ear bug, *Leptocorisa oratorius* (Fabricius) (Hemiptera: Alydidae), it was found that these attract mainly males (Kalshoven, 1981; and Ooi, 1998). The paper is largely based on the author's personal experience with nonpesticide methods and may not cover fully this large and interesting field.

BIOLOGICAL CONTROL

For the context of this paper, biological control is defined as the use, or encouragement, of natural enemies of a pest to reduce pest abundance (Waterhouse, 1992). Four types of biological control are recognized, namely; classical biological control, inundative method of biological control, augmentation method and a management method.

Classical biological control in Asia is exemplified by the first case study. This case study showed that it is not enough to introduce an efficient parasitoid. It is equally important that farmers are educated on the subject so that they can be equal partners in developing this nonpesticide method. As shown by Ooi (1992), farmers had to wait up to 12 years to realize the impact of the parasitoid. Lessons learned from this case study were transferred to the highlands of Dalat in Vietnam and cabbage farmers studied the biology of the parasitoid. Farmers also studied the use of a microbial insecticide (*Bacillus thuringiensis* [Berliner]) to replace chemical pesticides. When cabbage farmers in Dalat learned about the biology of the parasitoid and the action of *B. thuringiensis*, they stopped using chemical pesticides. The parasitoid was so effective that no further intervention was necessary (Ooi, *et al*., 2001).

Inundative biological control involved rearing large numbers of biological control agents and releasing them into the field. Lim and Chong (1987) reported the periodic release of *Trichogrammatoidea bactrae fumata* (Nagaraja) (Hymenoptera: Trichogrammatidae) to control the cocoa pod borer. While it appeared to be able to reduce cocoa pod damage, many farmers find the process both tedious and expensive. Moreover, rearing large numbers of parasitoids for timely releases can be very challenging. In some cases, the inundative releases appeared to have a placebo effect, allowing other natural enemies to control the pests when farmers stopped spraying chemical insecticides following periodic releases of the agent.

In the case of augmentative biological control, beneficial insects are introduced at the time when pest populations are about to build up. An example of augmentative biological control is the encouragement of the black ant, *Dolichoderus thoracicus* (Smith) (Hymenoptera: Formicidae) to manage cocoa mirid pest (Khoo and Chung, 1989). This involves establishing nests of the ant in cocoa plants. Liew, *et al*. (1999) also found that the black ants could control the cocoa pod borer.

Case study No. 2 demonstrates that a larger biological control exists as a naturally occurring phenomenon. However, we often do not appreciate this and rice farmers were not aware of natural enemies in the field until they attended Farmer Field Schools (FFSs). Farmers studied and learned that friendly arthropods can keep a serious pest like the brown planthopper (BPH) in check. In the process, they soon discover that other pests like the rice stemborers are also kept at low populations by natural enemies (Balasubramanian and Ooi, 1977; and Ooi and Shepard, 1994). The most frequently asked question at rice FFSs is why farmers are not aware of such a ubiquitous phenomenon as natural biological control. It suggests that farmers were denied this information. It is ironical that farmers who live next to the rice fields are not aware of friendly insects that protect them from pest species. Hence, there is a need to educate farmers so that they can make more informed decisions about growing a healthy crop.

Case Study No. 1. Imported Parasitoid Make Diamondback Moth a Nonpest

A review of diamondback moth (DBM) management in the early part of 1970s would reveal that the literature was dominated by chemical evaluations for poisons to control this cabbage pest. The preoccupation with chemical control resulted in many reports of insecticide resistance (Ankersmit, 1953; and Henderson, 1957). The response by the research community was to find more toxic chemicals with similar results – development of insecticide resistance. At that point, it was obvious that the only option for DBM management was chemical control and the frustrations of cabbage farmers drove them to use cocktails (Ooi and Sudderuddin, 1978) which increased the cost of production (Lim, 1972). This suggests that farmers want to be involved in DBM management, which hitherto was left to researchers and scientists with very little change from the 1950s.

An ecological approach was initiated in the 1970s (Ooi, 1979; and Lim, 1982) in the main cabbage growing area of Malaysia. This served to widen the options available to farmers when some parasitoids were imported (Ooi and Lim, 1989). However, these remain options until a chain of events resulted in a severe reduction in use of chemical insecticides in Malaysia. When farmers reduced the use of cocktails and focused on *B. thuringiensis*, the impact of *Diadegma semiclausum* (Hellen) (Hymenoptera: Ichneumonidae) was realized (Figure 1) (Ooi, 1992). However, farmers had to wait 12 years to appreciate this!

The lesson learned is that farmers should be involved in biological control from the beginning. Educating farmers about ecology should take precedence in pest management program to ensure a sustainable program. Farmers would not stop using chemical insecticides unless they understand biological control. At the heart of this is the lack of appreciation of ecology. Farmers, hitherto, had been exposed only to a unilateral approach to pest control and it would take a great effort to unlearn this and understand the need for a more holistic approach.

Case Study No. 2. Natural Biological Control of the Rice Brown Planthopper

Before 1977, the rice BPH, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) was not even considered an important pest of rice in Malaysia (Lim, *et al*., 1978). Like other countries in Southeast Asia, severe outbreaks demanded answers as to their causes. Many suggestions were advanced but groundbreaking studies by Kenmore, *et al*. (1984) showed that disruption of natural biological control was the main cause. Key natural enemies were generalist predators such as *Lycosa pseudoannulata* (Boesenberg and Strand) (Araneae: Lycosidae) and *Cyrtorhinus lividipennis* (Reuter) (Hemiptera: Miridae) (Ooi and Shepard, 1994).

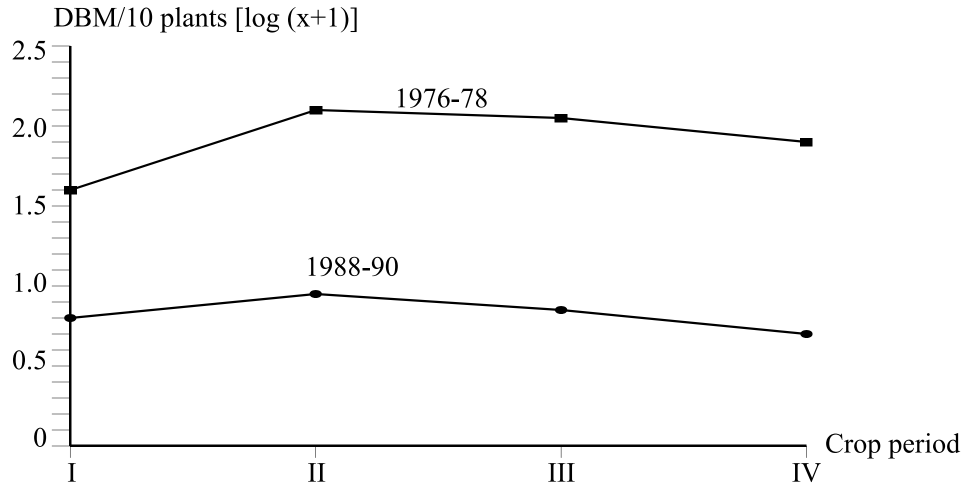

Figure 1. Seasonal Population Changes of DBM for 1976-78
(pre-introduction of *Diadegma semiclausum*) Compared with that for 1988-90

Source: Ooi, 1992.
Note: The results indicate a conspicuous decline in DBM population 11 years after introduction and release of *D. semiclausem*.

Repeated outbreaks of *N. lugens* in Indonesia was attributed to extensive use of insecticides, which were heavily subsidized by the government (Wardhani, 1992). Outbreaks were reduced following draconian measures taken by the government to ban 56 insecticides from the rice field and gradual removal of insecticide subsidy.

Insecticides killed off both pests and natural enemies and often pests recovered first leading to higher population levels than before, a phenomenon known as resurgence. Hence, in an area in Sekinchan, Malaysia where farmers reportedly treat their fields on a prophylactic basis, a field with three applications of insecticides had fewer predators as compared to fields with hardly any insecticide treatment (Ooi, 1986). Higher ratios of BPH to predators (mainly *L. pseudoannulata* and *C. lividipennis*) in sprayed fields suggested that use of insecticides led to higher populations of BPH (Figure 2).

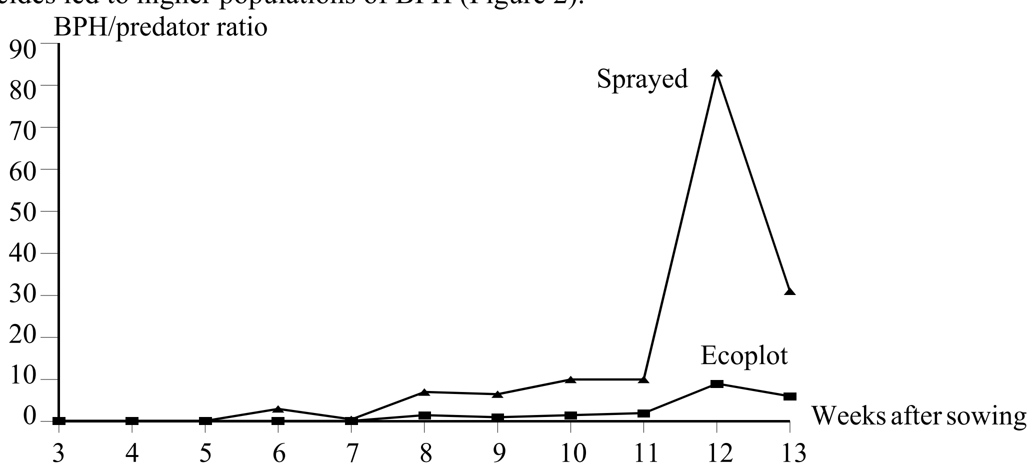

Figure 2. Number of BPH per Predator (mainly *L. pseudoannulata* and *C. lividipennis*)
in an Ecological Plot (Ecoplot) and a Sprayed Plot

Source: Ooi, 1986.
Note: This experiment was carried out in Sekinchan, Malaysia. It was only treated once ca.25 days after sowing (DAS) in an ecoplot and was treated three times at ca.25 DAS (endosulfan+trichlorfon), 70 DAS (fenitrothion) and at ca. 95 DAS (MTMC + phenthoate) in a sprayed plot.

The importance of predators in maintaining low populations of BPH was also shown using exclusion cages. It was shown that in the absence of predators, BPH populations reached a very high level. In cages where the bottom was opened to allow predators to enter, both *L. pseudoannulata* and *C. lividipennis* helped maintained BPH populations at very low levels (Figure 3). This simple experiment can be carried out by farmers in FFS and is a very powerful tool to understand the impact of biological control.

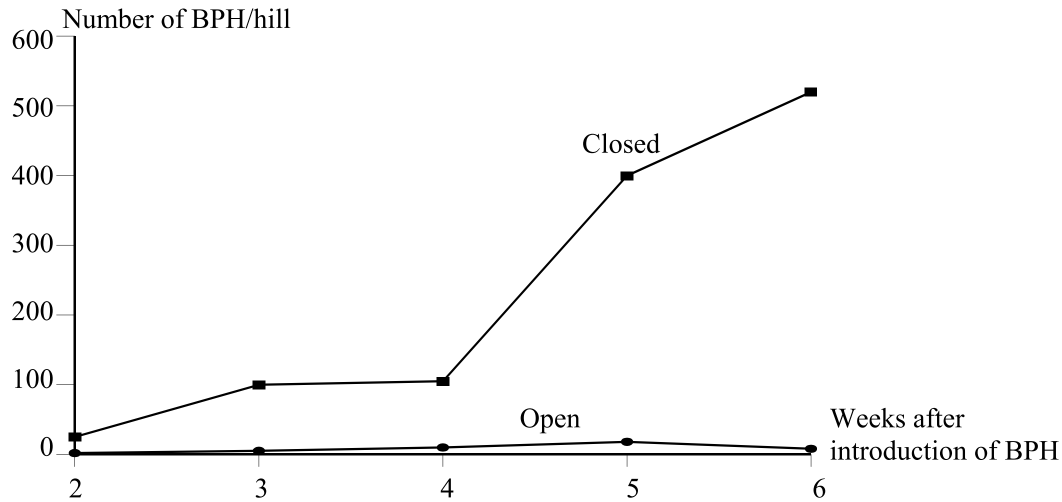

Figure 3. Results of an Exclusion Cage Experiment Set Up in Sungai Burong, Malaysia

Note: Six weeks after introducing BPH into cages without predators (closed cage), the population of BPH reached levels that caused hopper-burn.

PHYSICAL AND CULTURAL CONTROL OF INSECT PESTS

Prior to the availability of chemical insecticides, farmers developed various means to prevent insect pest infestation. Some of these have been refined through research both by farmers and researchers. Case study No. 3 is one such example of how farmers rediscovered an old method of avoiding pest attack. By studying the biology of the insect pest, farmers were able to confirm the findings made some 60 years ago by entomologists. More importantly, the information is now used by farmers to manage an important pest of rice. In Bangladesh, farmers who participated in vegetable FFS organized by an Integrated Pest Management (IPM) program funded by DANIDA (Danish International Development Agency) learned that the brinjal fruit and shoot borer, *Leucinodes orbonalis* (Guenée) (Lepidoptera: Pyralidae) pupated in leaf debris on the ground (Ramaswamy,* personal communication, 2002). Using this information, farmers would maintain clean fields and destroy all infested brinjal fruits. This dramatically reduced the incidence of the borer without using insecticides. In the past, farmers sprayed as many as 50 times per crop season!

Cocoa is an introduced crop in Southeast Asia. The key pest is the cocoa pod borer, *Conopomorpha cramerella* (Snellen) (Lepidoptera: Gracillariidae). It is one crop that physical and cultural control received much attention. Shah (1987) described several methods that were used to control the cocoa pod borer. These included bagging of all husks following extraction of cocoa beans and it was found that a minimum of nine days period was required to effectively kill all the larvae, pupae and adults. Besides bagging the husk, it was suggested that harvesting pods at the first hint of yellow may leave a large number of larvae inside the pod and bagging the husks will kill them off. To reduce pest population, it was recommended that a high standard of harvesting be maintained and that harvested pods be split the same day to extract the beans. Ecological harvesting refers to adoption of four aspects essential to effectiveness, i.e., regular harvesting, complete harvesting, a low minimum ripeness standard for plucking, and continuation throughout the year (Wood, 1987). A more draconian measure to manage the cocoa pod borer was reported by Roepke (1912) which involved complete removal of all cocoa pods and related fruits attacked by the cocoa pod borer, a method

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* CTA, Strengthening Plant Protection Services Project, Bangladesh-Denmark DANIDA.

named “rampasan”. If carried out efficiently, it would encourage a pest-free period the following season. For smallholders, the use of a transparent plastic bag to sleeve young pods has been practised in the Philippines and Indonesia (Wood, 1987).

Case Study No. 3. Using Avoidance Tactics Based on Ecological Understanding of the White Stem Borer

Despite annual outbreaks of the white stem borer, *Scirpophaga innotata* (Walker) (Lepidoptera: Pyralidae) in the district of Indramayu, province of West Java, rice farmers were not aware of nonpesticide methods for pest control. Equally intriguing was the lack of understanding by the authorities of studies to control this pest carried out some 60 years ago. It was not surprising that farmers did not understand the biology of the white stem borer, despite long association with the insect (see Kalshoven, 1981). Farmers observed that the white stem borer would occur in the first season following a three months drought. The farmers reported often seeing swarms of them in this first season. The only approach adopted by farmers and recommended by agricultural authorities in 1995 was to spray with chemical insecticides. Despite numerous sprays, the rice crops were often devastated by the white stem borer. The IPM facilitator assigned to the study used this observation as an entry point to introduce studies that help farmers find out what happened. The IPM facilitator suggested that farmers carry out studies to determine the effects of insecticides. So, in July 1995, some white stem borer moths were collected from the fields and farmers sprayed them with insecticides. To their surprise, the moths spawned eggs before they died. Farmers then concluded that spraying insecticides did not prevent egg laying.

The farmers’ group in the village of Kalensari were graduates of IPM FFSs. This group of 25 farmers decided to continue to work together to discover why they had the white stem borer problem. Regular meetings were held. Farmers went into the field to make observations and carry out field experiments. The IPM facilitator helped the farmers in experiment design and implementation.

In one study, farmers evaluated the official recommendation of using an insecticide (carbofuran) coated on sand particles and applied in the seedbed. Results were variable, depending on the time of oviposition of the eggs. Hence, farmers realized that application of carbofuran did not guarantee an insect-free nursery. Armed with this information, farmers went further, exploring why there were still outbreaks despite spraying insecticides on egg masses. They collected freshly-laid egg masses and sprayed these using the recommended dosage. Farmers noticed that after about a week, healthy larvae emerged. The results convinced farmers that spraying insecticides really did not stop an outbreak. They had to look for another approach and subscribed to the principle that the more they understood the biology and ecology of the stemborer, the greater the potential for management.

The next study concerned learning about the origin of early season flights. Farmers suspected that the moths came from the fields and decided to survey rice stubbles left in the field from the previous season. To their amazement, they found live larvae within some of the stubbles. Discussions with resource persons helped them understand the concept of insect aestivation (a form of hibernation during adverse weather conditions), observed by Goot (1925). This discovery led to different experiments to kill off the aestivating larvae. This showed that burning and flooding did not kill many larvae, and that the best approach was to remove egg masses. They organized a local campaign to do this. This campaign proved successful, as the incidence of stem borer in the locality was about 5 percent compared to neighboring areas which had about 25 percent bored tillers with prophylactic spraying of chemical insecticides.

Continued discussion among farmers led to the design of experiments for avoiding the peak flights of the stem borer moths (Warsiyah, *et al*., 1999). Farmers carried out studies to understand when the stem borer moths took flight. They were able to duplicate Dammerman’s study (1915) with light traps, using them to monitor the moth flights. Farmers also learned the role of water in breaking aestivation. Combining this information, farmers set up a strategy to ‘forecast’ peak flights and organized other farmers in their villages to only plant nursery beds after peak flights.

A PARTICIPATORY IPM APPROACH TO ENCOURAGE NONPESTICIDE METHODS

The problems arising from use of chemical insecticides were realized as early as 1950s. By the early 1950s, resurgence of pest outbreaks and resistance to chemical insecticides were reported from all over the world. Initial attempts led to the first development of IPM as a combination of chemical and biological control (Stern, *et al*., 1959). This did not go far enough to address the conflict of using two opposing approaches. Chemical insecticides by their very mode of action remove or inhibit the function of biological control and this poses a problem of integrating chemical and biological control. Recognizing this, steps were then taken in the 1960s to formulate a more ecological approach (Smith and Reynolds, 1966). In the 1970s, the approach recognizes the need to identify social and economic requirements in addition to ecological consideration (Bottrell, 1979). Despite all attempts at defining IPM, it remained very much at academic levels, particularly in the wet tropics. Part of this problem lies in the heavy reliance on the use of economic thresholds as a key element to decision-making. Economic threshold levels were insensitive to both social and economic situations of farmers and it was realized by 1980s that the use of economic threshold levels continued to maintain unnecessary use of insecticides (Moore, 1996) due in large part to lack of understanding of underlying ecological principles.

Realizing this dilemma, the FAO implemented IPM program for Asia in the late 1980s initiated a non-formal education approach to help farmers understand these underlying ecological principles. The process came to be known as the IPM Farmer Field School.

The IPM FFS is the primary learning approach piloted in Indonesia (Dilts and Pontius, 2000). The IPM FFS is a season-long learning experience. In the FFS, farmers learn about agro-ecosystem management. The FFS makes use of the crop field as a field laboratory. In the laboratory, FFS participants learn about the ecology of the crop by means of regular observation and hypothesis testing.

Discussions are based upon participant analysis of field conditions. The FFS uses a participatory learning process. The process emphasizes taking decisions and actions based on an open discussion of ideas which is free from the domination of any individual. These decisions are tested in the field laboratory. The FFS process, besides its emphasis on field ecology, provides participants with an opportunity to examine human social dynamics. As a result, FFS participants not only learn about the cause and effect relationships that exist in the field; they also acquire a greater understanding of human relationships.

The analytical processes employed in the FFS enhance farmers' capacities to examine the conditions, in which they live and work. Participants, having completed their FFS, are able to take decisions and take actions that would improve those conditions. The increased understanding of participants regarding human social dynamics enables them to develop collaborative efforts to ensure that planned actions are implemented.

Even after the FFS, farmers continued to experiment and in some cases worked in groups. For example, farmers in the village of Kalensari continued to study a nonpesticide method to control the white stem borer (Warsiyah, *et al*., 1999). Examples of follow-up studies by farmers are reflected in Ooi (1998 and 2000), Ooi, *et al*. (2001) and van den Berg, *et al*. (2001). This confirms that farmers are able to carry out experiments and develop innovative nonpesticide methods of controlling pests (Chambers, *et al*., 1989).

As noted in the first case study, encouraging IPM farmers to continue research is critical to the realization of the potential of a biological control agent (Ooi, *et al*., 2001). Results from a better understanding of nonpesticide methods have helped farmers to convince policymakers to take the right steps in preventing outbreaks. It is time that policymakers should make this approach *a priori*. An enabling policy to encourage farmer education in FFS and carry out field ecological studies will invariably promote the development of more nonpesticide methods to manage insect pests in Asia.

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2. NONPESTICIDE METHODS FOR SUSTAINABLE CROP DISEASE MANAGEMENT IN THE ASIA-PACIFIC REGION: PRESENT STATUS, ISSUES AND STRATEGIES

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AGRICULTURE IN THE ASIA-PACIFIC REGION

The Asia and Pacific regions represents almost 23 percent of the world's total land area and about 30 percent of the world's cultivated land but 56 percent of total world population and 72.5 percent of the world's agricultural population. Agriculture has been the important economic activity that has sustained populations in the Asia-Pacific region for thousands of years and it continues to be the most important economic activity for the majority of countries in the region. In some countries its share of GDP is as high as 60 percent. Although Asia and the Pacific are often grouped together as a political region there are stark contrasts between them and the statistics hide major discrepancies and differences of scale in terms of land area, natural resources, population, culture, access to information, production, commerce, human capacity and so forth. For example, in 1998 the combined population of Melanesia, Micronesia and Polynesia accounted for only 0.12 percent of the world total of six billion compared to the massive 56 percent contribution of the Asian region (SPC, 2000). Many of these physical and socioeconomic differences have important implications for plant protection and the search for appropriate agricultural technologies to combat pests. The Pacific region is composed of a vast number of islands which vary in size from Papua New Guinea (PNG) with a population of around four million, to Niue with a population of less than 2,000 and decreasing. This gives the Pacific a certain comparative advantage in terms of isolation and minimizing the number of exotic pests and diseases.

In terms of agriculture, Asia is responsible for more than 90 percent of the world's production of rice, 30 percent of wheat and about 20 percent of coarse grain (Khan, 1996). The area devoted to vegetables in Asia is about 21 million ha. The major perennial crops in Asia are coconuts (9 million ha), fruits (17 million ha), sugarcane (8.6 million ha), rubber (6.7 million ha), oil palm (4.7 million ha), tea (2 million ha) and coffee (1.6 million ha). In the Pacific, agriculture is mainly subsistence-based, though export markets have been developed for certain crops. Compared to Asia the scale is very small. Unlike Asia, the important crops grown are dominated by vegetatively propagated species such as taro, sweet potato, yams, cassava, banana, sugarcane, breadfruit, and kava. In terms of world production the contribution from the Pacific is minor except for crops such as kava and possibly breadfruit. Other important crops include coconut, vanilla, squash, Asian vegetables, pawpaw and cucurbits.

Agricultural intensification is a problem in the Asia-Pacific region, and is largely due to pressures resulting from rapid population growth and increasing demand from limited land. This is manifested by increased soil erosion, forest clearing, agriculture on steep slopes, declining fallow periods, pest and disease problems, erosion of crop genetic resources, loss in forest biodiversity, and loss of traditional knowledge once employed in agriculture and natural resource management. These negative ecological and sociocultural impacts have contributed to increasing farmer marginalization and increased rural poverty. With increasing population in the region we are faced with the challenge of producing more food from less land (Lenne, 2000). Such increased productivity will have to be based on agricultural research and technologies that have minimal adverse environmental and ecological impacts and that contribute to social equity and poverty alleviation. Improved technologies for pest management will be a significant component of this new approach. Nonpesticide control technologies such as host plant resistance integrated with other appropriate cultural practices and biological control will play a vital role in achieving this goal. Poor farmers will benefit from increased yields, the rural and urban poor will gain from better availability of cheaper, safer and higher quality food that has little adverse environmental impacts. Employment opportunities will increase as a consequence of improved productivity and the employment of labor-intensive technologies. Consumers will benefit from improved health as a result of safer technologies that minimize the need for pesticides (Lenne, 2000).

THE IMPACT OF CROP DISEASE

Plant disease epidemics have influenced the course of history in many Asian-Pacific countries and continue to be of great importance especially to those people whose day-to-day survival depends on crop production. By reducing productivity, plant diseases contribute to the decline in rural income and diminish food security, both of which are a major determinant of poverty. Many times in history, plant diseases have resulted in thousands of deaths due to the destruction of staple food crops and consequent starvation.

Worldwide, it is believed that plant diseases reduce agricultural productivity by more than 10 percent which is the equivalent of 500 million mt of food per year (Anon, 1998). Not only does the farmer have to cope with reduced levels of production he or she is also faced with the additional costs involved in trying to control the problem. Reduced production levels of diseased crops means increased product prices for consumers. Losses in terms of exports and foreign earnings can be devastating as Samoa realized in 1993 when taro leaf blight (TLB) arrived. If attempts at control involve excessive use of pesticides there are hidden environmental and health costs. Plant diseases can also reduce the level of biodiversity or limit the variety of plants grown in an area.

The devastating impact of plant disease on human affairs is vividly illustrated by the effect of late blight (*Phytophthora infestans*) of potato in Ireland from 1845 to 1946. At that time the potato plant was the staple food of hundreds of thousands of people. As a result of the blight there was mass starvation and three million deaths although other socioeconomic factors were also involved. There was a major exodus from the country as desperate people sought refuge in more ‘prosperous’ lands. The lingering impact of the potato famine in Ireland continues to this day and is deeply etched on the psyche of the people of that country. Interestingly, late blight of potato is once again becoming prevalent in some countries.

The impact of a plant disease epidemic on a national economy was vividly illustrated by the arrival of the coffee rust fungus (*Hemileia vastatrix*) in Sri Lanka (then Ceylon) in 1875. At that time there were around 160,000 ha of coffee planted and 45 million kg exported yearly. Within 20 years, production of coffee had virtually ceased and had fallen to 2,000 mt (Schumann, 1991). The impact of the South American leaf blight *(Microcyclus ulei)* on rubber in Latin America is a similar scenario. Epidemics of groundnut rosette virus disease in Sub-Saharan Africa in the 20th century have resulted in the loss of billions of dollars. African cassava mosaic virus disease in Uganda is estimated to cause losses of US$70 million annually (Lenne, 2000).

In the Asia-Pacific region, plant diseases have, and continue to, pose a serious threat to rural livelihoods. The Bengal famine of 1942-43 that resulted from *Biploris* brown spot of rice and contributed to the death of two million people is an important reminder of the power of disease epidemics in the region. Wheat rust in India from 1850 to 1950 contributed to 27 major famines and widespread starvation (Lenne, 2000). In the Pacific region the impact of TLB and the threat it poses to countries not yet affected by the disease illustrates this point clearly. The TLB fungus (*Phytophthora colocasiae*) arrived in Samoa in 1993 and immediately had a devastating effect on the country. Taro (*Colocasia esculenta*) was the principal staple crop at the time and of considerable economic, cultural and ceremonial importance. It was the major export commodity and income earner for many farmers. It has been estimated that this small island country lost approximately US$10 million as a consequence of this disease. In comparison to the economies of Asia such losses may not be significant but in small island states the impact can be devastating. The threat that this disease poses to other islands of the Pacific region continues to be of major concern and requires constant vigilance.

Although plant diseases have contributed to substantial global crop losses, these would have more than doubled, and many of the world's poor would have been poorer, without significant advances in crop protection research (Lenne, 2000). Continued crop protection research is essential in order to respond to future changes and challenges that will arise.

THE IMPACT OF AGROCHEMICAL CONTROL MEASURES

The second half of the 20th century was a buoyant time for the development of pesticides and very quickly became, and still is, a huge industry dominated by multinationals. People now talked of eradicating pests and initially the pesticides were so successful that there seemed to be no reason for carrying on the old preventative methods of pest control such as crop rotation and sanitation. Many farmers started to spray routinely even if pests were not present.

This dependence on chemical sprays very quickly led to a number of ecological problems. The first sign that something was going wrong was the development of resistance among the target pests. Pesticides were also destroying the pest's natural enemies leading to problems of pest resurgence and secondary pests. Very often the response to these ecological problems was to spray more frequently, often at higher doses, in order to achieve control, commonly referred to as the "pesticide treadmill".

The final group of problems observed with this intensive use of pesticides were problems related to the environment and health, which received wide coverage with the publication of Rachael Carson's *Silent Spring*. Problems arising as a result of excessive pesticide use included environmental pollution, contamination of soils and waterways and the destruction of many non-target species of wildlife. The health of users and other members of society were also placed at risk. The growing awareness of these problems in certain Asian countries has recently led to bans on a number of damaging pesticides accompanied with policy support for nonpesticide approaches.

Overall, fungicides are considered less toxic than the majority of other pesticides with the possible exception of the tin-based and organophosphate fungicides. They are also considered to pose less threat to the environment compared to herbicides and insecticides. Fewer non-target effects using fungicides have been reported. However, chemical fungicides, especially the older fungicides, have the potential to contribute to some of the negative effects outlined above and should be treated with caution. The major problem with fungicides in recent years has been the rise of fungicide resistance in the target pathogen. This has arisen largely to systemic fungicides with a very specific mode of action. By comparison, fungicides with multi-site activity are much less prone to resistance problems. Resistance to benzimidazole fungicides (benomyl) has been found in the banana black leaf streak (BLS) pathogen in the Pacific region (Fullerton and Tracey, 1984). Similar resistance problems can be anticipated with other dicarboximide or sterol inhibitor fungicides.

Pesticide use in developing countries is small compared to developed countries (Pingali and Gerpachio, 1997). However, the bulk of pesticides used in developing countries belong to those classified as highly hazardous such as organochlorines and organophosphates. In many instances these pesticides are banned in developed countries. It is predicted that pesticide use in developing countries will increase in the next decade or so. In 1997, the Food and Fertilizer Technology Center (FFTC) and the Asian Productivity Organization (APO) undertook a pesticide production and use survey in Asia. The results indicated an increasing trend in pesticide usage in the region. No such survey has been undertaken in the Pacific region but anecdotal evidence supports continued increasing trends in pesticide usage in the region. Clearly the challenge ahead is to develop alternative viable pest management technologies that will reduce the need for pesticides. It is interesting to note that US$570 million was spent on fungicides for rice cultivation globally in 1998, with over 50 percent being used in Japan. Crop protection inputs in Japan for rice totalled US$680 per ha compared to US$3 per ha in other Asian countries (Kloti and Potrykus, 1999).

NONPESTICIDE METHODS FOR MANAGING CROP DISEASES

The problems highlighted above can be greatly reduced by using an integrated approach based on some of the nonpesticide methods of disease control that will be outlined in the following section of this paper.

This will start with a discussion of methods used to prevent the entry of a pathogen to a new area or attempts to quickly eradicate such an incursion. Both approaches highlight the cost benefits achieved in preventing disease establishment and they should be the cornerstone of nonpesticide approaches to disease management in all countries of the region. This is followed by a description of certification schemes to provide pathogen-free plants to farmers and an in-depth examination of various cultural and physical practices and biological control methods that may reduce disease levels before discussing the importance of host plant resistance for achieving durable and sustainable disease control. The section concludes with an examination of the role of biotechnology and its application to disease control. It is stressed that no one method or approach to disease management holds the key to future success rather that solutions will be location-specific and will depend on a basket of options in order to achieve sustainable disease management. The problems and issues specific to all methods are discussed with possible strategies for future improvement. The paper highlights a number of case studies that highlight the impact of some nonpesticide approaches to disease management.

Regulatory Methods for Managing Crop Diseases – the Role of Quarantine and Eradication

Regulatory methods of disease management have as their objective measures that achieve exclusion of the pathogen from its host or a specific geographic area. This could be an entire country or a region within a country. These methods are enforced by regulations or acts of quarantine. Preventing the pathogen from coming into contact with its host will ensure that disease does not develop. Such an approach should be the foundation for the effective control of plant disease. It is the most cost-effective method for disease control and benefits all farmers in the region (see Box 1). The exclusion of banana bunchy top virus (BBTV) from PNG or TLB from Fiji saves both countries millions of dollars yearly. Unfortunately, exclusion is becoming increasingly difficult with the escalation in tourism, travel and commerce. There are growing demands on an effective quarantine service to support this objective. However, at the same time detection methods are becoming more reliable as sensitive diagnostics become available.

Box 1. The Benefit of Eradication

Despite all the noble efforts of our quarantine services there are going to times when new pathogens are introduced. Even at this stage an effective emergency response by quarantine and plant protection personnel can reduce the chances of a pathogen establishing in a country. The cost-benefit analysis of this approach highlights the advantages. In 1984 a survey detected citrus canker on Thursday Island. This disease has the potential to destroy the citrus industry in the moist coastal production areas of Australia. Eradication of the disease from the island involved the destruction of several trees and detailed monitoring of the remaining trees for four years. Thursday Island was declared free of citrus canker in 1988 at a cost of US$20,000. Similar eradication programs have been successful for black sigatoka.

The island countries of the Pacific have a comparative advantage when it comes to exclusion. The island nature and isolation of many of the countries provides natural barriers to the movement of plant pathogens and make it easier for these countries to police the movement of pathogens and plants compared to countries in Asia that share a common border. Consequently, many of the island nations of the Pacific such as Fiji, Samoa, Tonga grow crops that are still free from major diseases.

However, this comparative advantage is only as good as the enforcement and there are a number of constraints that face quarantine services in the Asian-Pacific region in the face of increasing trade and commerce. In recent years there have been a few notable cases of exotic diseases introduced to certain countries in the region with devastating impact. TLB is a good example. Most recently, TLB spread to Samoa and American Samoa in 1993, most likely from Hawaii, devastating production. Within a matter of months the disease had caused millions of dollars in lost production. Pathogens introduced into an area in which they did not previously exist often have a dramatic impact. This is because the plants that the pathogens attack have not had the opportunity to develop any significant level of resistance in the absence of the pathogen. The nearby islands of Fiji, Cook Islands, Tonga, Wallis and Futuna and Niue have important taro industries and for the time being remain free from the disease but constant vigilance is required by quarantine services.

At the western side of PNG, along the border of West Papua, villagers are dealing with many plant diseases that seriously constrain smallholder production across the country. In addition, they are facing the added difficulties of having to deal with new diseases and threats to food security that are coming over the border from West Papua and further afield. Of great importance are blood disease of banana and citrus huanglongbing (greening) disease. One other banana disease, fusarium wilt, has recently been introduced to PNG and could be catastrophic. Every effort needs to be made to prevent incursions of blood disease and citrus huanglongbing to PNG and the further spread of fusarium wilt to other parts of PNG (Gunua and Davis, 2001). Likewise, devastating taro virus diseases such as *alomae* and *bobone*, currently confined to Melanesian countries pose a major quarantine threat to Indonesia and other Asian countries where this crop is important.

Crop Certification and the Use of Pathogen-free Planting Material

A host plant will grow better and produce a higher yield if the planting material used is pathogen-free (Box 2). For this reason every effort should be made to ensure that farmers get access to such planting material. In developed countries certification schemes are well developed for potatoes and certain fruit species and the provision of certified stock has led to significant improvements in general health and production. Similar certification schemes or programs to produce pathogen-free planting material exist in developing countries. In the Asia-Pacific region, Taiwan has an extensive range of schemes covering staple crops such as rice and coarse grains such as corn, soybean and peanut. Other propagation and inspection systems of virus-free seedlings are now in place for potato, strawberry, sweet potato, asparagus, passion fruit, banana, citrus, sugarcane, anthurium, oncidium and bamboo. Most other countries in Asia have seed certification schemes, backed up by appropriate seed laws, for one or more crops, which have a degree of seed health testing to control the possibility of seed transmitted pathogens. In the Pacific region the formal seed supply network is poorly developed and there are no seed laws or quality standards. Some farmers have access to certified seed through agricultural merchants but generally most use farmer-saved seed.

Box 2. Impact of Virus-free Sweet Potatoes

Sweet potatoes are currently grown by small farmers on 600,000 ha in Shandong province, China with an annual production of about 17 million mt.

In the late 1980s, observations indicated high levels of virus infection and propagation of virus-free seed was identified as a possible means to improve yield. International Potato Center (CIP) and Chinese scientists began a project to develop and transfer methods for propagating virus-free planting material using tissue culture and Enzyme-linked Immunosorbent Assay (ELISA) (Fuglie, *et al*., 1999).

Between 1994 and 1998, virus-free plants were extended to about 80 percent of the hectares and contributed to a 30-percent yield increase with no change in the use of inputs.

The internal rate of return estimated at 202 percent with a net present value of US$550 million. By 1998, yearly productivity increases were put at US$145 million, improving the income of the provinces seven million sweet potato growers by 3-4 percent.

Compared to seed, vegetatively propagated planting material can potentially carry all pathogens that are present systemically in the mother plant in addition to pathogens that are carried externally. Pathogen-free plants may be obtained by meristem tip culture of the upper millimeter or so of the growing tip of the plant. Most viruses do not invade this portion of the plant for a number of possible reasons. Meristem tip culture is sometimes accompanied by heat treatment. This may involve putting plants in controlled temperature cabinets up to 40ºC for a number of weeks. Under these conditions the rate at which new meristematic tissue is synthesized may outstrip the rate of viral replication. Shoot-tips removed from these plants should be virus-free.

Virus and virus-like diseases are serious constraints to tropical fruit production in the region. Several large citrus development programs in the region have failed because of the quality of planting materials used. In Asia, a number of initiatives have been implemented for the production and cultivation of virus-free banana and citrus seedlings which have been integrated with other measures necessary for long-term control. The development of sensitive serological and molecular diagnostic tools for these damaging viruses has improved greatly the impact of disease-free nursery schemes. In Taiwan, a national scheme for certification of citrus bud-wood has been underway since 1983 which employs an improved method of shoot-tip micro-grafting, heat therapy combined with virus indexing that is conducted by the Plant Virology Lab (PVL) at the National Taiwan University (NTU) (Su, 2000). The stocks indexed as pathogen-free by the PVL/NTU are used as the pathogen-free citrus foundation stock collection for the program and are maintained in insect-proof screen-houses.

In Malaysia, several states have been involved in citrus rehabilitation programs and the use of pathogen-free planting materials has been recently implemented (Ong and Ong, 2000). The Malaysian Agricultural Research and Development Institute (MARDI) and Department of Agriculture, Sarawak maintain pathogen-free foundation stocks of popular citrus cultivars. Bud-woods from these plants are subsequently used for the propagation of pathogen-free planting materials.

In Thailand, the disease-free Citrus Nursery Program was implemented by the Thai-German Integrated Pest Management (IPM) project in collaboration with the Department of Agriculture (DOA) (Vichitrananda, 2000). The National Citrus Foundation Block was established in 1994. The DOA is responsible for the National Citrus Foundation Block and Certified Mother Tree Block. Disease-free bud-woods are produced from certified mother trees and released to approved citrus nurseries or farmer groups. A nursery accreditation scheme was introduced in 1993 in order to improve the quality control process. Those nursery owners who wish to be involved in the scheme must follow the conditions, regulations and recommendations indicated in the scheme and must reapply for accreditation every 12 months. Nurseries are inspected twice a year. Similar programs also exist in Japan, Philippines (Phil-German Fruit Tree Project), Vietnam (Southern Fruit Research Institute [SOFRI] Citrus Disease-free Seedlings Program) and Indonesia (Indonesian Citrus Variety Improvement Program).

In Taiwan, since 1983 a total of 26 million banana plantlets have been produced *in vitro* for commercial planting. This has benefitted growers by making available pathogen-free plants and also in the rapid multiplication of new varieties. To meet the demand for large numbers of samples, virus-free stock foundations are kept in special facilities that are insect-proof and vector-free and the viral status is closely monitored. These virus-free plants are used to produce mother plants that are used for multiplication by commercial nurseries. Meristem culture of banana for the production of pathogen-free plantlets has been developed elsewhere in the Asia-Pacific region. This approach is used in the Philippines as an ongoing eradication and banana rehabilitation program (Magnaye, 2000; and Espino, *et al*., 2000). A project for the control and rehabilitation of BBTV affected areas was implemented in 1994 and focused on a community-based approach for smallholder banana growers. This involved consultations with officials and banana growers and a rapid rural appraisal (RRA) with farmer cooperators to determine their understanding of disease management practices. This was followed by training on the early diagnosis of BBTV and proper eradication methods. Pathogen-free plantlets were distributed to farmers at four project sites. The results clearly indicate that areas previously devastated by BBTV can be made productive again. However, this can only be achieved with proper understanding of the disease by the farmers and appreciation of the need to integrate with other methods of control such as proper sanitation to remove alternative sources of inoculum and appropriate vector control.

Cultural Practices and Crop Disease Management

Many of the practices classified as cultural control have been practiced by farmers for centuries in the Asia-Pacific region and form a major component of their indigenous knowledge (Glass and Thurston, 1978; Thurston, 1990; and Hunter, 1996a, 1996b, 1997, and 1998). Thurston (1992) has extensively documented many of these traditional practices and there are increasing demands that such practices and knowledge are integrated to ensure sustainable crop disease management. Traditional smallholder farmers in the tropics can rarely afford the cost of pesticides and labor is relatively inexpensive. This has meant that cultural control has and continues to play a major role in the management of crop diseases.

In the Asia-Pacific region cultural control methods represent locality-specific options for disease management. They have proven their adaptability and worth in a particular environment. They have often arisen as a result of farmers' insightful knowledge of their farming systems and the pests within those systems. Dent (1991) has recognized the value of cultural control and believes that it should be the first line of defense in pest management programs. This can act as a foundation on which other control strategies can be implemented. Above all, cultural control is environmentally safe and is compatible with other control measures. The following list of cultural methods has been shown to have some benefit for disease management in the Asia-Pacific region (Hunter, 1998, Thurston, 1992).

1. ***Destruction of Plant Disease Inoculum***

Many pathogens can survive in soil or on plant residues, and readily infect newly-planted crops. Such practices as clearing land and burning residues is believed to have a number of beneficial disease control effects. Soil-borne fungal pathogens are destroyed in the upper soil levels during burning. Flooding with water is a common feature of taro cultivation and may reduce pathogenic fungi in soil. The early removal (rouging) of virus-infected plants may help reduce the incidence of disease. In some countries, such as Hawaii and Guam, removal of watermelon mosaic virus infected plants has led to a reduction in disease incidence by providing less inoculum for insect vectors. The early removal of dasheen mosaic virus and *alomae*- and *bobone*-infected taros may provide good control. Banana bunchy top may be controlled in a similar way. It is important to be careful when removing infected plants as there is the risk that the vectors will disperse to uninfected plants. Plants may be doused in kerosene and burnt. Roguing of *Pythium*-infected taros may be useful and care should be taken to remove all decayed roots and corms. In Palau, the traditional approach is to remove the plant and all the soil surrounding the roots.

2. ***Crop Rotations***

Asian and Pacific farmers have used rotations for millennia. Particular plant pathogens are associated with specific crops. If these crops are continuously grown then these pathogens can reach very high levels. By planting unrelated crops the buildup of disease is halted.

3. ***Plant Density and Spacing***

Low plant densities contribute to a reduction in humidity in the plant microclimate that lowers the incidence of a number of plant diseases such as Sigatoka of banana. In some Pacific countries increased plant spacing has been observed to reduce the incidence of TLB. In Asia, traditional spacing practices have been useful in managing downy mildew in maize. Sheath blight is now one of the major fungal diseases on high-yielding varieties (HYVs) of rice in Asia. The HYVs tend to be planted in high densities which make them more susceptible to the disease. Prior to the release of IR8 in 1966 sheath blight was considered a minor rice disease (Crill, 1981). There is evidence that planting at low densities reduces the incidence of disease.

4. ***Depth of Sowing***

The perfect stands found in many crops grown by traditional farmers in Asia reflects their knowledge in using this practice (Thurston, 1992).

5. ***Time of Planting***

Plant diseases can often be avoided by planting at times of the year that are unfavorable for disease development. In Asia, early planting of rice and maize has been reported to reduce the incidence of rice blast and downy mildew, respectively (Kozaka, 1965; and IRRI 1979).

6. ***Flooding***

The paddy system of rice production represents one of the oldest practices that uses flooding for plant disease management. Severity of rice blast is reduced on flooded paddy rice compared to upland rice due to reduced infection periods (Thurston, 1992). A similar system for taro production in the Pacific may contribute to disease management.

7. ***Mulching***

The placement of a mulch of old leaves or weeds around the base of beans has been shown to reduce infection by web blight (Thurston, 1992). Mulching is believed to prevent the dissemination of soil-borne fungi by not allowing soil splashing by rain to occur. This has been demonstrated for yam anthracnose in the Pacific.

8. ***Raised Beds***

The use of raised beds for modification and cultivation of wetland areas has been described for a number of countries in Asia (King, 1926). In the Pacific, raised bed agriculture has been, and continues to be, effectively employed for the cultivation of mainly root crops. Raised bed systems have been described for a number of different environments and represent a highly productive form of cultivation. Thurston and Parker (1995) report that, in addition to their obvious irrigation and drainage value, there is little doubt that disease management is an added benefit of raised bed systems. They cite examples of the suppressive nature of raised bed soils against damping-off fungi (*Pythium* spp.) This is attributed to the increased biological activity of known *Pythium* spp. antagonists such as *Trichoderma* spp., *Pseudomonas* spp., and *Fusarium* spp. in raised bed soils due to the addition of large amounts of organic matter. These antagonists are also likely to be active against other soil-borne plant pathogens. Raised bed soils were also found to suppress plant parasitic nematodes, containing nine organisms that had anti-nematodal activity. In addition, the high organic content of these soils was thought to contribute to the low numbers of nematodes in these soils.

9. ***Crop Diversity***

Polyculture or mixed cropping (the growing of two or more crops at the same time) has been observed to reduce the incidence of disease. It is believed that such environments represent a more stable ecosystem and offer a greater degree of protection compared with monocultures. A diversity of crops helps to delay the buildup of plant pathogens. It is interesting to note that the incidence of the disease kava dieback, caused by cucumber mosaic virus (CMV), is more severe in places such as Fiji where it is planted mainly as a monoculture. The incidence in Vanuatu where kava forms a component of the traditional mixed cropping system is lower. The virus is transmitted by an aphid vector and in the traditional mixed cropping system the aphid may have difficulty locating kava plants and along the way it will feed on other non-kava plants and quickly loses the ability to transmit the virus. There is abundant evidence to show that crop diversity contributes to the management of other pathogens also.

10. ***Destruction of Alternate Hosts***

Weed hosts act as carriers for a number of plant pathogens, especially viruses, over successive seasons. The control of these weeds is complicated, given that they are often symptomless carriers of viruses and root pathogens but their destruction has been demonstrated as contributing to a reduced incidence of certain diseases. Weed control is important for the control of a number of cucurbit viruses that cause damage in Pacific Islands and for control of CMV in bananas.

Biological Control and Crop Disease Management

Biological control is increasingly recognized as the foundation of a many successful IPM programs (Lenne, 2000). Biological control has a number of benefits. It is environmentally benign and once established can give long-term control. After initial costs it is relatively inexpensive. It also ensures control over a large area compared to other control measures such as chemical spraying which only gives control in the area treated. It can contribute to healthy food, cleaner environment and increased profits for farmers. In Asia it has been demonstrated that outbreaks of the brown planthopper (BPH) in rice were caused by the destruction of effective natural enemies through the indiscriminate use of broad-spectrum insecticides. Failure to recognize the importance of natural biological control led to continuous outbreaks of BPH in several countries in Asia until the FAO Inter-Country Programme encouraged countries to appreciate this ecological phenomenon. This Programme has encouraged extension staff to understand the role of natural enemies in their farming systems. This has been done by implementing Farmer Field Schools (FFSs) where biological control is the main focus of an integrated approach to pest control.

Unfortunately, efforts at biological control of plant pathogens have lagged behind developments in the field of entomology and there are few examples of successful field implementation of biological disease control. However, significant development work would seem to imply that biological control has great potential for the sustainable management of plant pathogens. Biological control of plant pathogens usually refers to the use of one organism as an antagonist to another. This can take the form of suppressive soils that contain antagonistic microorganisms, using antagonistic and trap plants. These biological control agents may be employed to keep the pathogen population below an acceptable threshold level, or may be used as a living barrier that prevents pathogen infection. Traditional farmers have been using biological control for millennia through the development of suppressive soils (Thurston, 1992) and this was highly developed in China (King, 1926) and a number of Pacific Island countries (Hunter, 1997). Examples of biological control of plant pathogens include the following:

Bacteria such as *Bacillus cereus, B. subtilis* and fluorescent pseudomonads have also been successfully used to control fungal root pathogens. In Indonesia, fluorescent pseudomonads have been shown in the laboratory to reduce the severity of *Ralstonia solanacearum*, the cause of blood disease in banana (Subandiyah, *et al*., 2001). Endophytic fungi of durian may have some potential as an antagonist of *Phytophthora palmivora* (Brown, *et al*., 2001). In Taiwan, a *Bacillus subtilis* isolate was recently commercialized by Kuan-Hwa Chemical Co. for the control of powdery mildew of pea. *B. subtilis* was also found outstanding because of the superior antagonistic activity against *Rhizoctonia solani* AG4, *Sclerotium rolfsii*, and *Xanthomonas* sp. pv. *mangiferae-indicae* (Xcm). Its mass production technique has been developed in Taiwan. Commercial preparations of *Trichoderma* and *Streptomyces* spp. are also commercially available.

Inoculation of a healthy plant with a mild, or less severe strain, of a particular virus, gives protection to the plant against other more severe strains of the same virus. Cross protection technology has been used in some countries of the Asia-Pacific region. This includes work on cucurbits infected with zucchini yellow mosaic virus (ZYMV). The process involves mechanically inoculating the leaves of cucurbits with the mild strain of the virus before they are transplanted into the field. In one trial in the Pacific, cross protection resulted in a reduction of almost 50 percent in the levels of disease compared to unprotected plants. Cross protection has been used in Taiwan and some other countries of Asia with mild strains of citrus triesreza closterovirus (CTV). One obvious problem with this technique is the need for labor to carry out the mild strain inoculations before plants are transplanted into the field.

Host Plant Resistance and Crop Disease Management

Traditional farmers in the Asia-Pacific region have been selecting, consciously and unconsciously, disease-resistant plants for centuries. These farmers often have knowledge of a large number of traditional varieties that they know will give good agronomic performance but also have a degree of resistance to the many injurious diseases that attack their fields. More recently, scientists have been breeding plants for improved resistance to plant disease (Hunter, 1998).

Since the 1960s, host plant resistance has been increasingly successful in the management of important diseases of staple food crops in developing countries with significant and sustained benefits to both smallholder farmers and their environment (Lenne, 2000). The gains from resistant varieties have been most significant in Asia. HYVs of wheat and rice of the Green Revolution with resistance to fungal and viral pathogens have contributed significantly to increased productivity, cheaper food and reduced poverty. Similar gains have been experienced in India with disease-resistant legumes (Bantilan and Joshi, 1996; and ICRISAT, 1997). Banana BLS-resistant varieties released by the Honduran Agricultural Research Foundation (FHIA) breeding program have had some positive impact in Pacific countries. These FHIA hybrids are currently undergoing screening for resistance to other pathogens including nematodes and are being evaluated in over 50 locations. Agricultural Research for Developing Countries (CIRAD) have plans to screen bananas from their breeding program for BLS resistance in New Caledonia (Persley and George, 1996). In the Pacific, the TaroGen project has supported taro breeding programs in PNG and Samoa. These programs, based on durable resistance to TLB, have resulted in the release of nine new resistant varieties. There are plans to distribute these new varieties to other countries in the Pacific with TLB and also to countries still free from the disease (Hunter, *et al*., 2002).

Resistance conferred on a plant by one or a few genes is often referred to as monogenic/oligogenic or race-specific resistance. This type of resistance usually results in the hypersensitive response and gives complete control against the pathogen. This is easy to work with in breeding programs because it is easily incorporated into plants and gives a high level of resistance. Unfortunately it is this type of resistance that is easily overcome by new races of the pathogen. For this reason, resistance based on one or a few genes has generally not proved to be long-lasting. The breakdown of resistance in potato to *Phytophthora infestans* clearly illustrates this point. When many genes control resistance it is referred to as polygenic or non-specific resistance. Unlike specific resistance this type of resistance does not give complete control but the host plant is able to reduce or restrict the colonization or spread by the pathogen or limit the rate at which it can produce spores. Because none of the genes involved confer resistance if acting in isolation they are referred to as minor genes. Non-specific resistance has the advantage of being long-lasting or durable, and it is being increasingly utilized in breeding programs such as the TaroGen taro breeding projects mentioned above.

Robinson (1996) describes a number of innovative participatory approaches to plant breeding based on horizontal or durable resistance aimed at 'demystifying' plant breeding and taking control away from professional breeders and putting it in the hands of university students and farmers. He describes the formation of university breeding clubs and decentralized farmer participation schemes. The first university breeding club in the world was started in 1995 in Mexico. A university taro-breeding club was initiated at the University of the South Pacific (USP), Samoa in 1999 (Box 3). This was the first club to be inaugurated outside of Latin America (Hunter, *et al*., 2001). The club represents an innovative approach to teaching and learning at USP. It is a cheap and easy approach to breeding. It ensures that there are many hands to do breeding work and has resulted in increased taro breeding activity. Robinson (1996 and 1997) has proposed university breeding clubs as a "hands-on" approach for students to learn about breeding for horizontal resistance and a way of "scaling-up" farmer participation in plant breeding. Robinson (1997) envisaged student members of breeding clubs returning to their family farms with potential new cultivars for evaluation. After a few decades, there could be hundreds, or even thousands, of former club members testing new lines as they emerge from clubs. Additional breeding clubs would increase the output even more, providing the widest extent and the highest possible quality of farmer participation in plant breeding.

Box 3. Participatory Plant Breeding and Farmer Participation Schemes

The overall aim of the USP taro breeding club is to produce high-yielding, good-quality taro cultivars that have high levels of horizontal resistance to TLB and other locally important taro pests, and that are adapted to a range of diverse environments.

Most members are students but some are professionals, such as lecturers, crop researchers, technicians, and university administrators, while a small percentage are farmers.

A successful farmer participation scheme, the Taro Improvement Project (TIP) was initiated at USP in 1999. TIP aims to bring together taro growers and provide them with more options for improving production and managing TLB in Samoa (Hunter and Fonoti, 2000; and Hunter, *et al*., 2000).

TIP supplies each participating farmer with planting material of several taro cultivars or seedlings. Information is provided on trial layout, labelling, and simple data collection. The trials are maintained and managed by farmers. To facilitate feedback and sharing of information regular monthly meetings held. These meetings help growers to learn about other growers' experiences.

Biotechnology – The Future of Crop Disease Management in the Asia-Pacific Region?

The rapid growth of biotechnology has generated considerable excitement and debate about its potential impact in the fight against plant disease and its contribution to the development of a more sustainable agriculture. There is no doubt that biotechnology has provided us with a very powerful new set of tools to manipulate novel traits for disease-resistance and to diagnose plant pathogen causes of disease. It expands the germ plasm base from which plant breeders can draw on for disease-resistance genes. Potentially, it represents a powerful precision tool that offers significant advantages over other disease-control strategies such as pesticides – better protection, reduced environmental impact, reduced health risks. Given the growing limitations imposed on agricultural productivity by land and water, novel biotechnologies will be a key factor in achieving the necessary productivity increases required over the next few decades to meet the food needs of a rapidly growing global population. Some countries in the Asia-Pacific region are already realizing the benefits of this new technology (Box 4).

Transgenic plants have been reported for some of the crops important to the Asia-Pacific region. Sugarcane plants with resistance to sugarcane mosaic virus have been reported (Arencibia, 1999). Potato, the most tested crop in field trials to evaluate transgenic plants, has been reported with genetically engineered resistance to PVX, PVY and PLRV (potato leaf roll virus). There is still someway to go in terms of resistance to the two most important potato diseases in developing countries – late blight and bacterial wilt (Ghislain, *et al*., 1999). In rice, transgenic plants with resistance to bacterial blight, blast, sheath blight and a number of viruses are available (Kloti and Potrykus, 1999). In Australia, efforts are underway to develop transgenic plants with resistance to banana viruses (although transgenic resistance to DNA viruses like BBTV has been difficult to achieve), taro viruses, papaya ring spot virus (PRSV), ZYMV and sugarcane Fiji disease virus (Rob Harding, personal communication). New transgenic varieties of banana with resistance to BBTV and papaya resistant to PRSV have been reported in the Philippines (Persley, 1999) and Taiwan.

Box 4. Impact of Biotechnology in Asia

In Asia, countries like China, India, the Philippines, Malaysia and Thailand are committed to investing in the development of biotechnology for agriculture (Persley, 1999, FAO/Asia-Pacific Association of Agricultural Research Institution [APAARI], 2002).

Early impacts would seem to be positive. A study in 2002 found that farmers in China were benefiting substantially from the use of transgenic crops with pest and disease resistance (Pearce, 2002).

Farmers' production costs have decreased by 28 percent and the average farmer income has increased by US$150 per year. In addition, there has been an 80-percent decrease in the use of organophosphate pesticides and a significant reduction in the number of pesticide poisonings. Reduce pesticide use is reflected in a recorded increase in the diversity of natural enemies. The survey also found scientists in the country had introduced over 120 genes to more than 50 plant species, many of which have been largely ignored by Western companies. Also, most of the transgenic plants in China target insects and diseases.

Biotechnology offers the opportunity for decreased use of pesticides with the associated benefits to the environment and health. While there is reason to be optimistic about the potential of biotechnology to address many of the important disease constraints that we face in the Asia-Pacific region it has also raised widespread opposition that is not confined to developed countries but has also occurred in the Asia-Pacific region. Many of these concerns center on a range of environmental, health, socioeconomic and ethical issues that will need to be addressed if we are to move ahead.

ISSUES CONSTRAINING THE USE OF NONPESTICIDE METHODS OF CROP DISEASE MANAGEMENT

The continued promotion of nonpesticide methods for crop disease control is essential for the development of a more sustainable agriculture. However, there are important obstacles that at present minimize their impact. One of the most important factors is the power of the pesticide industry and its lobbyists often reinforced in countries that provide subsidies for chemicals. Even if subsidies are not provided directly they are through the costs required to treat those whose health is compromised by their use or adverse environmental impact. Governments have a significant role to play here by stronger regulation of the pesticide industry. This would include restriction on the use of very damaging pesticides and a price system that is a true reflection of their real impact. At the same time governments need to actively support the use of nonpesticide methods through increased allocation of resources for research and staff and a policy environment that encourages the use of nonpesticide methods of control. More specific issues that need to be addressed at the individual method level are outlined below.

Within the Asia-Pacific region there is a wide discrepancy in the capacity of national quarantine services. Most, if not all, quarantine services in the region are constrained by one or a few of the issues that follow. Many quarantine services in the region are under-resourced in terms of trained human capacity and modern technologies required to effectively police the movement of plant material. This is more the case for Pacific countries but it applies also to many of the Asian countries that have much greater levels of trade and commerce to deal with. Many Asian countries share a common border and have multiple entry points that require more demands from quarantine services. This limited capacity makes it difficult for countries to adequately respond to a disease incursion and achieve eradication. Good quarantine requires effective regulations and laws. Although most countries in the region have adequate legislation there are still a few countries that do not. Pathogens pose a serious challenge to plant quarantine services compared to other pests such as insects because they may be introduced as spores or eggs on unsuspected carriers or occur as latent infections. Plants or plant parts with virus infections may not show symptoms. Very often quarantine services do not have adequate personnel trained in disease recognition or the necessary serological/molecular diagnostic tools. In the case of the Pacific, few of the major pathogen problems have been adequately characterized such as viruses causing disease in taro, kava and yams. Sensitive diagnostic methods have not been developed and this seriously constrains the international movement of crop germ plasm. This has been a major constraint to crop improvement programs in the Pacific. An important dilemma facing all countries of the region is the urgent need to find a viable alternative to methyl bromide which is to phase out by the Montreal Protocol in 2005.

Certification schemes or programs to produce pathogen-free planting material are costly and require a certain level of infrastructure and human capacity. This is required to enforce regulations and ensure a degree of quality control. Schemes are also reliant on access to sensitive diagnostic methods. Not all countries in the region have this capacity. In some countries, e.g., Thailand, there was a perception among most farmers that disease-free plants were resistant to pathogens when grown in orchards (Vichitrananda, 2000). This indicates the need for education and awareness to accompany programs and the diseases being targeted. What do farmers need to know to ensure that pathogen-free planting material remains so for longer? Other constraints identified in such programs include difficulty in getting farmers to remove healthy-looking trees and plants that are infected (again, education is very important). There may be a requirement to use pesticides to control vector buildup to ensure the program is effective. Molecular diagnostics are expensive and require expertise that may not be available in some countries. There is a need for simple and cheap diagnostics. The effectiveness of such certification strategies is dependent on the ability to accurately diagnose and detect viral pathogens. In certain countries, such as Thailand and Malaysia, there are problems related to accelerating the production of pathogen-free citrus seedlings to meet demand.

Although cultural methods offer appropriate approaches to obtaining sustainable disease management and a sound alternative to pesticides it is important to remember that many of the methods are locality-specific. Some methods are also labor-intensive and generally have not become widely adopted by farmers due to economic constraints and the long-term nature of the methods. The benefits and advantages of biological control are well documented. However, there are relatively few successful examples of the widespread application in disease management. There have not been the same successes as have been achieved with insect management. Despite extensive research on the use of biological control of plant pathogens there are few practical applications, even fewer for the Asia-Pacific region. Many of these antagonists are already present naturally in the soil and it may be best to encourage their activity through some of the other methods mentioned and which are common to traditional farming systems.

Host plant resistance has been an important tool for achieving sustainable crop disease management. Despite this it is a relatively long-term activity. In addition, many countries in the Asia-Pacific region do not have the capacity to sustain breeding programs. At present there are only two breeding programs in the Pacific on taro and rice.

The issues surrounding the use of biotechnology and its application to agricultural improvement are many and complex. There are many technical issues, such as the development of gene delivery and transformation systems, that are constraining developments for specific crops but these will be overcome with ongoing research. Although biotechnology and its role in disease management appears to be progressing in Asia, it is worth discussing its possible role in the Pacific region. It has already been highlighted that Green Revolution technology had a minimal role in the Pacific region and unless things change considerably over the next few years it is possible that the technology gap between Asia and the Pacific will widen further. At present there is little capacity or resources to undertake biotechnology research in the Pacific. There is little that exists in the form of policy or a regulatory framework to facilitate biotechnology research or applications. Costs and resource requirements for biotechnology are high. Can Pacific countries afford the costs required to undertake such research? If they cannot, can they rely on biotechnology organizations, private or public, to address their relevant crop disease needs? If they can, will farmers be able to afford the end-product? New transgenic plants are the product of millions of dollars in investment. The price of the end-product is likely to be beyond what a typical farmer in the Pacific can afford to pay. Staple crops important in the Pacific have been neglected by past developments in crop protection technologies, will they continue to be? Who are these neglected crops going to interest? Some of these issues apply to countries in Asia with similar human capacity and resource constraints.

The other issues that concern the role of biotechnology are more general and have been summarized by Conway (2000) and Tripp (2000) as:

* <u>Environmental issues</u>: gene transfer to wild relatives (genetic pollution), impact on natural fauna and flora, pathogen resistances.

* Health issues: possibility of transferring antibiotic resistance to soil fauna and eventually to livestock and humans, allergens ('Frankenfoods'), toxins, long-term health effects.
* Ethical issues: naturalness of genetic engineering, bypassing of public interest, domination by a few major private companies.
* Benefits to the poor: are the poor going to benefit, will farmers and consumers in the Asia-Pacific benefit?
* Sustainable agriculture issues: what will be the impact on the pursuit of sustainable agriculture, will biotech lead to increased domination by large-scale agriculture? There is concern regarding the 'marriage' between the pesticide and biotechnology industries.

STRATEGIES FOR FACILITATING THE SUCCESS OF NONPESTICIDE METHODS

Countries of the region need to appreciate the real cost associated with the past use and reliance on pesticides for pest control. These costs have been highlighted in depth in this paper. There is an urgent need to actively support and promote nonpesticide methods if we are to change from the prevailing approach to pest control to a more ecological approach. It is recommended that:

* governments put in place policies to promote all aspects of nonpesticide and a more ecological approach to crop disease control;
* farmers be educated and trained to enhance their skills and knowledge of nonpesticide methods. Over the last decade, there has been a significant shift in the emphasis of IPM programs throughout Asia, towards a more participatory, decentralized, community-based approach, termed community IPM, in which the farmers become the initiators, implementers and promoters of IPM and not just the recipients. In community IPM, farmers organize, manage and implement their own IPM activities, analyze problems, design field studies and carry out experiments and undertake efficient farming practices. This involves a range of approaches such as FFSs and farmer-to-farmer training, considered to be a cost-effective, decentralized, community-based, farmer-first approach that will promote sustainability and expansion of IPM and reduce reliance on pesticides. Although community IPM and FFS initially grew out of problems related to insect pest management there is a growing awareness among plant pathologists of their relevance to sustainable crop disease management in the region (Box 5). It is recommended that the FFS approach continue to be explored to enhance the use of nonpesticide methods;
* Linkages are developed between all stakeholders (farmers, extension workers, researchers, NGOs and other community-based groups including consumers) to enhance awareness and knowledge of nonpesticide methods through more effective networking;
* Countries strengthen regulation of the pesticide industry to reflect its real cost; and
* There is further cooperation and coordination among national/regional/international organizations and donors to highlight the problems with pesticide use and to promote a more ecological approach to crop disease control.

Box 5. Farmer Field Schools and Crop Disease Management

Small farmers understanding of disease is limited and management often ineffective. Farmers in Central Vietnam expressed interest in learning more about rice blast and disease management. A season-long FFS on management of rice blast was developed based on the approach used by FAO IPM program. Farmers implemented field experiments including testing promising varieties, breeding lines, varietal mixtures, along with cultural methods (Nelson, *et al.*, 2001). Farmers learned about host resistance, disease epidemiology. Farmers indicated the FFS very worthwhile. Farmers had a greater understanding of plant disease and the capacity to manage rice blast more effectively. Farmers reduced inputs and had healthier crops. Other approaches to help farmers learn about plant disease are worth exploring (Sherwood and Bentley, 1995).

CONCLUSIONS

This paper has identified a broad range of methods and approaches that can be used to achieve nonpesticide crop disease management. It has identified many problems and constraints that have limited the impact of these methods in the Asia-Pacific region. A range of broad strategies or solutions are outlined that might contribute to improving the success or wider adoption of nonpesticide approaches. However, it is important to remember that no one group of methods will solve crop disease problems. There is no blanket solution. Farming systems in the Asia-Pacific region are highly diverse and will require a range and diversity of solutions to crop disease problems. What is required is to ensure that countries have access to the widest possible basket of options. The challenge ahead for researchers is to identify and integrate sustainable disease management technologies that can contribute to increased productivity, such as breeding for durable resistance, biological control and cultural methods and which will have minimal adverse environmental and social impacts.

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3. BIOLOGICAL CONTROL OF VEGETABLE PESTS WITH NATURAL ENEMIES

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INTRODUCTION

Use of natural enemies to control pests is termed biological control. There are three kinds of biological control of pests, i.e., introduction of new natural enemy species, augmentation and conservation (van Driesche and Bellows, 1996). Reared natural enemies are released in greenhouses or in the field in augmentation. Suppressive effect of indigenous natural enemies on pests in the field is used in conservation. Use of natural enemies is essential in integrated pest management (IPM) of vegetables pests. Augmentative release of natural enemies is the key technology in IPM of greenhouse pests. On the other hand, conservation of indigenous natural enemies is crucial in IPM of vegetable pests in the field.

In Japan, protected cultivation in glass and plastic greenhouses has made rapid progress since the 1960s and the total protected area now comprised about 50,000 ha. Biological control of glasshouse pests using arthropod natural enemies has become important since the 1970s in Western Europe (Ravensberg, 1992). Biological control is also expected to become the basic system of pest control in Japan for safe and laborsaving crop production in greenhouses (Yano, 1993). Because of specificity of natural enemies to pests, integrated use of natural enemies and other compatible control measures for each crop is necessary for practical application.

Recently, some trials have been carried out to develop IPM of vegetables in the field. These are based on conservation of indigenous polyphagous predators and use of selective chemicals. Vegetation management for conserving natural enemies is also taken into account in some studies.

BIOLOGICAL CONTROL AND IPM IN PROTECTED CROPS

The Greenhouse Environment in Japan

The greenhouse environment in Japan is characterized by: (1) cultivation in small plastic greenhouses; (2) high temperatures from spring to autumn and relatively low temperatures in winter; (3) high humidity all the year round; and (4) immigration of pests from the surroundings because of poor isolation from the outside environment (Yano, 1993). These conditions cause several problems in pest and disease control, i.e., the need for frequent application of pesticides and fungicides, rapid population growth of pests, and unfavorable conditions for some of the natural enemies. Chemical control of pests is not easy and is always accompanied by the risk of development of resistance to pesticides. Also, the application of biological control is more difficult than in Western Europe.

Most of the greenhouse pests in Japan are cosmopolitan. They are small in size and suck fluids from plants. They belong to several groups of insects or mites, i.e., aphids, whiteflies, thrips, mites, leaf miners and nematodes. Noctuid moth species such as *Spodoptera litura* (Fabricius) (Lepidoptera:Noctuidae) sometimes outbreak in the southwestern region. Another important fact is that several exotic pests have become serious in protected cultivation (Table 1). After the rapid development of greenhouse cultivation in the 1960s, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) and *Thrips palmi* Karny (Thysanoptera:Thripidae) invaded in 1974 and around 1980, respectively. More recently, *Bemisia argentifolii* Bellows and Perring (Homoptera:Aleyrodidae), *Liriomyza trifolii* (Burgess) (Diptera:Agromyzidae) and *Frankliniella occidentalis* (Pergande) (Thysanoptera:Thripidae) were reported as new pests around 1990.

These species have established as major pests in protected cultivation in Japan. Another important fact is the high activity of indigenous natural enemies, which sometimes completely suppress the pests in greenhouses after immigrating into greenhouses from surrounding environment.

Table 1. Major Greenhouse Insect Pests in Japan*

Crop	Pest
Tomato	***Trialeurodes vaporariorum, Bemisia argentifolii, Liriomyza trifolii**, Myzus persicae, Aphis gossypii,* ***Aculops lycopersici**, Meloidogyne incognita*
Eggplant	***Thrips palmi, T. vaporariorum, B. argentifolii**, M. persicae, A. gossypii, Tetranychus urticae, Tetranychus kanzawai, Polyphagotarsonumus latus, Spodoptera litura*
Sweet pepper	***Frankliniella occidentalis**, Frankliniella intonsa,* ***T. palmi**, M. persicae, A. gossypii, P. latus, S. litura*
Cucumber	***T. palmi, T. vaporariorum, B. argentifolii**, M. persicae, A. gossypii, Rhopalosiphum rufiabdominalis, M. incognita*
Watermelon	***T. palmi**, M. persicae, A. gossypii, T. urticae, T. kanzawai, M. incognita*
Strawberry	***F. occidentalis**, A. gossypii, Chaetosiphon minor, Aphis forbesi, T. urticae, T. kanzawai, Nothotylenchus acris, Pratylenchus vulnus, S. litura, Anomala cuprea*

Note: Names in bold letters refer to imported species.

Biological Control in Protected Crops in Japan

Natural enemies released in greenhouses are produced in a large scale. In many countries, natural enemies are produced as commercialized products for pest control. Although biological control has the advantage with respect to risk of resistance development of pests against pesticides and environmental safety, it has the disadvantage with respect to specificity and dependence of effectiveness on environment (Table 2).

Table 2. Comparison of Aspects Related to the Application of Chemical and Augmentative Biological Control

	Chemical Control	Biological Control
Risk of resistance	Large	Small
Specificity	Low	High
Environmental safety	Depend on chemicals	Safe in most cases
Dependence of effectiveness on environment	Low	High
Cost	Depend on chemicals	Often expensive

In Japan, registration as biopesticides is necessary if natural enemies are sold as commercial products. Ten arthropod natural enemies have been registered as biopesticides until 2002 (Table 3). After the first registration of *Phytoseiulus persimilis* Athias-Henriot (Acarina:Phytoseiidae) and *Encarsia formosa* Gahan (Hymenoptera:Aphelinidae) in 1995, eight imported species have been registered. Two *Orius* species and indigenous and some other promising indigenous species will be registered soon.

P. persimilis has a long history of study in Japan, where it was introduced in 1966. After extensive fundamental and applied studies on its use (Mori and Shinkaji, 1977), several production facilities for the predator were constructed and the predators produced were distributed in several prefectures. However, its use by farmers was not developed until recently because of limitation of the supply and the lack of integrated control systems for greenhouse crops. *P. persimilis* was first registered as a biotic pesticide and commercialized in 1995 for controlling spider mites on strawberries. Since then, *P. persimilis* has been registered to control spider mites on eight greenhouse crops and the area of release is the largest among commercialized natural enemies in Japan.

Table 3. Registered Arthropod Natural Enemies in Japan, 2002

Natural Enemy	Pest	Crop
Phytoseiulus persimilis	Spider mites	Strawberry, eggplant, cucum ber, watermelon, sweet pepper, three other crops
Encarsia formosa	*Trialeurodes vaporariorum*, *Bermisia argentifolii*	Tomato, cucumber, melon,, eggplant
Diglyphus isaea	*Liriomyza trifolii*	Tomato, eggplant
Dacnusa sibirica	*L. trifolii*	Tomato, eggplant
Amblyseius cucumeris	*Thrips palmi, Frankliniella*	Cucumber, strawberry, watermelon, melon, eggplant, sweet pepper
Aphidius colemani	Aphids	Cucumber, strawberry, watermelon, melon, eggplant, sweet pepper
Aphidoletes aphidimyza	Aphids	Cucumber, melon, strawberry
Orius sauteri	*T. palmi, F. occidentalis*	Sweet pepper, cucumber, eggplant
Orius strigicollis	*T. palmi, F. occidentalis, F. intonsa*	Sweet pepper, eggplant
Chrysoperla carnea	Aphids	Strawberry, eggplant, sweet pepper

Source: Japan Plant Protection Society.

E. formosa was imported from the U.K. in 1975, the year after the first recognition of the occurrence of *T. vaporariorum* in Japan. The effects of temperature and release methods on the control capability of *E. formosa* were evaluated in greenhouse trials and by developing a simulation model of the host-parasite population interaction (Yano, 1987, 1989a, 1989b, and 1990). Use of the imported bumblebee, *Bombus terrestris* (L.) (Hymenoptera:Apidae), for pollination is increasing among tomato growers in Japan. This is helpful for the production of good quality fruits, and the application of insecticides must be regulated after introduction of the bumblebee in greenhouses. *E. formosa* is expected to control whiteflies in this case. After its registration as a biotic pesticide in 1995, the area in which the parasitoid is being released in tomato greenhouses is increasing.

The use of *P. persimilis* and *E. formosa* is not sufficient to develop a practical IPM system for each greenhouse crop. Aphids are very difficult to control as indigenous pests. Imported pests after 1980 (Table 1) also became serious on many crops. Imported natural enemies, which have been commercialized in Europe and in North America, are tested in many agricultural experimental stations for possible registration as biotic pesticides for commercial use and another six species have been registered to control pests on many kinds of crops (Table 3). Trials have not always been successful with some species of natural enemies. This was partly due to the lack of sufficient knowledge and experience about such exotic natural enemies on the part of the researchers involved.

Although most serious pests are exotic species from abroad, indigenous natural enemies can be used to control them if they are released artificially. This is also preferable to the use of imported species from the point of view of the possible effect of imported species on indigenous species in agro-ecosystems. Promising results were obtained in the use of *Orius* spp. for biological control of *T. palmi. Orius sauteri* (Poppius) (Hemiptera:Anthocoridae) suppressed the increase of *T. palmi* on eggplants in greenhouse trials (Kawai, 1995). Rearing techniques of *Orius* spp. in the laboratory have been developed using eggs of *Ephestia kuehniella* Zeller (Lepidoptera:Pyralidae) (Honda, *et al*., 1998). With respect to commercial application, *Orius strigicollis* (Poppius) (Hemiptera:Anthocoridae) is preferred to *O. sauteri* because of ease of mass production and weaker diapause response. *O. strigicollis* and *Amblyseius cucumeris* (Oudemans) (Acarina:Phytoseiidae) are widely used to control thrips on eggplants and sweet peppers in Kochi and Miyazaki prefectures.

Factors Limiting Use of Natural Enemies

Technically, extreme temperatures in greenhouses and the effect of chemicals are two major factors affecting control capability of *P. persimilis* in commercial greenhouses. Monitoring of the early infestation by spider mites to determine the time of introduction of *P. persimilis* is also crucial for the commercial use of the predatory mite because spider mite outbreaks occur in spring more readily than in Western Europe.

Delay of release in greenhouse and low temperature condition in winter are two major factors of failure of use of *E. formosa*. Monitoring of the early infestation of whiteflies is of paramount importance, because one of the reasons for failure of the use of *E. formosa* is delay in its release. Trapping of adult whiteflies by yellow sticky traps and check of occurrence of adults on each plant based on binomial sampling were developed as monitoring methods. Most of the insecticides are harmful to *E. formosa* except for some insect growth regulators (IGRs), while many acaricides and fungicides are less harmful. The most important technical factors for commercializing natural enemies is integration of use of natural enemies with other control measures for controlling other pests on a crop. If the control measures for other pests are incompatible with use of natural enemies, practical use of natural enemies is almost impossible.

Social limiting factors in biological control are: 1) low tolerance of pest damage; 2) supply of natural enemies; 3) poor advisory service for farmers; and 4) need of registration (Yano, 1993). Low tolerance of pest damage is the main reason for difficulty in biological control in flower production. Lack of the system for supplying enough natural enemies of good quality was the limiting factor in Japan, because private companies had been not interested in biological control in Japan until recently. However, 10 species arthropod natural enemies have been registered and sufficient number of imported or indigenous natural enemies is supplied by private companies now. Advisory service for farmers is very important to obtain good performance of natural enemies for promoting biological control.

Other Control Measures for IPM

Although cultural and physical control measures do not have a curative effect after heavy infestations of greenhouse pests, their preventive effect on the rapid increase of pests is of great importance in integrated control. Their effectiveness is related to regulation of life histories or regulation of dispersal.

T. palmi is a species of subtropical or tropical origin and is considered to be unable to survive in the field in Japan in winter (Ikeda, 1983). Suppression of *T. palmi* in greenhouses before the winter should decrease the density in the next season. *B. argentifolii* is also difficult to survive in winter. Most of the greenhouse pests are polyphagous and can infest many kinds of crops and weeds as host plants. If suitable host crops are cultivated, or host weeds grow, near greenhouses, the pests can migrate from the greenhouse to surrounding fields and *vice versa*. Host weeds growing in greenhouses are also important for the survival of pests after harvesting. Removal of host weeds inside and near greenhouses and avoidance of cultivation of host crops are fundamental conditions for preventive cultural control.

Helgesen and Tauber (1974) pointed out three possible routes of introduction of *T. vaporariorum* into greenhouses: (1) artificial introduction of the infested seedlings; (2) infestation from weeds or other crops in the greenhouse; and (3) infestation from host plants outside but near the greenhouse. This suggests several possibilities for control by prevention of artificial introduction or dispersal of pests. Cultivation of uninfested seedlings in nurseries, removal of host weeds in greenhouses and the use of nets to cover the openings of greenhouses to prevent immigration of pests from outside. These techniques are also applicable to other pests. Plastic films that absorb ultraviolet rays (UVA) are commonly used as covering materials for plastic greenhouses in Japan. One of its important and interesting effects is the prevention of immigration of pests from outside. It is effective against aphids, whiteflies and thrips. Another important physical control measure is the use of coloured traps. Winged aphids and whitefly adults are attracted to yellow and while thrip adults prefer white or blue. Many types of colored sticky traps have been developed and used for mass trapping or monitoring of these pests. Probably, their usefulness consists in the use in supervised control in chemical or biological control. Yellow sticky traps can be used to determine the time of release of *E. formosa* and to evaluate the effectiveness of control.

IPM in Protected Crops

Since the number of available natural enemies for biological control is limited and the technical development of the use of other natural enemies is still preliminary, integrated use of natural enemies and other control measures is essential for commercial application. Suitable crops for integrated control using natural enemies can be assumed to be crops attacked by a small number of serious pests, crops for which a low level of pest damage is tolerable, crops requiring insect pollinators. Tomato, strawberry and sweet pepper are three good crops for developing integrated control in Japan. Table 4 shows an integrated control scheme for tomatoes combining use of natural enemies and selective pesticides.

Table 4. A Scheme of IPM for Tomatoes in Greenhouses in Japan

Period	Control Measures	Pests
Middle of July	Application of granules in soil	Thrips, aphids
Late August	Sulfur application	Rust mites
September-October	*E. formosa, D. isaea*	Whiteflies, leaf miners
Early October	IGR application	Noctuid moths
Middle of January	IGR application	Whiteflies
Late March	IGR application	Thrips
April-May	*E. formosa, D. isaea*	Whiteflies, leaf miners

Source: Ishii, personal communication.

Noctuid moths sometimes cause severe damage in southwestern Japan, but they can be controlled by *Bacillus thuringiensis* Berliner or IGR. Soil application of systemic pesticides and spot treatment with non-selective pesticides are also possible options in integrated control.

In Western Europe, integration of the use of natural enemies and selective pesticides is emphasized (Ravensberg, 1992). However, the greenhouse environment in Japan is less favorable for biological control because of the extreme temperature conditions and incomplete isolation of the greenhouse environment from the surroundings. Integration with other control techniques is needed for more satisfactory biological control. For example, cultural control, including prevention of immigration of pests, removal of host weeds within and outside greenhouses and avoidance of cultivation of host plants near greenhouses, are fundamental for effective control. After infestation, pests increase almost exponentially in the high temperatures from spring to autumn. In such cases, delay of release of natural enemies often results in failure of biological control. Monitoring systems of early infestation by pests in greenhouses are crucial for successful biological control. Use of resistant varieties of crops should also be studied for integrated control. Partial resistance is adequate for integrated control including the use of natural enemies (de Ponti, *et al*., 1983). In conclusion, integration of all possible techniques is needed for the successful and reliable use of natural enemies in Japan.

INTEGRATED PEST MANAGEMENT IN THE FIELD

Some studies have been carried out to develop IPM systems for eggplants in the field. Potential of *O. sauteri* to control *T. palmi* on eggplants was first evaluated by insecticidal check methods in Okayama prefecture. Potted eggplants were introduced into a screen cage, and both *T. palmi* and *O. sauteri* were released. After spraying with fenthion, which controls *O. sauteri* but does not affect *T. palmi*, was sprayed, *T. palmi* increased rapidly. Without application of fenthion, *T. palmi* was kept at a very low level (Nagai, *et al*, 1988). Similar experiments were carried out in open fields of eggplants. When the eggplants were treated with fenthion, the peak density of *T. palmi* was four times as large as that on the untreated plants (Nagai, 1990a). Further experiments were also conducted using the selective pesticide, pyriproxyfen, which has a control effect on the pupal stage of *T. palmi* but is harmless to *O. sauteri. T. palmi* on eggplants decreased very rapidly after application of this pesticide, due to a combined effect of the pesticide and *O. sauteri* on the *T. palmi* population. On the other hand, when eggplants were treated with a non-selective pesticide, carbaryl, which is very harmful to *O. sauteri* and harmless to *T. palmi, O. sauteri* disappeared immediately, which caused the increase of *T. palmi* (Figure 1) (Nagai, 1990b and 1993).

Effectiveness of the IPM program with a combination of naturally occurring *Orius* spp. and selective pesticides was evaluated in eggplant fields in Fukuoka prefecture (Takemoto and Ohno, 1996). In most of the surveyed fields, the number of insecticide applications and the damage on the fruit by *T. palmi* were remarkably reduced in comparison with conventional fields. In these successful IPM fields, indigenous thrips species were abundant when *Orius* spp. colonized the eggplant fields. With regard to vegetation around eggplant fields, *O. sauteri* and *Orius nagaii* Yasunaga (Hemiptera:Anthocoridae) were predominant on white clovers and on paddy rice, respectively. It is likely that surrounding vegetation serves as a main reservoir for *Orius* populations on eggplants (Ohno and Takemoto, 1997). Indigenous natural enemies were well conserved in this IPM system and effectively suppressed other pests such as cotton aphids, spider mites, and broad mites.

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4. NONPESTICIDE METHODS FOR MANAGING CROP WEEDS IN THE ASIA-PACIFIC REGION – ALLELOPATHIC COVER CROPS

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INTRODUCTION

Abandoned paddy fields are increasing in numbers because of the aging of farmers and industrialization in Japan. It has reached nearly 5 percent, including fallow fields which the government regulated for overproduction of rice. These fields tend to have many weeds and in many field weeds cover the surface of land. Land recovery is difficult and requires much investment to restore to their original paddy field condition.

In a search for allelopathic plants to determine allelopathy and its mechanism, this study developed new methods to identify allelopathy from other competitive factors such as nutrients, light and water (Fujii, *et al*., 1991b, 1991c, 1991d, and 1991e). Allelopathy was found in velvetbean (Fujii, 1991c), hairy vetch (Fujii and Shibuya, 1992b; and Fujii, *et al*., 1994), medicinal plants (Fujii, *et al*., 1991a), and others.

In the course of this research, a new bioassay system was developed that could demonstrate and assess the possibility of allelopathy using a "plant box method", and "sandwich method". This method involves mixed planting using agar medium, and exudation of allelochemicals from leaves and/or roots. These methods can show the allelopathic action of root exudates and leaf leachates.

If other competition factors are the same, allelopathy will play an important role in weed suppression in combination with other factors. Some farmers suggested from their experiences that some ground cover plants suppress weeds drastically. There is a possibility that some cover crops could be used for practical weed suppression. Thus, a program to screen the allelopathic activity of cover plants by plant box method and sandwich method was initiated. From these primary selections, and experiences on the fields, field experiments were carried out to select the most promising cover crop for weed control in abandoned fields.

Velvet bean (*Mucuna pruriens* (L.) DC. var. *utilis* or *Stizolobium deeringianum* Piper et Tracy) is a tropical legume, grown generally for green manure. It is recognized that velvet bean increases the yield of its companion graminaceous crops and that it smothers the growth of harmful weeds such as nutsedge (*Cyperus* spp.) and alang-alang (*Imperata cylindrica*). A series of screening experiments was carried out to screen allelopathic plants with special emphasis on chemical interactions among them. The results of these experiments indicated that velvet bean was the most promising candidate (Fujii, *et al*., 1990b and 1991c). A field test showed that the velvet bean stands minimized weed population as compared with those of tomato, egg plant, upland rice and fallow (Fujii, *et al*., 1991e).

The genus *Mucuna* consists of about 100 species growing in the tropics and subtropics (Tateishi and Ohashi, 1981; and Wilmot-Dear, 1983). There are two subgenera in *Mucuna*: one is *Mucuna* which is perennial and woody, and the other is Stizolobium which is annual or biennial and herbaceous. Cultivars that belong to Stizolobium, utilized for green manure and/or cover crop, their leaves for fodder, their grains for food and seeds, and their stems for medicine in Africa and China (Watt and Breyer-Brandwijk, 1962). Grain yield reaches as high as 1.5-2.0 mt/ha, and fresh leaves and stems weigh 20-30 mt/ha, indicating that velvet bean is one of the most productive crops in the world. If the physiological mechanism of its allelopathic activities is identified, the use of velvet bean could be further developed. For example, it can be cultured in larger areas in the tropics, it can have a greater utilization as green manure and/or weed-control crops. This paper reviews the results of studies on allelopathic activities of *M. pruriens* with special emphasis on L-3, 4-dihydroxyphenylalanine (L-DOPA) as a potential allelochemical with weed suppression property.

MATERIALS AND METHODS

Origin of Seeds of Cover Crops and Definition of Hairy Vetch

Most of the seed used in this experiments are from "Kaneko Shubyou, Kaneko Seed Co.", "Takii Shubyou, The Takii Seed Co.", "Yukijirushi Shubyou, The Yukijirushi Seed Co.", and "Sakata-no-Tane, Sakata Seed Co." The term 'hairy vetch' was used in Japan both for hairy vetch and woolly pod vetch. All seeds of hairy vetch were imported from the United States, and although some seed company would not know the origin, these are considered as hairy vetch. But there are differences such as *Vicia villosa* and *Vicia dasycarpa* (=syn. *V. villosa* subsp. *varia*). The allelopathic activity and inhibitory activity on the field of both is almost the same.

Screening of Allelopathic Cover Crops by the Plant Box Test

Primary selection of cover crops for allelopathy was done using "Plant Box Method", developed for the assessment of allelopathy (Fujii and Shibuya, 1991a). Young plants were cultivated for 1-2 months in sand, with standing water containing a nutrient solution. The receiver plant used for bioassay was lettuce (Great Lakes 366), because its high sensitivity to bioactive substances.

Extraction of Inhibitory Chemicals from Cover Crops

Plant growth inhibitory activities of some cover crops were tested by water and methanol extraction. Dried leaves and shoots (60ºC, overnight, forced air dry) were extracted by 150 times of water and 40 times of methanol. These extracts were mixed with agar (0.5 percent) to make a stuff bed to support lettuce seeds. After three days in a dark condition at 20ºC, radicle and hypocotyl lengths were measured.

Screening of Cover Crops for Weed Control in the Experimental Fields

To know the practical weed suppression ability by cover crops, field tests for weed suppression were designed. All field trials for screening were done in the experimental field of Shikoku National Agricultural Experimental Station. For the first screening for spring seeding cover crops, 46 plants were sown on 1 m x 1 m quadrates on 23 May 1992, then after three months of no weeding, weed density and dry weights were measured on 25 August 1992. For the preliminary screening for fall seeding plants, 39 candidates were sown on 2 m x 2 m quadrates on 5 November 1992, and after no weeding for six months, weed dry weight of each plot was measured on 20 April 1993. For selected 21 cover crops of fall sown, four times replications by complete randomized bloc design were designed and seeded on 2 m x 2 m quadrates on 5 November 1992, and weed and crop dry weighs were measured on 20 April 1993.

Application of Hairy Vetch to Abandoned Paddy Field in the Experimental Station

From the results of screening of cover crops, the focus was on hairy vetch, and four trials were conducted on the experimental field in Shikoku National Agricultural Experiment Station.

1) A larger-scale application test of hairy vetch was conducted in comparison with Chinese milk vetch on the uniform paddy field of 1,000 m^2. This field was divided into 16 block and four replications of four different cover crop trials were designed. Cover crop designs were: (i) hairy vetch; (ii) hairy vetch and oat; (iii) Chinese milk vetch; and (iv) no treatment as control. This experiment was started in 1992 and continued. Data from 1992 to 1994 was reported in this paper.
2) Changing the seeding ratio from standard seeding to four times was examined using a field of 500 m^2, and arranged with split-split-plot test with four replications. This test started from 25 October 1993 and weed and crop yield were measured in 20 May.
3) Changing the seeding date from October to February was tested using the same field with tree replications. This test was started from 1992 and ended in 1994.

4) Effect of soil water contents on the growth of hairy vetch was tested in the lysimeter. This lysimeter was designed to know the suitable water ratio for crops, and it is possible to change the water level by stair-step system of overflowing. Each block was about 10 m^2, and there were four stages with two replications. Soil type of above four tests showed that it was sandy loam.
5) The combination of leguminous cover crops and barley were examined on the slope land experimental field of Shikoku National Agricultural Experiment Station on the Oo-asa mountain. The slope angle of this field was 9º. Seeding date was 6 November 1993, and crop and weed yield were measured on 30 May. The total area of this field was about 800 m^2. Soil type of this field is volcanic ash soil.

Direct Application Test of Hairy Vetch to Farmer's Field

Direct application and demonstration trial of hairy vetch were done using the field of cooperative farmers by the courtesy of each district counselors for farmers (in Japan, there are counselors for farmers in each county. These counselors are public service officers belong to the Ministry of Agriculture). Six different farming systems were chosen.

1) Paddy field in Man'ou town: The owner is Mr. Tsunekane. The area is about 800 m^2. This paddy field is in a slightly mountainous area, and slightly dry condition. This field has just stopped rice production.
2) Paddy field in Marugame city: The owner is Mr. Hirata. The area is about 1,000 m^2. This field is close to road, wet and was abandoned two years ago.
3) Paddy field in Zentsuji city: The owner is Mr. Kawada. The area is about 900 m^2. This field was abandoned for four or five years and they used Chinese milk vetch as green cover crop, but suffered from serious weed infection.
4) Grassland in Chu-nan town: The owner is Mr. Morichika. The area is about 600 m^2. This grassland in a slopeland, and used as exhibition.
5) Orchard for khaki, Japanese persimmon in Kounan town, Oka village: The owner is Mr. Oka. The area used for cover crop trial was about 10,000 m^2 for the first year, 1992, and extended by 50,000 m^2 in the following year and continue until present. Oka family is a pioneer in this orchard area, and produces sweet type of khaki of supreme quality.
6) Pear orchard in Toyohama town: The owner is Mr. Oohiro. The area used for the trial for hairy vetch was about 80,000 m^2. He continued cover crop trial after 1993.

RESULTS AND DISCUSSIONS

Screenings of Allelopathic Cover Crops

The results of screening of candidates for allelopathic cover crops from leguminous and graminaceous species by Plant Box Method are shown in Tables 1 and 2, respectively. In these tables, radicle percentage means the percentages of the root radicle by length of the young lettuce plants present in the root zone of each donor plant, based on the calculation of radicle length within the root zone controlled by donor plants. As shown in Table 1, leguminous cover crops such as velvet bean, hairy vetch, yellow sweet clover and white sweet clover have strong allelopathic inhibitory activities. Of these legumes, velvet bean, *Crotalaria, Canavalia, Cajanus, Cicer, Vigna* and *Glycine* are summer cover crops, and most of others are winter cover crops. *Melilotus* and *Pueraria* are perennial crops. It is important to know the characteristics of each cover crop to use on the farmland.

Graminaceous species, such as oat, wheat, millet (*Setaria*), rye also showed strong inhibitory activity, but most of Compositae family such as *Helianthus* showed only medium inhibitory activity by this method (Table 2).

Extraction of Inhibitory Chemicals from Cover Crops

To know the existence of allelochemicals in plants, we checked the extraction of chemicals for some principal cover crops. Table 3 shows the inhibitory activities of water and methanol extracts of cover crops. Hairy vetch and velvet bean showed the strongest inhibitory activity in both water and methanol extract. We have already published the results about the allelochemicals extracted from velvet bean (Fujii, *et al*., 1990b; and Fujii, 1994). Velvet bean contains an extraordinary high amount of L-DOPA and the inhibitory activity of this compound is rather high in acidic and non-oxidative conditions. However, in the case of hairy vetch, there is a possibility of inclusion of still more inhibitory allelochemicals than velvet bean. The results of solvent extraction are consistent with the results from Plant Box Test for root exudates in these experiments.

Table 1. Assessment of Allelopathic Activity of Leguminous Cover Crops by the Plant Box Method

Scientific Name (English Name)	Inhibition (percent)[a]	Criteria[b]
Mucuna pruriens var. *utilis* (average of six cultivars)	87	★★★
Vicia faba (broad bean) (average of 10 cultivars)	81	★★
Vicia villosa (hairy vetch) (average of four cultivars)	80	★★
Calopogonium mucunoides	78	★★
Melilotus albus (white sweet clover)	77	★★
Vicia sativa (common vetch)	75	★★
Medicago rugosa	74	★★
Canavalia ensiformis (Jack bean)	72	★★
Pueraria phaseoloides (tropical kudzu)	71	★★
Vigna angularis (adzuki bean)	69	★
Medicago sativa (alfalfa)	68	★
Trifolium incarnatum (crimson clover)	64	★
Tephrosia candida (white Tephrosia)	63	★
Cajanus cajan (pigeon pea)	62	★
Latyrus sativus (grass pea)	59	★
Cicer arietinum (chickpea)	56	★
Vigna radiata (mung bean)	53	
Stylosanthes hamata (stylo)	52	
Arachis hypogaea (peanut)	51	
Trifolium pratense (red clover)	47	
Crotalaria juncea (sunn hemp)	43	
Astragalus sinicus (Chinese milk vetch)	41	
Lupinus albus (white lupine)	40	
Trifolium subterraneum (subterranean clover)	30	
Trifolium repens (white clover)	28	
Glycine max (soybean)	24	

Notes: [a] Inhibition (percent) means the allelopathic activity measured by the Plant Box Test. All data are compared to the control and 100 means complete inhibition.
[b] Criteria for the allelopathic activity are shown as ★★★ = >85 percent; ★★ = 70-84 percent; and ★ = >55 percent, respectively.

Screening of Cover Crops for Weed Control in the Experimental Fields

To assess the activity of these cover crops, field experiments were started on a small-scale field in the experimental station. Spring-sown cover crops were not promising. Under Japanese weather condition, a rainy season is experienced in June, and soon after the beginning of this season, vigorous growth of weeds is noted. Some cover crops such as *Helianthus, Celosia* and *Panicum* showed relatively strong inhibitory activity to weeds, and *Mucuna, Vigna* and *Cassia* followed to them. Competition for light and nutrients are the most important factors in the fields, and all of these plants have vigorous growth rate and have large leaves. Most of these cover crops were reported as allelopathic, and have relatively strong inhibitory activity in the Plant Box Test (Tables 1 and 2). For example, there are many reports on the allelopathy of *Helianthus*, and *Celosia* (Rice, 1984). However, the field with more than 20 percent of weed cover looks weedy and disagreeable to the public had only 50 percent weed suppression. Thus, spring sown cover crops under this condition appeared to be unsuccessful.

Table 2. Assessment of Allelopathic Activity of Gramineous Cover Crops and Some Other Family by the Plant Box Method

Scientific Name (English Name)	Inhibition (percent)[a]	Criteria[b]
Avena sterilis (wild oat)	88	★★★
Triticum polonicum (Polish wheat)	87	★★★
Triticum aestivum (wheat, for mulching)	82	★★
Celosia argentea	75	★★
Secale cereale (rye)	71	★★
Avena sativa (oat)	71	★★
Setaria italica (Italian millet)	70	★
Festuca rubra (chewing fescue)	70	★
Sorghum bicolor (sorghum)	64	★
Hordeum vulgare (barley)	62	★
Amaranthus tricolor[c]	61	★
Panicum maximum (Guinea grass)	60	★
Brassica napus (rape)[c]	59	★
Festuca arundinacea (tall fescue)	55	★
Brassica alba (white mustard)[c]	53	
Helianthus anuus (sunflower)[c]	51	
Carthamus tinctorius (safflower)[c]	45	
Ricinus communis (castor bean)[c]	44	
Momordica charantia (balsam pear)[c]	42	
Poa pratensis (Kentucky bluegrass)	40	
Dactylis glomerata (orchard grass)	38	
Gossypium barbadense (cotton)[c]	36	
Lolium perenne (perennial ryegrass)	36	
Paspalum dilatatum (Dallis grass)	28	
Paspalum notatum (Bahia grass)	27	
Lolium multiflorum (Italian ryegrass)	26	
Phalaris arundinacea (reed canary grass)	24	

Notes: [a] and [b]: same as Table 1; and [c] non-gramineous cover crop.

Table 3. Effect of Water and Methanol Extracts of Cover Crops

(Unit: Percent)

Cover Crop	Water Extract (x 150)[a]			Methanol Extract (x 40)[a]		
	G[b]	R	H	G	R	H
Vicia villosa	100	12	89	90	18	52
Mucuna pruriens	100	17	102	87	26	61
Cajanus cajan	97	41	76	83	13	15
Centrosema pubescens	100	53	118	100	37	80
Crotalaria juncea	100	55	120	97	51	105
Tephrosia candida	100	58	106	100	41	95

Notes: [a] Extraction ratio and the concentration of each cover crops are: water extract, x 150: 6.7 mg of leaves (d.w.)/ml of water; methanol extract, x 40: 25 mg of leaves (d.w.)/ml of methanol; [b] G = germination percentage; R = radicle growth; and H = hypocotyl growth compared to the control of water; and [c] Underlined show strong inhibition (<66 percent inhibition).

If weed suppression by spring-sown cover crops is not enough, increasing the seeding rate might help to suppress successfully. Three steps of seeding rate were tried but it was not successful. About 50-70 percent of inhibition of weed growth was possible, but insufficient for practical application to the fields. Hence spring seeding of cover crops was abandoned.

If cover crops are sown in fall, they tend to grow slow but steadily in winter to make enough biomass in spring and could eliminate vigorous weeds. As a primary selection, there was no replication in this test. It was obvious that dry weight of each cover crop was most important to reduce the growth of weeds. This is true for rye, oat, wheat, woolly pod vetch and Italian ryegrass. Because of the overwhelming canopy of these crops, weed would not have enough space. Comparing the relationship between dry weight and weed suppression activity, *Brassica, Vicia* and *Medicago* did not have enough biomass but showed better weed suppression and allelopathy may play a role in these cases.

Without weeding, hairy vetch, oat, barley, rye, wheat showed strong inhibitory activity of weeds, but Chinese milk vetch, which is a traditional green manure in Japan and China, showed little weed suppression.

In conclusion, spring-sown cover crops are not promising in Japanese conditions, but fall-sown cover crops such as hairy vetch, rye, oat, wheat, and barley have enough inhibitory activity for weed from spring to early summer. Their inhibitions are almost the same as that of traditional weeding such as rice straw mulch and herbicide application.

Application of Hairy Vetch to Abandoned Paddy Field in the Experimental Station

From the results from large-scale application of hairy vetch, Chinese milk vetch and mixed planting of vetch and oats, it was noted that hairy vetch almost completely inhibits the growth of weeds in spring. On the other hand, Chinese milk vetch, traditionally used in Japanese paddy field as green manure, could inhibit the weed biomass up to 80 percent. However, to let 20 percent of weeds grow will make this field weedy next year, which will be abandoned in two or three years without weeding. These results coincide with the observation of farmers that continuous using of Chinese milk vetch will result in a severe weedy condition.

Addition of oat to hairy vetch was aimed to increase the weed suppression ability. In both years, addition of oat decreases the population of weeds, to nearly perfect inhibition of weed until fall. Mixed planting of vetch and oat have companionship and both yields increased per acre increased. However, if no care was taken, the outlook of field from spring to summer of mixed cover field was not beautiful because of the remaining stems of oat. On the other hand, hairy vetch kept the stand height of maximum 50 cm, and the outlook of this field was uniform and flat, and free from weeds. Hairy vetch would not survive when maximum temperature reaches to 30ºC. In the experimental field, hairy vetch made a straw like mulch without additional work and this mulch protect the field from weed invasion after the death of the plant. Thus, we concluded that using hairy vetch alone can be recommended to farmers because of its simplicity of sowing and reduced labor.

Some abandoned paddy fields suffered from water-logging. Resistance of hairy vetch to water-logging in paddy field was measured by using water-logged lysimeter. Hairy vetch is resistant to heavy water-logging. Water cover of 40 percent in most of the water-logged paddy field showed no growth retardation of vetch.

The combination of leguminous cover crops and barley were examined on the slope land experimental field of Shikoku National Agricultural Experiment Station. The aim of this experiment was to use barley as a cover crop in slopeland. Barley, especially known as 'Hadaka-mugi', a naked barley, is the traditional cultivar and suitable to Shikoku and southeast area of Japan. Hairy vetch slightly reduced the growth of barley, but the weed inhibitory activity of hairy vetch and combination of vetch and barley were the best.

As for optimum seeding rate, standard seeding rate was enough for the weed control, and increasing the seed volume made no difference for biomass and weed suppression. The cost per 1,000 m^2 (Japanese standard unit of farming) is about ¥2,500 (US$20).

As for optimum seeding date for weed suppression in Japan, late seeding tend to have more weeds and it was concluded that early seeding no later than the 1st week of November is recommended.

Direct Application and Demonstration of Hairy Vetch to Farmer's Field

Direct application and exhibition trial of hairy vetch were done using the field of cooperative farmers. In most cases, hairy vetch suppress weed enough, and the impression of farmers were very good. Before this trial, there were no custom to use hairy vetch as cover crops to control the weeds. Many farmers came to the experimental station or demonstration field of cooperative farmers, and most of them started to try hairy vetch. At present, the use of hairy vetch under khaki orchard are spreading to 600 ha, and still expanding.

MATERIALS AND METHODS FOR VELVET BEAN

Survey on Allelopathic Plants (Fujii, *et al*., 1990c)

Seventy plant species were tested on their allelopathy following Richards' function method (Richards, 1959), which proved to be suited to germination tests of lettuce and some weed plants (Lehle and Putnam, 1982). In order to destroy the enzymes which degrade some constituents of a plant, and to minimize the changes of the organic chemicals contained, the leaves, stems and roots were dried at 60ºC for 24 hours. One hundred mg of the dried samples each was extracted with 10 ml water. Extraction mixtures were sonicated for 60 sec. to complete the migration of chemicals. The extract was filtered with Whatman No.4 filter paper. Ten lettuce seeds were placed in 4.5 cm diameter-petri dishes containing 0.5 ml of test solution on Whatman No.1 filter paper. The petri dishes were incubated in the dark at 25ºC. Numbers of germinated seeds were counted and hypocotyl and radicle growth were measured on the fourth day. The parameters for germination tests were: onset of germination (Ts), germination rate (R), and final germination percentage (A). A simplex method was applied for the computer simulation of germination curves with the Richards' function.

Velvet Bean Cultivar

A dwarf cultivar of velvet bean, *Mucuna pruriens* var. *utilis* cv. *ana*, was used for the field test and the extraction of allelochemicals. The seed was a gift from Dr. Shiro Miyasaka or purchased at Pirai Seed Company in Brazil.

Incorporation of Velvet Bean Leaves into Soil

Two treatments of velvet bean were added to the volcanic ash soil in Tsukuba, one was dry leaves oven-dried at 60ºC overnight, the other was fresh leaves. One gram of oven-dried leaves was added to 100 g of soil. The same weight of cellulose powder was added to the other pots as control. Fertilizers added to each pot were as follows: N, P, K of 50, 100, 50 mg/100 g-soil d.w., respectively. Available nitrogen containing in the velvetbean residues (1.2 percent) was supplemented to control pots.

Weed Appearance in the Fields with Velvet Bean Stands

Planting of velvet bean and some other plants were repeated for a period of 2-3 years (Fujii, *et al*, 1991; and Fujii, *et al*.,1991e). Plants were grown in lysimeters: each size is 10 m^2 and six replications, where the surface soils of 10 cm depth were replaced with uncultivated soils for each starting year. Each plot received a standard level of chemical fertilizers: N, P, K of 80, 80, 80 g/10 m^2 except for fallow.

Mixed Culture of Velvet Bean by Allelopathy Discrimination Methods

Allelopathy of velvet bean in the field was confirmed using stair-step (Fujii, *et al*, 1991c) and substitutive experiment (Fujii, *et al*., 1991e). The stair-step experiment was designed according to the method of Bell and Koeppe (1972) with three replications within two mixed plants. Circulation of nutrient solution was about 600-800 ml/hour per pot. Half strength of Hoagland's solution was used. The substitutive experiment was modified from the methods in the references (Fujii, *et al*., 1991d).

Isolation and Identification of Allelopathic Substances

Some fractions were extracted from fully expanded leaves and roots of velvet bean with 80 percent ethanol. The acid fraction of the extract inhibited the growth of lettuce seedlings. This fraction was subjected to silica gel column chromatography and high performance liquid chromatography (HPLC) with an ODS column, and the major inhibitor was identical to L-DOPA (Fujii, *et al*., 1990b). The identification was confirmed by co-chromatography with an authentic sample using two HPLC column systems (silica gel and ODS) equipped with an electro-conductivity detector.

RESULTS AND DISCUSSION FOR VELVET BEAN

Survey of Allelopathic Plants

Sixty-five plants were investigated with lettuce seed germination tests (Fujii, *et al*., 1990a and 1990c). It was observed that the activity of velvet bean was distinctive (Table 4). Some other plants such as *Artemisia princeps, Houttunia cordata, Phytolacca americana*, and *Colocasia esculenta* also shows the inhibitory response. The allelopathic nature of these plants was important in further studies.

Table 4. Screening of Allelopathic Plants with Lettuce Germination/Growth Test

Plant Part[a]	Germination Test					Growth Test		Extraction Ratio[h]
	A[b]	R[c]	Ts[d]	I[e]	T_{50}[f]	Hypocotyl	Radicle[g]	
Compositae								
Ambrosia elatior (R)	87	141	1.7	78	1.2	146	63	10
Ambrosia elatior (S)	94	74	2.1	34	1.6	139	54	10
Artemisia princeps (S)***[i]	65	20	2.9	5	3.3	51	50	20
Carthamus tinctorius (W)	100	173	0.9	206	0.7	141	65	8
Erigeron canadensis (L)	89	80	1.3	56	1.2	114	50	25
Erigeron canadensis (R)	94	66	1.2	55	1.2	121	67	25
Helianthus annuus (R)	100	191	1.2	167	0.7	130	52	12.5
Helianthus annuus (S)*	86	38	1.2	27	1.5	102	33	10
Helianthus tuberosis (R)	94	99	1.3	71	1.2	114	63	25
Helianthus tuberosis (S)	91	96	1.4	62	1.3	104	67	25
Ixeris debilis (W)	85	96	1.3	71	1.6	114	63	10
Saussurea carthamoides (R)	90	78	2.1	36	1.7	112	64	10
Saussurea carthamoides (S)	97	74	2.1	34	1.7	139	63	10
Senecio vulgaris (W)	86	70	1.4	62	1.8	104	67	10
Solidago altissima (L)*	67	39	1.4	19	1.5	90	70	25
Solidago altissima (R)	89	59	1.3	42	1.3	109	78	25
Taraxacum officinale (R)	99	32	0.5	64	1.6	108	66	10
Taraxacum officinale (S)	97	37	0.4	94	1.3	105	79	6.3
Gramineae								
Alopecurus geniculatus (R)	91	78	1.8	39	1.5	127	94	10
Alopecurus geniculatus (S)	95	89	2.5	34	1.8	138	62	10
Avena sativa (L)	98	117	1.4	88	1.0	105	105	2.5
Avena sativa (R)	98	84	1.2	70	1.2	131	126	5
Digitaria sanguinalis (R)	91	41	1.5	23	1.6	97	96	25
Digitaria sanguinalis (S)	90	25	1.6	15	2.1	98	42	10
Gramineae								
Hordeum vulgare (L)	100	102	0.9	114	1.0	144	65	6.3
Hordeum vulgare (R)**	99	84	1.4	62	1.3	72	36	25
Miscanthus sinensis (S)	97	70	3.3	20	3.4	118	52	25
Oryza sativa (L)	100	226	2.2	105	1.0	114	77	12.5
Sasa sinensis (S)	94	55	3.2	17	2.7	134	44	25
Secale cereale (L)**	91	62	1.2	48	1.3	79	21	10
Secale cereale (R)	100	186	1.4	142	0.8	132	55	12.5
Sorghum bicola (R)*	98	131	1.0	133	0.8	84	43	12.5
Sorghum bicola (S)	85	60	1.3	39	1.3	104	55	10
Sorghum sudanense (R)	100	132	1.0	135	0.8	106	58	12.5
Sorghum sudanense (S)*	86	66	1.3	47	1.3	107	31	10
Leguminosae								
Arachis hypogaea (L)*	83	90	4.9	16	1.8	98	60	10
Arachis hypogaea (R)	94	93	3.3	21	1.9	97	57	16
Glycine max (S)	96	44	0.6	70	1.4	117	41	10
Lupinus albus (S)*	95	98	2.8	33	1.6	100	37	12.5
Mucuna prurience (L)***	96	82	9.3	9	4.6	79	26	25
Mucuna prurience (R)	95	98	1.8	49	1.1	95	51	6
Mucuna prurience (Stem)	96	45	1.1	38	1.6	96	54	10
Pisum sativum (S)	99	45	0.5	99	1.1	115	38	10

... To be continued

Table 4. Continuation

Plant Part[a]	Germination Test					Growth Test		Extraction Ratio[h]
	A[b]	R[c]	Ts[d]	I[e]	T_{50}[f]	Hypocotyl	Radicle[g]	
Pueraria lobata (L)**	82	72	5.0	12	2.2	73	45	12.5
Pueraria lobata (R)	95	32	0.5	103	1.4	95	68	10
Pueraria lobata (Stem)*	98	57	3.4	17	3.5	111	32	10
Trifolium repens (S)	98	49	1.8	28	1.9	105	56	10
Vicia angustifolia (S)*	97	60	3.6	16	2.8	126	22	6.7
Vicia hirsuta (S)*	100	62	3.6	18	2.8	114	24	6.7
Chenopodiaceae								
Beta vulgaris (R)**	90	75	4.3	16	2.1	57	21	25
Beta vulgaris (S)	96	86	1.5	56	1.2	109	64	5
Chenopodium album (L)	98	43	1.0	44	1.9	90	48	10
Chenopodium album (R)	92	76	1.1	66	1.1	88	48	25
Spinacia oleracea (L)	94	68	2.4	28	1.7	119	38	5
Spinacia oleracea (R)*	97	73	4.5	16	2.1	102	36	10
Polygonaceae								
Fagopyrum esculentum (S)	100	235	2.4	100	1.0	107	60	12.5
Polygonum blumei (S)**	84	48	1.3	31	1.5	86	37	25
Labiatae								
Lamium amplexicaule (W)*	85	54	2.4	19	2.0	70	45	10
Melissa officinalis (L)**	39	23	3.7	3	2.3	101	57	8
Melissa officinalis (R)	98	73	1.6	45	1.4	164	103	8
Mentha spicata (L)*	99	51	1.9	27	1.9	121	28	8
Mentha spicata (R)	95	75	0.9	80	1.2	139	89	8
Salvia officinalis (L)	94	106	3.3	31	1.3	112	67	10
Salvia officinalis (R)	98	86	3.1	27	1.9	123	83	8
Solanaceae								
Lycopersicon esculentum (R)	98	123	3.3	38	1.4	131	45	10
Lycopersicon esculentum (S)	96	136	5.9	23	1.9	135	37	10
Solanum carolinense (S)	96	120	0.8	153	0.9	144	117	6
Solanum melongena (S)	86	83	4.9	15	1.9	125	51	10
Solanum tmelongena (R)	98	84	2.9	29	1.6	130	58	10
Solanum tuberosum (L)	99	75	1.3	127	1.3	127	62	6
Solanum tuberosum (Stem)	99	72	0.4	167	0.8	148	88	2.5
Cucurbitaceae								
Citrullus lanatus (L)	95	102	3.7	26	1.3	133	69	6
Citrullus lanatus (R)	94	103	4.2	23	2.2	113	74	12.5
Citrullus lanatus (Stem)	96	116	3.0	36	1.7	129	59	6
Cucumis sativus (R)	98	224	4.3	52	1.3	159	71	10
Cucumis sativus (S)	99	123	3.1	41	1.3	187	78	5
Cucurbita maxima (R)	100	109	2.3	48	1.1	113	84	17
Cucurbita maxima (S)	93	153	4.8	30	1.8	119	50	12.5
Other Genus								
Amaranthus tricolor (L)	92	66	4.0	15	2.4	93	81	6
Amaranthus tricolor (Stem	94	100	4.0	23	2.1	116	97	10
Brassica campestris (L)	93	27	0.5	58	1.6	141	94	3
Brassica oleracea (L)*	76	97	5.6	14	1.4	146	88	5
Brassica juncea (S)	87	61	1.6	34	1.5	154	71	3
Brassica napus (R)**	76	60	1.3	37	1.3	98	37	10

... To be continued

Table 4. Continuation

Plant Part[a]	Germination Test					Growth Test		Extraction Ratio[h]
	A[b]	R[c]	Ts[d]	I[e]	T_{50}[f]	Hypocotyl[g]	Radicle[g]	
Brassica napus (S)	84	85	1.3	56	1.2	108	98	10
Calystegia hederacea (R)	99	87	2.5	35	1.8	103	46	10
Calystegia hederacea (S)	96	66	2.4	27	1.9	94	60	10
Cerastium glomeratum (W)*	90	74	2.1	31	1.7	103	29	10
Colocasia esculenta (L)***	92	22	6.3	3	4.9	22	32	10
Colocasia esculenta (R)	98	95	4.9	20	1.9	149	42	10
Colocasia esculenta (Stem)*	99	74	3.1	24	1.8	133	35	5
Commelina communis (L)	91	62	4.5	12	1.8	132	65	10
Garium spurium (W)*	92	65	2.1	29	1.8	85	58	10
Houttuynia cordata (R)	95	66	0.9	68	1.5	126	50	10
Houttuynia cordata (S)***	98	33	3.6	9	3.4	62	26	5
Other Genus								
Impatiens balsamina (L)	93	101	3.3	28	1.9	117	64	6
Impatiens balsamina (Stem)	93	80	3.1	24	1.9	136	77	3
Oenothera biennis (R)	91	61	1.1	52	1.2	119	40	25
Oenothera biennis (S)	84	48	1.3	31	1.5	105	39	25
Paederia scandens (L)	97	46	1.5	86	1.2	123	92	12.5
Paederia scandens (Stem)	98	52	0.5	96	1.1	143	98	10
Paulowinia tomentosa (L)	100	53	1.2	45	1.5	119	61	12.5
Paulowinia tomentosa (Stem)	100	139	1.5	98	1.2	136	52	12.5
Phytolacca americana (L)**	98	44	2.3	19	2.2	57	33	6
Phytolacca americana (R)***	75	40	1.8	16	1.8	78	37	10
Phytolacca americana (Stem)	93	61	1.6	37	1.5	124	39	6
Plantago major (L)	88	101	3.5	26	1.6	121	73	5
Plantago major (R)	84	75	3.3	19	1.8	138	74	12.5
Portulaca oleracea (W)	90	117	4.8	22	1.9	119	49	3
Stellaria media (W)	97	69	1.4	51	1.4	99	67	5
Average	92.3	78.7	2.4	47.0	1.71	113	58.4	
Standard deviation (σ_{n-1})	9.4	40.3	1.5	38.2	0.72	26.8	21.6	

Notes: [a] S = shoot, R = root, W = whole plant (=S+R), and L = leaf; [b] germination percentage at the end of germination process speculated with cumulative germination curves fitted to Richards' function (percent of control); [c] germination rate (percent of germinated seeds per day, percent of control); [d] start of germination (a time spent until one seed germinate, ratio to control); [e] germination index (I=A•R/Ts); [f] 50 percent germination time (a time spent until 50 percent of seed which can germinate, ratio to control); [g] percent of control (control dish is cultured with water); [h] extraction ratio (mg-D.W./ml), it was determined in order that EC of the assay solution did not exceed 1 mS/cm; and [i] * marks after plant name shows the degree of inhibition. When each value exceed the criteria of average ±σ, we judge the possibility of inhibition. The number of * is the number of inhibition in four criteria: hypocotyl elongation, radicle elongation, A (germination percent), and I (germination index).

Incorporation of Velvet Bean Leaves into Soil

An experiment was performed to examine the effects of velvet bean on the growth of other plants in a mixed culture. The treatment also included an incorporation of velvet bean leaves into soils. Fresh leaves incorporation to soils (1.0 percent W/W in dry weight equivalent) reduced succeeding emergence of kidney bean (*Phaseolus vulgaris*) up to 60 percent, plant biomass up to 30 percent of the control. This effect diminished two weeks after the incorporation. Dried leaves incorporation showed no inhibition.

Weed Appearance in the Fields of Velvet Bean Stands

Weed populations were observed in spring in the continuous cropping fields grown in lysimeters. The velvet bean plot showed a lower population of weeds dominated by sticky chickweed (*Cerastium glomeratum*), than the other plots of egg plant, tomato plant, upland rice and fallow field.

Mixed Culture of Velvet Bean with Stair-step Apparatus

The stair-step method is a sort of sand culture with a nutrient solution recirculating system on a staircase bed. Through this method, the presence of velvet bean reduced the growth of lettuce shoot growth to the level of 70 percent of the control. This result indicates that velvet bean root exudates have allelopathic activity.

Allelopathic Compound in Velvet Bean

The analysis on effective compound of velvet bean in restraining the growth of companion plants confirmed its association with L-DOPA. It is well known that velvet bean seeds contain a high concentration of L-DOPA (6-9 percent) (Damodaran and Ramaswamy, 1937; and Rehr, *et al*., 1973), which plays a role of chemical barrier to insect attacks. In mammalian brain, L-DOPA is the precursor of dopamine, a neurotransmitter, and also important intermediates of alkaloids. In animal skin, hair, feathers, fur and insect cuticle, L-DOPA is oxidized through dopaquinone to produce melanin. As L-DOPA is an intermediate and rapidly metabolized, usually normal tissues have little concentrations of L-DOPA.

Fresh velvet bean leaves contain as much as 1 percent of L-DOPA (Fujii, *et al*., 1991). It actually exudes from root, and its concentration reaches 1 ppm in water-culture solution, and 50 ppm in the vicinity of roots. This concentration is high enough to reduce the growth of neighboring plants and the growth inhibition in a mixed culture is shown in agar-medium culture (Fujii and Shibuya, 1991a and 1991b). It also leaches out from leaves with raindrop or fog dew. Since velvet bean produces 20-30 mt of fresh leaves and stems per hectare, approximately 200-300 kg of L-DOPA may be added to soils a year.

Phytotoxic Effects of L-DOPA

Some effects of L-DOPA on germination and growth of the selected crops and weeds. L-DOPA suppresses the radicle growth of lettuce and chickweed to the level of 50 percent of the control at 50 ppm (2x10-4 mol/l). It is however less effective to the hypocotyl growth and practically not effective to the germination. L-DOPA strongly inhibits the plant growth of *Cerastium glomeratum, Spergula arvensis* (both Caryophyllaceae), *Linum usitatissimum* and *Lacutuca sativa*, and moderately inhibits the growth of Compositae, while very limited effects on Gramineae and Leguminosae. Such selective effectiveness is comparable with other candidates of allelochemicals. The L-DOPA contained in fresh velvet bean leaves fully contributes to the plant growth inhibition through its crude extract. The result that L-DOPA strongly suppresses the growth of chickweed agrees with weed inhibition in the velvet bean field. All these data suggest that L-DOPA function as an allelopathic substance.

In the aged leaves, the content of dopamine increases, and L-DOPA and dopamine are presumably changed to catechol in the leaf litter.

It is an earlier understanding that velvet bean smothers weeds under its rapid and thick covering effect with leaves. However, the above results suggest that L-DOPA or its associate compounds, accumulated in an extremely high concentration in plants, function as an allelochemical in reducing a weed population. The role of L-DOPA in velvet bean seeds was earlier regarded as a chemical barrier to insect attacks. It is now confirmed, however, that it plays another role of its allelopathic activity in weed control.

Apart from the L-DOPA in velvet bean, caffeine in a coffee tree (Rizvi, *et al*., 1981), mimosine in *Leucaena* spp. (Chou and Kuo, 1986), nordihydroguaiaretic acid (NDGA) in a creosote bush (Elacovitch and Stevens, 1985), each of which is contained in a high quantity in the respective plants, are well known to have physiological effects on animals, while their associations with other plants in terms of allelopathy have only recently been identified. It is expected that some secondary metabolites would be identified in the field of allelopathy.

Since velvet bean has special abilities such as weed smothering, tolerance to pests, suppression of nematode population, and soil improvement in its physical structure, it could be more widely used to reduce applications of artificial chemicals to a lower level. Velvet bean seed yields are very high in the tropics, and the seed contains a high level of protein with a useful protein score. If detrimental factors such as L-DOPA and Trypsin inhibitors could be eliminated through proper cooking, it would also contribute to alleviation of the food problems in some tropical countries.

DISCUSSIONS FOR HAIRY VETCH AND COVER CROPS

Hairy vetch is a well known green manure and cover crop in the United State and Europe. The origin of hairy vetch was estimated to the area from west Asia to east Mediterranean coast. It was cultivated in England and Germany in the early 19th century then introduced to the United States in the middle of 19th century, had a good reputation from the US Department of Agriculture, and now widely distributed in the southern part of the United States. Hairy vetch was introduced to Japan in the early 20th century and had good results at the agricultural experimental station, but was not distributed until now.

There are some reports on the allelopathy and weed control by hairy vetch. Lazauskas and Balinevichiute (1972) tested the inhibitory activity of extract of seeds to barley, and found that hairy vetch showed the strongest activity. White, *et al*. (1989) reported that the incorporation of residue of hairy vetch and crimson clover reduced the emergence Solanaceae weeds to 60-80 percent, and water extract of hairy vetch had the stronger inhibitory activity. Johnson, *et al*. (1993) reported that the mulch made from hairy vetch or rye completely inhibited the weed in non-tillage systems by killing them by herbicide or mechanical cutting. Teasdale and Daughtry (1993) reported that the living mulch of hairy vetch showed better inhibitory activity than the desiccated one. Abdul-Baki and Teasdale (1993) reported a unique system using hairy vetch mulch to compensate for the vinyl plastic film mulch in tomato production. There are so many reports and field observation about the weed suppression of hairy vetch, but hitherto the contribution of allelopathy and its allelochemicals are unknown. It is now possible to separate allelochemicals from hairy vetch and the chemical nature reported.

Hairy vetch has many merits other than weed control in the field: 1) nitrogen fixation to reduce chemical fertilizer; 2) organic materials to reduce chemical fertilizer or soil conditioner; 3) prevent soil erosion by surface cover; 4) deep root system promotes soil porosity; 5) thick cover palliates the micro climate to reduce maximum temperature and increase minimum temperature; and 6) induce carnivorous ladybug to reduce the population of harmful insects.

After these series of experiments, it was concluded that hairy vetch is the most promising cover crop for the control of weeds in abandoned fields, grassland and orchard in the central and southern part of Japan.

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1. REPUBLIC OF CHINA

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INTRODUCTION

Chemical pesticides have long been regarded as the most convenient and effective materials for the control of plant diseases and pests. Although the use of pesticides is unavoidable, high amount of consumption not only wasted money but also caused a lot of problems including chemical residue in foods, environmental pollution and adverse effects on ecosystem. Therefore, developing and applying nonpesticide methods as alternative to chemical control of plant diseases and pests has become a global trend. Located in subtropical area, Taiwan has warm and humid climate that is suitable for the occurrence of plant diseases and insect pests. Farmers in Taiwan are used to controlling diseases and pests with pesticides. In an era of increasing consciousness for food safety and environmental protection, the top authorities of plant protection, Council of Agriculture (COA), has set the development and extension of nonpesticide methods as a national mission in terms of plant protection since 1984. With the efforts through years, we has promoted awareness of nonpesticide control, and brought many techniques into extensive application resulting in satisfactory outcomes. This paper states the development and extension of nonpesticide methods for controlling plant diseases and pests in Taiwan.

NONPESTICIDE CONTROL OF INSECT PESTS

Use of Natural Enemies

In Taiwan, natural enemies of plant insect pests have been used for biological control since early 20th century. Starting in 1947, an indigenous parasitic wasp, *Trichogramma chilonis* (Ishii) (Hymenoptera: Trichogrammatidae), had been studied for its effectiveness of controlling gray borer, stalk borer and shoot borer of sugarcane and has been extensively released since 1972 to sugarcane fields resulting in successful control (COA, 1996). However, extensive studies on biological control had not been common until early 1970s due to the prevalence of chemical control. Natural enemies that interest Taiwanese researchers, especially those who work at Agricultural Research Institute (TARI), include exotic and indigenous ones in terms of their origin. Many kinds of exotic natural enemies have been introduced into Taiwan and tested for their effectiveness of controlling domestic insect pests. Some of them performed well as control agents, whereas some of them failed to establish. In recent years, the natural enemies that have commonly been studied and applied in Taiwan included parasitic wasps, predatory mites, green lacewing, and flower bugs. Some of them have been extensively applied with satisfactory results and some of them are still limited to small-scale field trials (Table 1).

1. ***Parasitic Wasps***

Citrus plant lice, *Diaphorina citri* (Kuwayana) (Homoptera: Psyllidae), is a vector of citrus Likubin in Taiwan. Data showed that it could be effectively controlled by a nymphal parasitoid, *Tamarixia radiata* (Waterston) (Hymenoptera:Eulophidae), in Reunion Islands. The parasitic wasp was introduced into Taiwan to control citrus plant lices. A total of 64 adult parasitoids in four shipments were obtained from 1983 to 1986 and subsequently a total of 21,164 adults of *T. radiata* were propagated and released to 39 citrus groves and common jasmine orange (*Murraya paniculata* Jack. var. *paniculata*) bushes in 12 counties during 1984-88. Survey data showed that the wasp has successfully established in this island and kept citrus plant lice at low density (Chien, *et al*., 1989).

Table 1. Records of Introduced Natural Enemies during 1971-95

Year	Natural Enemy	Target Pests	Origin	Status*
1971	*Opius importatus*	Bean flies	Hawaii	F
1971	*Opius phaseli*	Bean flies	Hawaii	F
1973	*Apanteles vestalis*	Diamondback moth	Holland	F
1973	*Diadegma fenestralis*	Diamondback moth	Holland	F
1974	*Apanteles glomeratus*	Imported cabbage worm	Japan	E
1983	*Tetrastichus brontispae*	Coconut leaf beetle	Guam	S
1983	*Tamarixia radiata*	Citrus psylla	Reunion	S
1983	*Trissolcus basalis*	Green sting bug	Hawaii	E
1983	*Amblyseius californicus*	Two-spotted spider mite	Hawaii	E
1983	*Typhlodromus occidentalis*	Two-spotted spider mite	USA	F
1984	*Trichogramma nubilale*	Asian corn borer	USA	F
1985	*Amblyseius fallacis*	Two-spotted spider mite	USA	S
1985	*Diadegma eucerophaga*	Diamondback moth	Indonesia	E
1987	*Cotesia erionotae*	Banana skipper	Hawaii	E
1987	*Ooencyrtus erionotae*	Banana skipper	Hawaii	E
1988	*Dacnusa sibirica*	American leafminer	Holland	F
1988	*Encarsia formosa*	Greenhouse whitefly	Holland	F
1988	*Trichogrammatoidea bactrae fumata*	Litchi fruit borer	Thailand	E
1988	*Curinus coeruleus*	Jumping plant-lice	Hawaii	F
1989	*Typhlodromus occidentalis*	Two-spotted spider mite	USA	-
1989	*Phytoseiulus persimilis*	Two-spotted spider mite	USA	S
1990	*Phytoseiulus persimilis*	Two-spotted spider mite	Australia	S
1990	*Nephaspis annicola*	Spiraling whitefly	Hawaii	F
1990	*Nephaspis bicolor*	Spiraling whitefly	Hawaii	F
1993	*Macrocentrus grandii*	Asian corn borer	USA	F
1995	*Encarsia haitiensis*	Spiraling whitefly	Hawaii	-
1995	*Encarsia guadelopupae*	Spiraling whitefly	Hawaii	-

Note: * S = successful in control; F = failure in establishment; E = established; and - = status uncertain.

Coconut leaf bud beetle, *Brontispa longissima* (Gestro) (Coleoptera:Chrysomelidae) was a serious pest of coconut palm in Taiwan during early 1980s. Its larval and pupal parasitoid, *Tetrastichus brontispae* (Ferr.) (Hymenoptera:Eulophidae), was introduced into Taiwan from Guam in November 1983. A total of about 143,082 adults were released by 106 times to Kaohsiung, Pingtung, Taitung, Hualien, Taitung, Chiayi, Yunlin and Taipei from January 1984 through June 1986. It was evident that the introduced parasitoid had already established in Taiwan and performed as an excellent biological control agent of the coconut leaf beetle. Survey data indicated that this biological control project was a great success (Chen, 1992b).

An indigenous parasitic wasp, *Trichogramma ostrinae* (Pang and Chen) (Hymenoptera: Trichogrammatidae), has been used as a biological agent to control Asian corn borer, *Ostrinia furnacalis* (Guenée) (Lepidoptera:Pyralidae), the most important insect pest of corn in Taiwan since 1984. So far, it has been applied to a total of 200,000 ha of corn resulting in a considerable success in terms of effect on direct control of the pest and significant reduction of the use of pesticides. The wasp was propagated to a large number with the eggs of rice moth, *Corcyra cephalonica* (Stainton) (Lepidoptera:Pyralidae), as substitute hosts. An egg card machine was developed to improve the efficiency of producing cards stuck with eggs of the rice moth harbored by the wasp. Production of the egg cards with this machine is 10 times faster than that by laborers. It saves 2,626 hours and US$4,700 in every lot of three million egg cards (3.5 x 1.5 cm) that are used to release the parasitoid to 10,000 ha of corn for controlling Asian corn borer (Chen, 1992a; and COA, 1996). The improvement of technique for mass production will facilitate the application of the biological control method.

2. ***Green Lacewing***

Green lacewing, *Mallada basalis* (Walker) (Neuroptera:Chrysopidae), is an indigenous predatory natural enemy of several kinds of plant insect pests including spider mites, whiteflies, leafminers, thrips, and aphids. Successful control of those pests using the larvae of the green lacewing was achieved on citrus, muskmelon, papaya, jujube, and strawberry in screen houses and in the open fields as well. To improve the efficiency of mass rearing of the green lacewing, a prototypical machine with control of temperature, pressure and fluid level was developed to make microcapsulated artificial diets. The microcapsules about 396±48 μm in diameter and 10 μm in thickness were produced with 90 percent success rate. When *M. basalis* larvae were reared with the microcapsulated artificial diets modified from Hassan and Hagen's formula, 90 percent of individuals reached the adult stage in 20.7 days and the females deposited 348.5 eggs on average. The results were comparable with those reared with eggs of *Corcyra cephalonica* or *Aphis glycines* (Matsumura) (Hemiptera:Aphididae) (TARI, 1999). The improvement of rearing the predatory biological control agent will make its large-scale extension possible.

Another green lacewing, *Chrysopa boninensis* (Okamoto) (Neuroptera:Chrysopidae), is a polyphagous predator. Larvae are known to feed on a wide variety of small, soft-bodied insects such as aphids, scales insects, mealybugs, plant lices, spider mites, and on eggs and small larvae of a number of lepidopteran insects. *Chrysopa* was thus chosen as an agent for citrus red mite control. A preliminary experiment was conducted in a citrus grove. One thousand eggs of *Chrysopa* were released per tree. Twenty days later, the population density of citrus red mites in the released plot was much lower than in the control plot. The level of predation was sufficient to greatly reduce the mite population and keep it down to a very low level (TARI, 1999).

3. ***Flower Bug***

An indigenous predatory flower bug, *Orius strigicollis* (Poppius) (Hemiptera:Anthocoridae), had proved to be a good predator of small insects, such as thrips, and spider mites in Taiwan. Large number of *Orius* flower bug can be propagated under constant temperature and photoperiod conditions with bean [*Glycine max* (L.) Merill] sprouts as food and ovipositional substrate and flour moth, *Ephestia cautella* (Walker) (Lepidoptera:Pyralidae) eggs as prey. Field-release tests were conducted on eggplant and adzuki bean grown in open fields in central and southern Taiwan in 1998 and 1999 to evaluate the effect of *O. strigicollis* on biological control. In the biological control plots, densities of thrips gradually declined after the release of the flower bugs. The number of thrips in the chemical control plots dropped immediately after insecticide applications, but increased rapidly afterwards. Significant differences between biological control plots and chemical control areas appeared 4-6 weeks after the first release. The control effect lasted for several weeks. It was shown that the flower bug, when released at the proper timing, is an effective natural enemy for the control of thrips on certain crops in open fields (TARI, 1999).

4. ***Predatory Mites***

Predatory mites, *Amblyseius fallacis* (Garman) (Arachnida:Phytoseiidae) and *Phytoseiulus persimilis* (Athias-Henriot) (Arachnida:Phytoseiidae), have long been regarded as promising biological control agents of plant spider mites. They were introduced from the USA and trials to evaluate their usefulness were carried out in three commercial strawberry fields for controlling two-spotted spider mite, *Tetranychus urticae* (Koch) (Arachnida:Tetranychidae), in Taiwan over three seasons during 1986-89. Cooperating growers controlled diseases, mites and insect pests by means of a weekly or biweekly spray schedule before the fruiting stage. When the strawberry plants began to blossom, all chemical applications were stopped. *A. fallacis* and *P. persimilis* were released at a rate of 10/plant, at the time when two-spotted spider mite reached two active individuals/leaflet or infested 30 percent of sampled leaves. Satisfactory control of *T. urticae* was achieved when enough predatory mites were released and/or selective acaricides were applied as auxiliary control agents (Ho and Lo, 1992). The establishment of an integrated pest management (IPM) system based on the biological control of *T. urticae* by both two predatory mites is in progress.

Both of the abovementioned predatory mites also gave effective control of Kanzawa spider mite, *Tetranychus kanzawai* (Kishida) (Arachnida:Tetranychidae), the most common spider mite on papaya. *P. persimilis* was more effective than *A. fallacis* when 500 predators/plant were released each time for two or three times in the test fields. The best releasing position on plant was found to be the lower leaves. The results showed that spider mite could not be found in the biological control plots. However, 41.4 mites and 469.0 mites/leaf were found in chemical control plot and untreated plot, respectively (Lo, *et al.*, 1990). *A. fallacies* was also tested for its effectiveness of controlling Kanzawa spider mites (*T. kanzawai*) on mulberry. A total of 5,271 million *A. fallacis* were mass produced, and released to 179.33 ha of mulberry orchards. Encouraging results were obtained at Miaoli, Natou, and Chiayi. Moreover, *A. fallacies* has been found to be well established in pear trees and gave effective control of both species of spider mite. During the winter, the predatory mite migrated down into the ground cover, where it lived on broadleaf weeds and continued to prey on the two-spotted spider mite (Ho and Chen, 1992; and Ho and Lo, 1992).

Use of Sex Pheromones

In order to enhance the application of nonpesticide method in the field, the Taiwan Government has financed researches and extension in using sex pheromones for controlling the insect pests on many crops since 1983. The kinds being promoted included sex pheromones of tobacco cutworm, *Spodoptera litura* (Fabricius) (Lepidoptera:Noctuidae); beet army worm, *Spodoptera exigua* Hübner (Lepidoptera: Amphipyrinae); sweet potato weevil, *Cylas formicarius* (Fabricius) (Coleoptera:Brentidae); carambola fruit borer, *Eucosma notanthes* (Meyrick) (Lepidoptera:Tortricidae); smaller tea tortrix (*Adoxophyes* sp.); rice stem borer, *Chilo suppressalis* (Walker) (Lepidoptera:Pyralidae); tomato fruit worm, *Helicoverpa armigera* (Hübner) (Lepidoptera:Noctuidae); turnip moth, *Euxoa segetis* (Schiffermiller) (Lepidoptera:Noctuidae); Asian corn borer, *Ostrinia furnacalis*; and cabbage looper, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae). Different kinds of sex pheromones were applied to crucifer, shallot, peanut, soybean, flowers, sweet potato, corn, carambola and tea, respectively (Table 2).

Table 2. Application of Sex Pheromones and Attractants

Sex Pheromones or Attractants	Purposes	Extension (ha)*
Tobacco cutworm (*Spodoptera litura* Fabricius)	Monitoring Mass trapping: 6-8 traps/ha/month	22,000
Beet armyworm (*Spodoptera exigua* Hübner)	Monitoring Mass trapping: 6-24 traps/ha/1-2 months	1,700
Tomato fruitworm (*Helicoverpa armigera* Hübner)	Monitoring Mass trapping: 6-24 traps/ha/1-2 months	350
Sweet potato weevil (*Cylas formicarius* Fabricius)	Monitoring Mass trapping: 40 traps/ha/1-2 months	2,800
Carambola fruit borer (*Eucosma notanthes* Meyrick)	Monitoring Mass trapping: 40-50 traps/ha/5-8 months Mating disruption: 120 spots/0.1 ha/5 months	400
Smaller tea tortrix (*Adoxophyes* sp.)	Monitoring Mass trapping: 25-40 traps/ha/month	250
Tea tortrix (*Homona magnanima* Diakonoff)	Monitoring Mass trapping: 25-40 traps/ha/month	1,350
Asian corn borer (*Ostrinia furnacalis* Guenée)	Monitoring	-
Oriental fruit moth (*Grapholita molesta* Busck)	Monitoring	-
Litchi fruit moth (*Cryptophlebia ombrodelta* Lower)	Monitoring	-
Methyl-eugenol (95%) and nales (5%) mixture	Monitoring: 549 detection points Trapping and killing: 4-6 pic/ha/2 months	580,000
Cuelure (85%)	Monitoring: 162 detection points Trapping and killing: 4-6 pic/ha/2 months	Commonly used
Methyl-eugenol (95%), cuelure (85%) 1:1 and naled (5%) mixture	Monitoring: 36 detection points Mass trapping and killing: 4 pic/ha/2 months	1,550

Note: * Total hectares that the methods were applied under government subsidy from 1998 to 2001.

In practice, they were used mainly to monitor or mass trap the target insect pests and occasionally to disrupt mating. Among them, the sex pheromone of sweet potato weevil has been most extensively applied in the fields. A funnel-shaped bottle suitable for trapping sweet potato weevil was invented and patented. The traps containing the sex pheromone lure were set in the fields at the rate of 40/ha. The density of the weevil was reduced by 55-65 percent (Hwang and Hung, 1992). This method has been applied to a total of 12,000 ha of sweet potato since 1991. Besides, the sex pheromones of carambola fruit borer, Z-8-dodecenyl acetate and Z-8-dodecenol, had also been intensively studied. When they were used for mass trapping (40-50 traps/ha lasting for five months), the density of the fruit borer was reduced by 75-89 percent as compared to untreated orchards. Assessment of using sex pheromone for mating disruption of carambola fruit borer was studied in the cage and orchards of small acreage. Data displayed that when the ratio of pheromones were properly formulated and the amount used were sufficient (53.28 g/ha), the mating inhibition in the orchards reached 97.45 percent. The fruit damage was reduced by 71 percent as compared to conventional chemical control (Hung and Hwang, 1993).

Other Nonpesticide Methods

Male annihilation by using materials other than pheromones has also been extended in Taiwan. Oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera:Tephritidae), has always been a serious problem on several kinds of fruits. Different approaches to controlling Oriental fruit fly had been compared and using sugarcane-fiber plate absorbed with methyl eugenol (95 percent) and naled (5 percent) for male annihilation was found to be the most effective and convenient method (Liu, 1992). Subsidized by the government, this method has been applied to about 580,000 ha of orchards and groves since 1998. Melon-fly, *Bactrocera cucurbitae* (Coquillett) (Diptera:Tephritidae), has long been the key pest of cucurbits. Cuelure [4-(p-acetoxyphenyl-2-butanone)]mixed with insecticides has been recommended for male annihilation and commonly adopted by the farmers (Chen and Chang, 1993). Yellow sticky cards are commonly employed by farmers to trap small insect pests such as whiteflies, thrips, leafhoppers and aphids for monitoring and/or control purposes (Wang and Lin, 1992).

Pathogenic microbes including bacteria, viruses, and nematodes are regarded as promising biological control agents of insect pests. However, *Bacillus thuringiensis* Berliner has been the only microbe commonly used in Taiwan so far. It was first officially recommended to control diamondback moth and then Asian corn borer (Hsiao, 1984). Further studies showed that when mixed with fried rice bran, its efficacy of controlling Asian corn borer was significantly improved (Wu and Tseng, 1997).

NONPESTICIDE CONTROL OF PLANT DISEASES

Physical Control

1. *Mulching and Screen Housing*

There are two physical methods that are commonly used in Taiwan to prevent weeds, diseases or insect pests. For planting papaya, seedlings free from papaya ring spot virus (PRSV), the limiting factor of papaya production in Taiwan, are planted in screen houses that prevent aphids, the transmission vectors of PRSV, from entering. The soil is covered with plastic sheets that prevent the growing of weeds. By this way, papaya has been stably produced at about 138,600 mt per year since early 1990s (Wang and Wang, 1995). Mulching of soil with plastic sheets is also commonly adopted by the growers to cultivate many kinds of crops such as watermelon, muskmelon, cucumber, tomato, eggplant, pepper, strawberry, etc. By this way, weeds are mostly inhibited and the occurrence of insect pests and soil-borne diseases are also reduced to some extent. Besides, the simple facilities, tunnels constructed with transparent plastic sheets under which muskmelon is planted, are also commonly adopted by the growers. By this way, viral diseases, downy mildew and some insect pests are effectively controlled (Huang, *et al*, 1999).

2. *Steam Sterilization*

Recently, plant disease control by steam sterilization was used in planting high-value horticultural crops in Taiwan. Soils and cultural composts contaminated with plant pathogens were sterilized by injecting steam (60-80ºC for 30 minutes). Plant diseases, such as lily yellowing caused by *Fusarium oxysporium* Shlechtend:Fr. emend f. sp. *lilii* Imle, *Thanatephorus cucumeris* (Frank) Donk, bacterial wilt of lisianthus caused by *Ralstonia solanacearum* Yabuuchi, *et al*., southern blight of ornamentals caused by *Athelia rolfsii* (Curzi) Tu and Kimbrough, etc., were controlled significantly by steam sterilization. In addition to the disease control (Table 3), the quality of ornamental products and weeds control were also improved. Some horticulture growers, such as those who plant lisianthus and potted flowers, by the assistance of plant pathologists, developed their own steam pipe systems to improve the efficiency of operation in fields and screen houses (Lee, 1997). Although this method is labor-costly and time-consuming and, therefore, did not appeal to some growers, the benefits of reducing both the use of pesticides and adverse impacts on the environment still make it promising in the future, especially in the ornamental industry.

Table 3. Lethal Temperatures for Soil Microbes and Weeds

Lethal Temperature (ºC)	Soil Microbes
100	All pathogenic microbes and weeds
93	Heat-tolerance viruses, actinomycetes and weeds
82	Most weeds and viruses, all plant pathogens
60-71	Most plant pathogenic fungi and bacteria, insects, mites, earthworms, snals, centipedes
49-60	*Rhizoctonia solani*
49	Nematodes
38-49	Algae

Use of Pathogen-free Propagating Materials

Since seeds and seedlings are the starting materials for the production of crops and might be the carriers of pathogens and pests, the use of healthy seeds and seedlings is one of the most important strategies for nonpesticide controlling methods in many countries. By using healthy seeds and seedlings, the crop productivity and quality can be increased and improved. In Taiwan, the system of healthy seeds and seedlings production was started from the propagation and extension programs for seeds of the staple crops such as rice and coarse grains such as corn, soybean, peanut, etc (Table 4). In 1959, the Seed Testing Laboratory (STL) was established for the inspection of fields for foundation, registered, and certified seeds production and laboratory testing of the quality including their purity, moisture content, germination rate and health. The acreage of fields, mainly paddy rice, inspected amounted to about 2,000 ha annually over the years (Kao and Lee, 2001).

Subsequently, other propagation and inspection systems of virus-free seedlings of other crops were taken effect. Among them, the systems for potato, strawberry and sweet potato were established in 1972, 1991 and 1998, respectively. In the systems, STL are engaged in all the inspections and testing, and TARI, Chiayi Agricultural Experiment Branch Institute, and TSIPS are responsible for the supplies of foundation seeds of sweet potato, potato and strawberry, respectively. The inspection systems of those three crops operated well and were successful in supplying high quality seeds and seedlings (Kao and Lee, 2001).

The production technique of virus-free seeds of asparagus bean had been developed by TARI and worked in practice by TSIPS. The extension area of healthy seeds has amounted to 824 ha since 1996 (Kao and Lee, 2001). With regard to passion fruit and bamboo, TARI and Tainan DAIS are responsible for, respectively, the inspection and maintenance of virus-free nuclear stock repositories founded to meet the needs of commercial nurseries. By estimate, 250,000 virus-free passion fruit seedlings have been released per year since 1989 and 60,000 healthy bamboo seedlings free from CMV have been provided since 1992 (Cheng and Yeh, 2001). With regard to citrus, the system is carried out mainly by Chiayi Agricultural Experiment Institute with technical support from NTU. Pathogen-free budlings of citrus are provided by Chiayi Agricultural Experiment Institute to meet the needs of commercial nurseries. In recent years, over 20,000 pathogen-free budlings of citrus were produced annually (Su, 2001). In addition, Taiwan Banana Research Institute and Taiwan Sugar Company take charge of the propagation and indexing of healthy seedlings of banana and sugarcane in Taiwan. The amount of healthy banana seedlings, produced by tissue culturing, supplied was estimated to 28 million during 1983-90 (Hwang, 2001; and Kao and Lee, 2001).

Table 4. Crops in the System of Healthy Seed and Seedling Production (Part I)

	Field Crop	Potato	Strawberry	Sweet Potato	Asparagus Bean
Suppliers of foundation stock	Breeding institutions	TSIPS	TSIPS	Chiayi Agricultural Experiment Station, TARI	TSIPS
Inspector	STL	STL	STL	STL	TSIPS
Technical support	Agricultural research and improvement institutions	NCHU	NCHU	NCHU	TARI
Initiation year	1957	1972	1991	1998	1995
Pathogens inspected/ indexed	Major diseases	Potato A potyvirus (PVA), potato X potexvirus (PVX), potato S carlavirus (PVS), etc.	*Ralstonia solanacearum; Coleosporium* sp.; strawberry latent ring spot virus; strawberry mild yellow edge associated potexvirus, etc.	Sweet potato feathery mottle virus (SPFMV); sweet potato leaf curl virus (SPLCV); sweet potato yellow dwarf virus (SPYDV); sweet potato latent virus (SPLV), etc.	Black-eye cowpea mosaic virus (BlCMV); cucumber mosaic virus (CMV)
Amount supplies	2,000 ha of fields inspected per year	100 mt of foundation seed potatoes per year	20,000-40,000 pathogen-free seedlings per year	7,240,000 virus-free seedlings since 1998	900 kg of virus-free seeds per year since 1996, with about 824 ha of extension areas in total

Notes: NCHU= National Chung Hsing University;
NPUST= National Pingtung University of Science and Technology;
NTU= National Taiwan University; and
TSIPS= Taiwan Seed Improvement and Propagation Station, COA.

Table 4. Crops in the System of Healthy Seed and Seedling Production (Part II)

	Green Bamboo	Passion Fruit	Citrus	Banana	Anthurium
Suppliers of foundation stock	Tinan District Agricultural Improvement Station (DAIS), COA	TARI	Chiayi Agricultural Experiment Institute, TARI	Taiwan Banana Research Institute	Breeding companies
Inspector	Tinan DAIS, COA	TARI	Chiayi Agricultural Experiment Station, TARI	Taiwan Banana Research Institute	NCHU; TARI; Chiayi Agricultural Experiment Institute, TARI; DAISs
Technical support	NCHU; NPUST; Academic Sinica	NCHU; Taitung DAIS, COA	NTU	NTU	NCHU
Initiation year	1980	1989	1986	1983	2000
Pathogens inspected/ indexed	Bamboo mosaic virus (BaMV)	Cucumber mosaic virus (CMV); passion fruit woodiness virus (PWV); and passion fruit mottle virus (PMV)	Fastidious bacteria (*Liberobactor asiaticum*); citrus trisreza closterovirus (CTV); citrus tatter leaf capillovirus (CTLV); citrus exocortis viroid (CEV), etc.	*Fusarium oxysporium* f. sp. *cubense* (race 4); banana bunchy top virus (BBTV); CMV	*Xanthomonas campestris* pv. dieffenbachiae; designated nematode; *Phytophthora parasitica*
Amount supplies	60,000 virus-free seedlings since 1992	250,000 virus-free seedlings per year	20,000 pathogen-free budlings per year	28 million pathogen-free seedlings until 2001, with 14,459 ha of extension area	690,000 seedlings certified since 1990

Furthermore, to comply with the "Guidelines for Inspection of Designated Plant Diseases and Pests on Anthurium Seedlings", a mandatory inspection to ensure that the propagating materials are free from quarantine nematodes and bacterial blight pathogen, *Xanthomonas campestris* pv. *Dieffenbachiae* Vauterin, *et al*. has been implemented since September 1990 and over 690,000 healthy seedlings have been certified so far (Kao and Lee, 2001).

Besides, the government is in the process of establishing of voluntary seed and seedling certification systems to encourage the production of high quality and healthy seeds. The certification system for oncidium orchid seedling will be the first to be taken effect and asparagus bean will be the second. In the future, many more crops will be included in the voluntary seed and seedling certification system when the techniques are available. It is expected that the implementation of the voluntary seed and seedling certification system will significantly enhance the quality of seeds and seedlings of related crops and subsequently promote the competitiveness of Taiwan's agriculture (Kao and Lee, 2001).

The followings are detailed descriptions regarding some of the prominent cases that used pathogen-free propagating materials to control major diseases in Taiwan.

1. ***Application of Tissue Culture Technology for Controlling Fusarium Wilt of Banana***

Fusarium wilt of Cavendish banana caused by *Fusarium oxysporium* Schlechtend:Fr. emend f. sp. *cubense* (E. F. Smith) Snyder and Hansen race 4 has been the major constraint for banana production in Taiwan. Previously, the disease had destroyed the banana industries of many countries in Central America despite many attempts to control the disease. Continued banana production in Taiwan in recent years to supply both local and the Japanese market was attributed to the successful development of tissue culture technology for controlling fusarium wilt. There have been two major achievements based on tissue culture technology leading to the success of controlling fusarium wilt. Firstly, the technology was employed for mass propagation of disease-free plantlets for commercial planting. During 1983-2001, the tissue culture program has produced a total of 28 million plantlets for planting over 14,459 ha and has effectively contained the spread of wilt pathogen via infected suckers traditionally used by farmers. Secondly, because propagation of banana by tissue culture has shown the potential of producing substantial genetic variability, a mass screening program to select tissue culture plants resistant to fusarium wilt was taken. Two resistant varieties, Tai-Chiao No. 1 and Tai-Chiao No. 3, developed by this breeding program were released for controlling fusarium wilt in 1992 and 200l, respectively. Another new, higher-yielding, resistant variety, Formosana, selected most recently is scheduled for release in 2002. It is estimated that planting Formosana to replace Giant Cavendish would have the potential to increase yield by over 50 percent, and thus boost banana production considerably (Hwang, 2001; and Hwang and Su, 1998).

2. ***Production and Extension on Bamboo Mosaic Virus-free Clones/Plants of Green Bamboo***

Because green bamboo shoot is rich in nutrition and delicious, it has been considered an important vegetable especially during the summer. BaMV is the most destructive disease affecting the cultivation of bamboo shoots. The percentage of infection on green bamboo based on visible symptoms was 80-98.8 in the major growing areas of green bamboo. Previous studies revealed that the disease was transmitted mainly by cultural practices via farming tools. The control for the disease by planting the virus-free clones was effective. Since 1989, eye-inspection and/or the ELISA (enzyme-linked immunosorbent assay) methods were used for the indexing of the disease, and green bamboo virus-free mother plant fields were set up at Tainan DAIS Hsinhua Branch Station in 1990. A virus-free clones nursery was set up at Paiho, and has been indexed periodically once a month and the new clones were distributed to the bamboo farmers at their request. This nursery has produced 60,000 virus-free clones for farmers until 2001 (Cheng and Yeh, 2001; and Kao and Lee, 2001). The establishment of the pathogen-free seedling system has significantly improved the quality and ensured the stable yield of green bamboo shoots. This system will also facilitate expanding the international markets of green bamboo shoots.

3. ***Production and Application of Virus-free Seeds to Control Virus Diseases of Asparagus Beans***

Asparagus bean, *Vigna sesquipedalis* (L.) Fruwirth, is one of the important vegetables in Taiwan in hot and wet summer seasons. Among various kinds of diseases attacking asparagus bean, viral diseases are identified as major limiting factors for its production. CMV and BLCMV were previously found as the two major viruses attacking asparagus bean in fields. Both viruses were found seed-borne and the infected seedlings could serve as primary inoculum for the consequent early epidemic as resulted form mechanical and aphid transmission. Investigation was directed to evaluate the effects of planting virus-free asparagus bean seeds in controlling the viral disease in fields. An asparagus bean cultivar "San-Tse-Chin-Pi" was selected for production of virus-free seeds in 1990. By rouging virus-infected plant after detection by ELISA using antisera against BLCMV and CMV, plants were cultivated in insect-proof screen houses until seeds were harvested. The seeds were then served as foundation virus-free stock.

A large-scale virus-free seed propagation system was subsequently developed in order to satisfy sufficiently the demand from the growers in Taiwan. In 1991-92 we conducted four field trials to test the feasibility of using virus-free seeds to control viral diseases of asparagus bean. The result indicated that the application not only significantly delayed the virus epidemic but also increased the yield and quality of bean pods and eventually the profit earned by the growers. In the field experiments, as low as 30-72 percent of final virus incidences was recorded in the plots sowed with virus-free seeds while in the same time 100 percent of incidences were detected in the control plots planted with commercial seed lots (Chang, 2001). Since 1993, planting of virus-free seeds has been routinely taken as one of the key measures in the integrated pest control program of asparagus bean in various production areas. Because of the consistent and significant control effect the virus-free asparagus bean seeds, produced in this program, have become more and more popular in Taiwan with time. Over 1,086 kg of virus-free asparagus bean seeds were produced and released to four different major asparagus bean producing counties in 2001 (Kao and Lee, 2001).

Use of Antagonistic Microorganisms

1. *Control of Plant Diseases with Antagonistic Bacteria*

Bacillus subtilis Cohn, a gram-positive endospore-forming bacterium ubiquitous in soil and many plant surfaces, has long been used as a beneficial microbial agent for the control of plant diseases. The fungicidal application of *B. subtilis* was one of the primed focuses of biopesticide product development during the past decade and attempt of commercialization development was increasing. In Taiwan, a *B. subtilis* isolate was recently commercialized by Kuan-Hwa Chemical Co. The product has been registered for the control of powdery mildew of pea, whereas its potential market remains to be evaluated. In order to explore the usefulness of native bacilli resources, *Bacillus* spp. with broad spectrum of antagonistic activity against various phytopathogenic fungi and bacteria were selectively isolated from cultural substrate and soil samples collected from field.

Among them, isolate BS1 of *B. subtilis* was found outstanding because of the superior antagonistic activity against *Rhizoctonia solani* Kühn, *A. rolfsii* and *Xanthomonas campestris* pv. *mangiferaeindicae* Robbs, *et al*. Its mass production techniques were developed. As for the practical uses, more than 30 crop species have been tested in greenhouse and/or field trials. Effective control of soil-borne and foliar diseases has been demonstrated, and significant growth promoting effect was generally observed. The efficacy of disease control apparently had certain connection to the production of iturin-like antibiotic. By spraying application of the liquid formulation at 500-1000 x dilution, effective control of foliar infection of tobacco by *Cercospora* sp. (tobacco white spot disease), and leaf and fruit infection of mango by *X. campestris* pv. *mangiferaeindicae* (bacterial spot of mango) were demonstrated by field trials. In cooperation with private enterprises, the commercialization of BS1 isolate is in progress (Tzeng et al, 2001).

Streptomyces spp., being gram positive also, are found ubiquitous among various terrestrial and aquatic natural habitats. The members of streptomyces mostly are known to be saprophytic, aerobic, exist commonly in soil, grow well in slightly alkaline environment, and adapt well in high temperature and drought conditions. As many *Streptomyces* spp. are known to produce important antibiotic secondary metabolites and hydrolytic enzymes, the wide and extensive industrial application has been well recognized. In Taiwan, a *Streptomyces saraceticus* Berger, *et al*. isolate, SS31, was selected and was shown to be effective in knocking down root-knot nematode population in soil primarily because of its chitinase producing characteristics. In a preliminary screening test, it was noted that the test isolate was strongly antagonistic against fairly wide spectrum soil-borne fungal pathogens – especially members of Oomycetes. When solid formulation of SS31 was added to a soil amendment consisting mainly spent forest mushroom compost, fish meal, crab shell powder, and rapeseed pomace, and amended into the soil, the mixture effectively controlled fusarium wilt of lettuce, and fusarium wilt of banana. By spraying application of the liquid formulation at 1000 x dilution, effective control of Phytophthora diseases of papaya and citrus has been demonstrated. It was also found effective for the control of downy mildews on cucurbit, rose, grapevine, etc. In addition, the formulation was found useful as soil drenching agent for the control of soil-borne diseases. The drenching treatment of the liquid formulation at 100-300x in dilution significantly reduced damping-off of cucumber seedlings caused by *Pythium aphanidermatum* (Edson) Fitz. In cooperation with private enterprises, the commercialization of SS31 isolate is in progress (Tzeng, *et al*., 2001).

2. ***Control of Plant Diseases with Antagonistic Fungi***

In Taiwan, *Trichoderma viride* Persoon:Fries and *Trichoderma koningii* Oudemans had been reported to be pathogenic to mushroom in 1967 and water chestnut in 1955, respectively. However, most of species/strains of *Trichoderma* were found to be the effective microorganisms for suppression of the plant pathogenic fungi after 1980. During 1980-90, antagonistic *Trichoderma* spp. were studied and the promising ones were selected, formulated and added into soils and found to be effective on the control of several plant diseases including *Rhizoctonia* diseases, *Sclerotinia* disease, *Pythium* damping-off and *Phytophthora* blight. Among them, *T. viride* T20, *T. knoningii* T12, *T. knoningii* T12-R33-D25, and *Trichoderma harzianum* Rifai TVCN2 were tested in large-scale trials. The results showed that they could inhibit *Rhizoctonia* disease of chrysanthemum and adzuki-bean (Liu, 1991). Recently, it was found that *T. virens* strain R42 and *T. harzianum* T22, when added to the soils, could induce cucumber resistance to cucumber green mottle mosaic virus and suppress the sudden death of melon caused by *Monosporascus* spp. Both of the biological control agents also promoted the seedling and root growth of the crops in greenhouse and field trials. In addition, two isolates, *T. harzianum* T2 and *T. virens* T3 that had been formulated as granules, were found to be effective on the control of dollar spot of turf grasses caused by *Sclerotinia homoeocarpa* Bennett, when the dose applied had reached 10^6 cfu/g soil dry weight (Lo, 2001). The techniques for the mass production of the antagonistic fungi have been exploited.

Use of Soil Amendments

Eight formulated soil amendments, S-H mixture, SF-21 mixture, L-T mixture, AR-3 mixture, CH-1 mixture, GS mixture, FBN-5A and CF-5 liquid, have been developed, mostly by plant pathologists at NCHU, and used for the control of soil-borne plant pathogens in Taiwan. The ingredients of these compounds are mainly fertilizers and organic wastes. Among them, S-H mixture and L-T mixture have been commonly used and FBN-5A is ready for commercialization (Table 5).

1. ***Control of Fungal Diseases with S-H Mixture***

S-H mixture, developed in 1983, has been commercialized in Taiwan for the control of soil-borne diseases. Amendment of soil with S-H mixture, significantly reduced the incidence of watermelon wilt caused by *Fusarium oxysporium* Schlechtend:Fr. emend Snyder and Hansen f. sp. *niveum* (E. F. Smith) Snyder and Hansen, radish yellows caused by *Fusarium oxysporium* Schlechtend:Fr. emend f. sp. *raphani* Kendric and Snyder, pea wilt caused by *Fusarium oxysporium* Schlechtend:Fr. emend f. sp. *pisi* (van Hall) Snyder and Hansen, fusarium wilt of banana caused by *F. oxysporium* f. sp. *cubense*, clubroot of crucifers caused by *Plasmodiophora brassicae* Woronin, cucumber damping-off caused by *P. aphanidermatum*, southern blight of pepper caused by *A. rolfsii, Rhizoctonia* blight of bean caused by *R. solani* and bacterial wilt of tomato caused by *R. solanacearum* (Table 6). The effective rate of application for the effective rate of application for S-H mixture varied with diseases and crops, ranging from 0.5 to 2 (w/w) of soil. In more than 5,000 ha of field trials in a variety of vegetable crops, S-H mixture not only reduced disease incidence but also improved root health, plant growth and plant stands (Sun and Huang, 1983 and 1985).

2. ***Control of Rhizoctonia Damping-off with FBN-5A***

Formulated in Taiwan, FBN-5A is a mixture of spent forest mushroom compost, fish meal, bone meal, blood wastes, lime and allyl alcohol which is effective in controlling *R. solani* AG-4, *Sclerotinia sclerotiorum* (Lib.) de Bary and reduce the incidence of *F. oxysporium* f. sp. *raphani* and *Fusarium oxysporium* Schlechtend:Fr. emend f. sp. *lactucum*. FBN-5A at 1 percent also inhibits the seed germination of weeds such as purslane, black nightshade, etc. The control effect of FBN-5A is due to the ammonia released from chitin and blood meal that poison and weaken the mycelia. The microorganisms and some inhibitors exiting in the mixture also reduce the colonization on cabbage seedlings by *R. solani* AG-4. When FBN-5A was mixed with the commercial BVB No. 4 medium, composed of 30 percent black peat, 10 percent sand, and 70 percent white Germany peat, at the rate of 0.1 percent, the treatment was very effective in controlling damping-off of cabbage caused by *R. solani* AG-4. It not only reduced the disease incidence, but also enhanced the growth of cabbage. The results were confirmed in a large-scale experiment in a commercial automatic environment-controlled greenhouse (Huang and Huang, 2000). This study suggests that the FBN-5A compound offers potential for commercial use as an organic amendment for the management of *Rhizoctonia* damping-off vegetable crops. In 2000, a patent was issued on the formula of FBN-5A, and is about to licensed to industry for further commercialization.

Table 5. Ingredients of Formulated Products for Control of Soil-borne Plant Pathogens

Designation	Disease Controlled	Ingredients
S-H mixture	Several diseases (see Table 6)	4 kg bagasse, 84 kg rice husks, 42.5 kg oyster shell powder, 82.5 kg urea, 10 kg potassium nitrate, 332 kg calcium superphosphate and 605 kg mineral ash
SF-21 mixture	Damping-off of slash pine	150 kg aluminum sulfate, 25 kg potassium chloride, 30 kg calcium chloride, 10 kg triple superphosphate, 35 kg ammonium sulfate, 750 kg milled pine bark, and 750 litter glycerine (10%)
L-T mixture	Parasitic nematodes	40 kg shrimp/crab shell meal, 40 kg castor pomace, 10 kg marine algae powder, 5 kg soybean meal and 5 kg molasses
AR-3 mixture	Southern blight of lily	35 kg cattle manure, 10 kg chaff, 10 kg crab shell meal, 5 kg urea, 3 kg calcium superphosphate, 1 kg potassium chloride and 36 kg mineral ash
CH-100 mixture	Several diseases (see text)	44 kg chopped fresh cabbage leaves, 10 kg chopped dry tobacco leaves, 5 kg $CaCl_2$, 1 kg beef extract, 30 kg S-H mixture and 200 litter Hoagland solution mixed to ferment for 45 days at 25-30ºC, then 0.5% (v/v) alcohol (95%) was added to the extract.
GS mixture	Pythium pod rot of peanut	4 kg gypsum, 15 kg rice husks, 8.5 kg sulfur, 7 kg oyster shell powder, 6.5 kg dry fish meal, 4 kg tobacco grounds and 5 kg complex fertilizer No. 43*
CF-5 liquid	Rhizoctonia blight of kale and peas	25 kg dry fish meal, 20 kg waste mushroom manure, 5 kg oyster shell powder, 1 kg sugar, 30 kg lime and 240 litter water fermented at 24-28ºC for one month and then mixed with 10% (v/v) allyl alcohol.
FBN-5A	Rhizoctoria damping-off in cabbage	Spent forest mushroom compost, fish meal, bone meal, blood wastes, lime and allyl alcohol

Note: * Complex fertilizer No. 43 is a product of the Taiwan Fertilizer Company containing N, P, K, and Mg.

Table 6. Control of Soil-borne Vegetable Crop Diseases by Amendment of Soil with S-H Mixture in Fields

Disease Name (Pathogen)	Disease Incidence (percent)	
	Amended	Non-amended
Clubroot (*Plastmodiophora brassicae*)	1.6b*	46.0a
Damping-off (*Pythium aphanidermatum*)	13.0b	89.0a
Wilt (*Fusarium oxysporium* f. sp. *Niveum*)	32.1b	81.5a
Wilt, yellows (*F. oxysporium* f. sp. *Raphani*)	20.0b	58.3a
Wilt (*F. oxysporium* f. sp. *Pisi*)	46.0b	76.0a
Southern blight (*Sclerotium rolfsii*)	0.6b	11.7a
Rhizoctonia blight (*Rhizoctonia solani*)	1.2b	14.5a

Note: * Numbers in the same row followed by the same letter were not significantly different according to test of significance.

3. ***Control of Plant Parasitic Nematodes with LT-M***

In Taiwan, parasitic nematodes have been big problems on different kinds of crops. A mixture, Lively Tiller Mixture (LT-M) consisting of 40 percent crab shell powder, 40 percent castor pomace, 5 percent soybean powder, 10 percent marine algae powder and 5 percent molasses was formulated. When amended into soil, the mixture significantly inhibited *Meloidogyne incognita* Chitwood, *Tylenchlus semipenetrans* Cobb and *Pratylenchus coffeae* Filipjev and Schuurmans Stekhoven. It was able to increase the population of nematode-trapping fungi such as *Streptomyces saraceticus*. Among the ingredients, castor pomace and crab shell powder were toxic to the nematodes. Hatching of egg masses or dispersed eggs was inhibited by castor pomace. The amendment of marine algae powder made the roots of host plants repellent to juveniles of *M. incognita, T. semipenetrans, P. coffea* and *Paratylenchus curvitatus* van der Linde (Tsay, 1997 and 1998).

When applied at the rate of 2,000 kg/ha to grape vines, LT-M significantly decreased the root-knot indices and disease indices by 47.5, 67.8 and 42.8, 69.5 percent at summer and winter harvest, respectively, as compared to untreated control. Besides, LT-M also increased weight of grape by 57 g, 76 g per cluster and increased sugar content by 3, 5 Brix^{o} at the two harvest seasons, respectively. Antinematodal effect was enhanced when LT-M was applied for two successive years. LT-M in soil of citrus groves also reduced the population of *T. semipenetrans* and *P. coffeae* by 94.1 and 63.6 percent, respectively, as compared to the control. Application of LT-M again significantly controlled root-knot disease of African daisy (Tsay, 1997 and 1998).

Use of Resistant Rootstock

1. ***Resistance of Bitter Gourd-loofah Grafts to Fusarium oxysporium f. sp. momordicae***

The fusarium wilt of bitter gourd caused by *Fusarium oxysporium* Schlechtend:Fr. emend f. sp. *momordicae* Sun and Huang is hard to control in the field (Lin, *et al*., 1996). The technique of cleft grafting to a loofah rootstock was developed and adopted in Taiwan.

F. oxysporium f. sp. *momordicae* can only attack bitter gourd and summer squash, but not other cucurbits that have the potential to be used as resistant rootstock for bitter gourd (Lin, *et al*., 1996). The grafting experiments showed that among the various cucurbit plants tested, only pumpkin, bottle gourd and loofah could be used as rootstock for successful grafting with bitter gourd. Loofah was found not only the best candidate as rootstock for having a highest survival rate in plastic houses and displaying vigorous growth in fields but also showed high resistance to the wilt pathogen even when inoculated by artificial root-pruning method. For three years of field cultivation, the combination of bitter gourd scion (variety of Known-You New No. 3) cleft grafted to loofah rootstock (a local line of L39) was the best one to have high bitter gourd yields which reached 61-108 mt/ha. In contrast, the non-grafted bitter gourd or grafted seedlings by whip root grafting only gave a yield from none to 24 mt/ha (Lin, *et al*., 1998). This method has been commonly adopted by the growers in Taiwan (Table 7).

2. ***Control of Soil-borne Diseases of Tomato by Grafting on Resistant Eggplant Rootstock***

The planting area of tomatoes in Taiwan measures about 4,000 ha with the cultivated season during autumn and winter. In recent years, in order to meet the need of the market, cultivation of tomato within protective facilities during summer time has become more and more prevalent in southern Taiwan. Under high temperature and humid conditions, soil-borne diseases such as bacterial wilt caused by *R. solanacearum*, root-knot nematode caused by *M. incognita* and fusarium wilt caused by *Fusarium oxysporium* Schlechtend: Fr. emend f. sp. *lycopersici* (Sacc.) Snyder and Hansen took place and caused severe losses.

To eliminate the greatest limiting factor in the production of tomatoes, Tainan Agricultural Improvement Station and Asian Vegetable Research and Development Center (AVRDC) have cooperated to develop practical control measures since 1998, and have obtained some encouraging results. Currently, TA 6 is the main cultivated variety of tomatoes which is resistant to high temperature and tomato rugose yellowing virus (TRYV), but very susceptible to root-knot nematode. With regard to the widespread and persistent characteristics of soil-borne diseases, the researchers focused on screening varieties of eggplants for compatible resistant rootstocks. They found that grafting of tomatoes on eggplant rootstocks, EG190, EG203 or EG219, could provide resistance to nematodes, and increased the yield by 8 percent to 43.3 percent. The resistant eggplant rootstocks were grafted with Known-You 301 cultivar of tomato, which was susceptible to bacterial wilt, and bacterial wilt was significantly reduced as well (Cheng et al, 2001).

Table 7. Yield and Fusarium Wilt of Non-grafted and Grafted Bitter gourd by Using Loofah as Rootstock Grown in Farmers' Fields

Treatment	Location	Previous Crop	Area (ha)	Cultivated Period	Yield (mt/ha)	Disease Incidence* (percent)
1991						
Cleft grafting	Ta-Chia (Chen)	Rice, garlic	0.36	Feb.-Oct.	100	0
Cleft grafting	Ta-Chia (Lin)	Rice, garlic	0.23	Feb.-Oct.	80	0
Whip root grafting	Wu-Jih	Rice	0.25	Mar.-Aug.	24	10
Whip root grafting	Ta-Ya	Fallow	0.10	Mar.-Sept.	20	20
Non-grafted	Hsin-sheh	Bitter gourd	0.12	Mar.-Apr.	0	100
1992						
Cleft grafting	Ta-Chia (Lee)	Green onion	0.16	Mar.-Sept.	89	0
Cleft grafting	Ta-Chia (Chen)	Bitter gourd-loofah grafts	0.36	Mar.-Sept.	68	0
Cleft grafting	Wai-Pu (Chen)	Fallow	0.38	Apr.-Nov.	66	0
Cleft grafting	Ta-Chia (Hsiao)	Green onion	0.20	Mar.-Oct.	61	0
Non-grafted	Ching-Shui (Chen)	Rice	0.30	June-Oct.	24	20
Non-grafted	Ching-Shui (Huang)	Rice	0.45	May-July	5	95
1993						
Cleft grafting	Ta-Chia (Chen)	Bitter gourd-loofah grafts	0.36	Mar.-Oct.	108	0
Cleft grafting	Ta-Chia (Lin)	Bitter gourd-loofah grafts	0.40	Mar.-Oct.	82	0
Cleft grafting	Ta-Chia (Lee-1)	Bitter gourd-loofah grafts	0.25	Mar.-Oct.	71	0
Cleft grafting	Ta-Chia (Lee-2)	Green onion	0.25	Mar.-Oct.	69	0
Cleft grafting	Ta-Chia (Hsiao)	Rice	0.15	Mar.-Oct.	63	0

Note: * Percentage of fusarium wilt of bitter gourd causes by *Fusarium oxysporium* f. sp. *momordicae*.

Genetic Engineering

In Taiwan, several measures have been adopted trying to control plant viral diseases. The measures include the application of integrated cultural practices to escape the transmission vectors, the utilization of artificially induced mild strains for cross protection (Wang, *et al*., 1987; and Wang, *et al*., 1992) and the generation of transgenic plants resistant to specified viruses by genetic engineering. Among them, the studies on the control of PRSV by genetic engineering have reached the most remarkable achievement.

1. ***CP-Transgenic Papaya***

PRSV is a major limiting factor for papaya (*Carica papaya* L.) production in tropical and subtropical areas throughout the world. Control measures that have been used to protect papaya plants from PRSV infection, including selection of planting time to avoid the peak of winged aphids, the use of silver mulch to prevent aphids from visiting seedlings, and conventional cross protection. None of these control methods provided a long period of effective protection against PRSV. The CP gene of a local mosaic type strain isolated from Taiwan, designed PRSV YK, has been sequenced, and transferred into papaya via *Agrobacterium*-mediated transformation by Dr. S. D. Yeh at NCHU, and 45 putative transgenic lines were obtained. When the transgenic lines were challenged with PRSV YK by mechanical inoculation, they showed different levels of resistance ranging from delay of symptom development to complete immunity. After the evaluation of resistance under greenhouse conditions, four highly resistant transgenic papaya lines 16-0-1, 17-0-1, 17-0-5 and 18-2-4 were further evaluated under field conditions for their reactions to infection by PRSV and for fruit production. The data obtained from two rounds of field trials displayed that lines 16-0-1, 17-0-1, and 17-0-5 were highly resistant to PRSV. The total fruit yields in the second trials of each line harvested for six months showed a 3.0-3.2-fold increase, and the commercially valuable fruits a 54.3-56.7-fold increase (Yeh, *et al*., 1998). These results indicated that the CP-transgenic papaya lines have a great potential for control of PRSV in Taiwan.

2. ***Control of PRSV by Genetically-engineered Mild Strains***

An attenuated strain, PRSV HA 5-1, that infects papaya without conspicuous symptoms was previously obtained by nitrous-acid induction from the severe parental Hawaii strain HA. It has been used successfully for control of PRSV by cross-protection on a large scale in Hawaii and Taiwan. However, strain-specific protection limits its application in Taiwan and other geographic areas (Yeh, *et al*., 1988; and Yeh and Gonsalves, 1994). In order to analyze the genomic region responsible for the pathogenicity of PRSV, infectious *in vitro* transcripts of both HA and HA 5-1 were constructed and various virus hybrids between severe parental virus and its mild mutant were generated by recombination at the cDNA level. The genomic region responsible for the attenuation of HA 5-1 was determined, analyzed and compared with parental severe strain HA. This genomic segment (nt606-3526) of HA 5-1 was transferred to and replaced the corresponding region of the infectious cDNA clone of Taiwan severe strain YK. The pathogenicity of the generated hybrid virus YKMF was demolished and induced symptoms similar to those caused by to HA 5-1. The cross-protection effectiveness of YKMF was evaluated under greenhouse condition. Over 80 percent of YKMF-protected papaya plants did not show symptom for three months after inoculation with different severe strains (Cheng et al, 2001). The result indicated that the attenuated strain YKMF provides much higher degree of cross-protection and is less strain-specific than HA 5-1 and can potentially be used as a better protective strain than HA 5-1 to protect papaya from PRSV severe infection in Taiwan.

In another attempt to improve the cross-protection effectiveness of HA 5-1 against heterologous strains, the CP gene of Taiwan type W-strain TW was amplified by RT-PCR (reverse transcription-polymerase chain reaction) and used to replace the CP gene of HA 5-1 at the cDNA level. The generated recombinant HA 5-1W also induced mild infections on papaya and cucurbits similar to that induced by HA 5-1. Under greenhouse conditions, results of cross-protection tests indicated that HA 5-1W provides a better degree of protection against PRSV-W than HA 5-1 in *Citrullus lanatus* (Thunb.) Matsum and Nakai, and *Cucumis metuliferus* Naudin, respectively (You, *et al*., 2001). The results indicated that these recombinant mild strains could potentially be used to control the important PRSV-W strains in cucurbitaceous crops.

CONCLUSIONS

As the general public has become more concerned about environmental conservations, attention has been paid to the use of chemical pesticides especially the effect of their residue. IPM has been regarded as an important approach to reduce the application of the agrochemicals, and nonpesticide control method is one of the principle components of the IPM. In recent years, development of nonpesticide measures has obtained some successful achievements those are now being adopted for agricultural production in various countries. To follow the global trend, our government has set the development and implementation of nonpesticide control an aim to safeguard our agricultural production and to protect our environment in the 21st century. As we have gained accession to the WTO in January 2002, it is important for us to strengthen our competitiveness in agricultural production and international agricultural trade. The extensive application of IPM including nonpesticide-based crop protection methods will help reduce the consumption of chemical pesticides and produce safer agricultural products appealing to consumers.

Being aware of the significance of nonpesticide control methods, Bureau of Animal and Plant Health Inspection and Quarantine (BAPHIQ) has put great emphasis in supporting and coordinating research and extension projects in relation to this aspect since its establishment in 1998. Efforts have also been made to promote local awareness of nonpesticide control through demonstration and extension programs, and to educate farmers through training sessions and workshops. Some satisfactory research results were obtained and are ready for the application for patents for commercialization. To continue promoting nonpesticide control and bring it into practical application, some important issues still needs to be further addressed:

1. Firstly, how to integrate nonpesticide control methods into practical IPM models so that farmers are willing to adopt?
2. Secondly, how to formulate nonpesticide agents for commercial production so that they can be produced at low cost and applied without fast decline in efficacy over time?
3. Thirdly, what are the impacts to our ecosystem of the nonpesticide control methods especially that use introduced or genetically engineered agents?

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2. INDIA

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INTRODUCTION

India produces 201.6 million mt of food in 124 million ha with a productivity of 1,625 kg/ha. The oilseed production is about 22.3 million mt grown in 25.26 million ha with a productivity of 873 kg/ha (Anon., 2001).

Pests and diseases cause huge damage in the production of various crops. It is estimated that 53.1 million mt of food grains and 56.8 million mt of sugarcane worth Rs.292.4 billion were lost to pests and diseases attack. Normally the farmers depend on chemical pesticide for the control of pests and diseases. The use of chemical pesticides has caused a lot of environmental hazards apart from resistance developed by the pests to the chemical. In view of the above reasons, nonpesticide methods of controlling pests and diseases have gained considerable importance.

STATUS OF DIFFERENT NONPESTICIDE METHODS

Mechanical Methods

1. ***Collecting and Killing***

The moths of several harmful insects emerge during *Kharif* (June-September) season as well as in subsequent months. After the emergence, male and female moths mate and gravid female lay eggs from 500 to 2,000 in soil or on crop plants. These moths normally rest under clods, in cracks or under dry vegetation matter in soil. Such moths can be physically collected and burnt. This helps in reducing population of pests. Collection and killing or trapping of moths of red-headed hairy caterpillar, *Amasacta albistriga* Walker (Lepidoptera:Arctiidae), cotton bollworms, *Earias insulana* Boisd. (Lepidoptera:Noctuidae) and *Earias vitella* Fabr. (Lepidoptera:Noctuidae), pigeon pea and chickpea pod borer, *Helicoverpa armigera* Hübner, (Lepidoptera:Noctuidae) have been reported from the endemic areas of Karnataka, Tamil Nadu, Kerala and Andhra Pradesh in South India. For instance, in Pavagada taluk of Tumkur (13º18’ N, 77º12’ E) and in Karimnagar (18º26’ N, 79º10’ E) and Mahbubnagar (16º45’ N, 77º59’ E) districts of Andhra Pradesh in South India, villagers collect the moths and caterpillars in large numbers, deploy light-traps for attracting moths and mass-kill the insects. Apart from the adults, the larvae or grubs in soil can be collected large numbers and destroyed. The root grub comes out of the soil during summer (February-April) or pre-monsoon (May-June) showers and feeds on the leaves or fresh twigs of neem (*Azadirachta indica)*, tamarind (*Tamarindus indica*) and *Ficus* species. Adults of root grubs are attracted to light and bonfire. Such adults can be collected in containers containing kerosene and water and destroyed. It is an important, proven integrated pest management (IPM) tool, practiced in many South-East Asian countries. Mass collection and destruction of root grubs has been reported from endemic areas of Karnataka, Gujarat, Maharashtra, Rajasthan, etc. For instance, in Karnataka, sugarcane (*Saccharum officinarum*) root grubs are collected in large numbers and destroyed in Bhadravathi taluk of Shimoga (13º57’ N, 75º32’ E), Gundlupet in Mysore district (13º15’ N, 77ºO’ E), of coffee (*Coffea arabica* and *Coffea robusta*) in parts of Chickamagalur (13º15’ N, 75º45’ E) district, of areca (*Areca catechu*) in Thirthahalli, Sagar and Soraba taluks of Shimoga, and of groundnut (*Arachis hypogaea*) in Chintamani taluk of Kolar district (13º12’ N, 78º15’ E).

The practice of collecting and destroying in huge numbers the eggs, grown-up larvae and adults of pests like grasshoppers, locusts, hairy caterpillars on bunds, sticks, weeds, stretches of wastelands, is common. Such insects can be collected and destroyed or put in a tin pasted with grease on the top portion. Such larvae are killed in tin. *H. armigera* is a pest which is difficult to suppress by methods other than mechanical methods. The larvae can be collected by stirring the plants and by sweeping the larvae fallen underneath the plants. Such larvae are concentrated in pits and can be destroyed/burnt.

2. ***Hot Water Treatment***

Sugarcane setts treated in hot water for 10 minutes controls whip smut (*Ustilago seitaminea*) in Gujarat (Wala, *et al*., 1992). It is a recommended practice in all sugarcane areas in India.

3. ***Soil Solarization***

Soil solarization in the vegetable nursery with the help of polythene mulch (25 microns) for 40 days after flood irrigation kills *Pythium* spp. and *Fusarium* spp. up to 30 cm soil depth. Raising vegetable nursery later in such solarized beds will have lower incidence of pest emergence, damping off, higher seed germination and better seedling vigor (Harender Raj, *et al*., 1997) in Himachal Pradesh, Northwest India.

4. ***Detopping***

Clipping of terminal shoots that serve as oviposition sites for 110 days in cotton (*Gossypium hirsutum* and *G. arboreum*) and 40-50 days in chickpea (*Cicer arietinum*) reduces the *H. armigera* infestation in egg stage, which is being practiced in cotton, as well as in chickpea (Lingappa, 2001).

5. ***Bird Perches***

Wooden or metallic 'T' or 'Y' perches are placed randomly in the cropped area to attract predatory birds to devour larvae/adults of pest insects. In India especially insectivorous birds like drongo (*Dicrurus adsimilis*) and mynah (*Acrido theres*) have been reported to be effective agents of suppressing populations of *H. armigera, Achaea janata* Linn. (Lepidoptera:Noctuidae) and hairy caterpillars in pigeon pea, chickpea, cotton, castor (*Ricinus communis*) ecosystems.

Birds feed on the larvae and reduce their population. For instance, about 80 percent of *H. armigera* (Puri, 1998). Spreading boiled rice balls or balls of Bengal gram preparation in semi-looper (*A. janata*) affected castor fields help in attracting birds, which eat larvae of semi-looper and reduce the populations. Spreading fried rice (puri) in *H. armigera* affected fields of chickpea also attract birds which predate on larvae of *H. armigera* and other pests.

Physical Methods

Light traps in the form of gas lights or mercury lamps placed in large contiguous areas help in trapping moths of *A. albistriga*, wherever the pest is endemic. This will reduce the moth population and multiplication. This has been reported from endemic areas like Pavagada taluk in Tumkur, Kadur in Chickamagalur and Hosadurga in Chitradurga district (14º15' N, 76º28' E) Karnataka, South India.

Cultural Methods

1. ***Crop Rotation***

Monocropping, ratooning and growing the same crop year after year favors the pest and disease buildup. Therefore, it should be avoided. The population of the fungus, *Fusarium* sp. can be reduced when soil is kept fallow, compared to growing successive pigeon pea in the same soil, pigeon pea-fallow-chilies and pigeon pea-fallow-tobacco cropping pattern appreciably reduces *Fusarium* spp. (Dasgupta, *et al*., 1992). Growing maize, (*Zea mays*) chickpea crop sequence decreases root-knot nematode population in chickpea (All India Coordinated Research Project [AICRP], 2000).

2. ***Tillage Practices***

Fall ploughing with a furrow turning plough by the end of the cropping season is advocated to expose the diapausing insect stages in several agro-ecosystems. The tillage practices expose the larvae and pupae of pest insects like cutworms (*Agrotis* spp.), hairy caterpillars (*Amsacta* spp.), grasshoppers (*Hieroglyphus* spp.), root grubs (*Holotrichia* spp.) and locusts (*Locusta* spp.) either to inimical conditions or to predators like insectivorous birds.

3. ***Planting Time***

Planting time has been exploited by many entomologists and pathologists to check insect-pests and disease buildup. For instance, sowing black gram (*Phaseolus mungo*) in the second fortnight of June reduces the foliar diseases in the hill region of Uttar Pradesh (Mittal, 1998). The pigeon pea fusarium wilt is reduced when the crop is sown after July and also by sowing under rainfed conditions in Kanpur, Uttar Pradesh, North India (Choudhry, *et al*., 2001). Sowing early and synchronizing preferably with short duration genotypes lowers bollworms (*Earias* spp.) incidence and damage in cotton in Southern India (Venugopal Rao, 1994). Planting rice during second fortnight of July reduced rice neck-blast in Haryana, India (Dodan and Ramsingh, 1994). Sowing mustard in October reduces white rust incidence in Karnataka (Hegde and Anahosur, 1994).

4. ***Plant Geometry***

Inter- and intra-row spacing has direct and indirect influence on the population of bollworm (*Earias* spp.) because of variation in plant habit and in architecture. Closer spacing (75x30 cm) attracted higher numbers of bollworms than wider spacing (90x30 cm) (Iiango and Uthamasamy, 1989). Wider spacing alters the microclimatic conditions to make it unfavorable for pest multiplication and also make easy to reach pest with bioagents and chemicals. Closer spacing of 25x10 cm reduces mung bean yellow mosaic virus compared to 40x10 cm (AICRP, 2000).

5. ***Trap Cropping***

Trap cropping is yet another technique to successfully suppress pests or pathogens in cultivated ecosystems. Planting highly preferred crops in and around the cotton field serves as trap crops for bollworms. Variation in attractiveness of crops for egg laying or larval feeding is exploited as an effective tool to concentrate early pest populations on selected plants. The major benefit of this is that either the insect can be collected manually or control measures with bioagents or chemicals can be effected, to a limited area, thus avoiding chemical applications to the entire area. The overall application will be less than in conventional farming. Okra (*Ebelmoschus esculentus*), marigold (*Tagetus* spp.), pigeon pea, chickpea, tomato (*Solanum esculentus*), tobacco (*Necotiana tuberosum*), maize (*Z mays*), sorghum (*Sorghum vulgare*), and beans (*Phaseolus* spp.) have been used as trap crops in India and proved effective to lower the incidence of *H. armigera* on cotton. Several studies have been made in India to suggest that okra and marigold have the potential to work as effective trap crops for *H. armigera* on cotton. Trap crops may also attract natural enemy by the presence of semio-chemicals, thereby enhancing effectiveness of natural control (Lingappa, 2001).

Suppression of diamond back moth (DBM) (*Plutella xylostella* Linn.) (Lepidoptera:Yponomeutidae) by trap cropping is popular among cabbage (*Brassica oleracea*) growers in and around Bangalore, Karnataka. For suppressing DBM, paired rows of mustard (*Brassica juncea*) for every 25 rows of cabbage planting and second row sown 25 days after planting exhibited 90 percent attack to mustard than cabbage (Krishnamurthy and Krishnakumar, 1997). Similarly planting marigold one row for every 16 rows of tomato attracts *H. armigera* moths to oviposit on marigold (*Tagetes* spp.) (Krishnamurthy and Krishnakumar, 1997).

6. ***Intercropping***

Intercropping with cowpea, (*Vigna unguiculata*) (Natarajan and Sheshadri, 1988), maize, onion, finger millet (*Eleusine coracana*), mung bean, soybean (*Glycine max*) groundnut (Venugopala Rao, 1994) in south and central zones of India to colonize biological control agents have been advocated. Growing cotton with groundnut/green gram at 1:3 or with onion 1:4 or five proportions have been agronomically accepted practice for remunerative yield in Karnataka (Anon, 1995). Intercropping barley (*Hordeum vulgare*) with chickpea reduced blight disease (*Ascochyta rabiei*) in Rajasthan, India (Gour and Singh, 1994), marigold or cowpea planted around cotton crops as border crop reduces incidence of bollworms (*Earias* spp. and *H. armigera*) in cotton (Puri, 1998).

7. ***Nutrient Management***

Manuring and fertilization are practices adopted to promote rapid growth in plants and shorten the period of susceptible stage of attack to the herbivores. Nutrients provide greater tolerance and compensates for insect damage. However, such practices may also change the physiology of plants in favor of insects to make the plant most desirable for survival and multiplication. Selected examples are provided below for the role of nutrients in conferring resistance/susceptibility to insect attack or pathogen invasion.

i. Increased nitrogen level lead to increased oviposition and increased infestation and damage by *H. armigera* in cotton (Iiango and Uthamasamy, 1989).
ii. Use of 100 kg nitrogen/ha induces moderate incidence of false smut in paddy compared to higher doses of nitrogen in Gujarat (Patel, *et al*., 1992).
iii. One hundred kg potash/ha decreases stem rot disease (*Macrophomina phasiolina*) and increased fiber yield in jute in West Bengal (De and Chattopadhya, 1992).
iv. Boron application at 2.5 ppm in pearl millet (*Pennisetum typhoides*) reduced the primary incidence of downy mildew to the extent of 76.4 percent at 35 days after sowing in Rajasthan (Guptha and Singh, 1996).

8. ***Water/Moisture Management***

Managing or altering the moisture levels or extent of moisture in cultivated tracts is important for the management of pests and diseases as illustrated in instances given below.

Early termination of irrigation avoids crop prolongation and this reduces bollworm succession. However, this is mainly for pink bollworm, *Pectinophora gossypiella* (Lepidoptera:Gelechiidae).

Increased soil moisture due to mulching, farm yard manure and low plant population alone or in combination in cluster beans (*Cyamposis tetragonoloba*) helps to increase the population of resident bacteria, which reduces the dry rot caused by *Macrophomina phasiolina* (Satish, 1996).

Plant Resistance

Host plant resistance is deployed as unique approach for pest management with predictable problems. It helps in suppressing the pest population at low cost with least disturbance to the ecosystem. Unequivocal advantage of plant resistance is its compatibility with all other methods of pest control. Even low levels of field tolerance/resistance are desirable in cultivated plant varieties. A selected list of cultivated crop varieties tolerant/resistant to pests and diseases is given in Table 1.

Biological Control Methods

Several species of natural enemies including parasitoids, predators and pathogens have been recorded in paddy, cotton, pigeon pea, chickpea, tomato and cabbage ecosystem. These natural enemies help in killing the eggs, larvae of different pest. These natural enemies play an important role in the agro-ecosystem. Examples where the natural enemies have suppressed the insect pests are provided in Table 2.

Biorational Tools

1. ***Pheromones***

Pheromones are semio-chemicals secreted by insects to complete normal life cycle activities. Entomologists have exploited these chemicals to interfere with the normal activities such as mating and reproduction and thus reduce their populations in the cultivated patches. Pheromones are also key component of cotton, pigeon pea, chickpea IPM and are mostly utilized for monitoring the pest populations so that timely interventions are made. Monitoring helps in early detection of bollworm populations and its buildup. Use of pheromones has helped in monitoring *H. armigera* population on tomato (Krishnamurthy and Krishnakumar, 1997). Two sex pheromone traps per acre were fixed and lures have to be changed in 15 days for monitoring *H. armigera* which helps in assessing attack of pests in advance and intensity of pest which helps to take control measures (Patil, 1996).

2. ***Biotechnology***

The important contribution of biotechnology is the capacity to express pesticidal proteins within transgenic plants. Bt cotton could provide effective control of target pests (Lingappa, 2001). Transgenic bollworm (*H. armigera*)-resistant cotton is seen as an improvement over traditional cotton and has achieved significant social and economic benefits. The use of insecticides in Bt (*Bacillus thuringiensis*) cotton decreased by 60-80 percent and the density of predators increased by 24 percent (Lingappa, 2001). The Government of India has given provisional approval for commercial cultivation of Bt cotton in March 2002.

Table 1. A Selected List of Cultivated Crop Varieties Tolerant/Resistant to Pests and Disease Pathogens

No.	Crop	Resistant/Tolerant Variety	Insect Pest/Disease Pathogen	Reference
1.	Paddy *Oryza sativa*	IET-8116 IET-7575	Brown plant hopper *Nilaparvata lugens* Stål (Homoptera:Delphacidae) *N. lugens*	Gubbaiah, *et al*., 1990 Gubbaiah, 1990
2.	Pigeon pea *Cajanus cajan*	ICP 8863 ICPL 87119 ICPL 87119 BSMR-736	Wilt resistant Wilt resistant Wilt and sterility mosaic resistant Sterility mosaic resistant	Asthana, 1999
3.	Chickpea *Cicer arientinum*	ICCV-10 Vishal, Phule, G81-H, KWR-108, Ja-74, PBG-1, GNG 663, H82-2 PBG-1, GNG-469	Wilt resistant Ascochyta blight tolerant	Asthana, 1999
4.	Mung bean *Vigna radiata*	Varha, Mum 2, Pant M-4, PDM-11, PDM-54, Narendra Mung-1	Yellow mosaic virus resistant	Asthana, 1999
5.	Urd bean *Vigna mungo*	PDU-1, Narendra, WBU 108, Mash 338	Yellow mosaic virus resistant	Asthana, 1999
6.	Field pea *Pisum sativum*	Aparna, Uttara, Malaviya, Matar 2, KFP 103, Shikha	Powdery mildew resistant	Asthana, 1999
7.	Lentil	Priya, Lens 4076, Pant L4, Shashi	Rust resistant	Asthana, 1999
8.	Cotton *Gossypium* spp. *G. hirsutum* *G. berbadense* *G. arborium* *G. herbacicum*	 G-100, SRT-1, DHY-286, RS-501, NH-54, LK-861, C-1998, B-147, TH-14, Abhadita, HGIPS-755, MCU-6, MCU-7, HGIPS-170, CO-2, Bikaneri, Nerma, CPD-6, B-16, F-505, JK-276-4, Sahana Sujatha, Suvin G-27, G-46, CJ-73, Lohit, NAS-3, Ld-230 Jayadhar, Digvijay Hybrids NH-452, AKH-081	Cotton bollworm tolerant	Lingappa, 2002
9.	Okra *Ebelmaschus esculentus*	Arka Anamika, Arka Abhay, Parbani Punjab-7	Resistant to yellow mosaic virus	Sokhi, 1994
10.	Tomato *Lycopersicum esculentus*	Arka Varadan, H-24, H-36	Nematode resistant hybrid	Sokhi, 1994

... To be continued

Table 1. Continuation

No.	Crop	Resistant/Tolerant Variety	Insect Pest/Disease Pathogen	Reference
11.	Potato *Solanum tuberosum*	Kufri Jyoti, Kufri Badshah, Kufri Swami, Kufri Megha, Kufri Kharigan, Kufri Muthu, JH 222, F 5242 and AB-286	Resistant to late blight	Sokhi, 1994
12.	Bell pepper *Capsicum annum*	Punjab lal Bengalgram, H-1, H-4, Szo-1, H-6 Lorai and perennial	Resistant to anthracnose, leaf curl, tobacco mosaic virus and cucumber mosaic virus Resistant to anthracnose	Kaur and Singh, 1985 Singh and Thind, 1980
13.	Onion *Allium cepa*	Arka Kalyan	Resistant to purple blotch	Sokhi, 1994
14.	Brinjal *Solanum melongena*	BB-7, BWR-12, Pant Risturaj	Resistant to phomopsis blight bacterial wilt and little leaf	Sokhi, 1994

Table 2. Examples of Successful Suppression of Insect Pests

Crop	Natural Enemy	Pest	Reference
By natural enemies			
Cotton	*Trichogramma* spp. (Hymenoptera:Trichogrammatidae) @ 100,000/acre at 50th and 57th day	Bollworms	Patil, 2001
	Chrysoperla carnea Stephens (Neuroptera:Chrysopidae) 100-125 days	Bollworms	Puri, 1996
Tomato	*Trichogramma pretiosum* (Hymenoptera:Trichogrammatidae) @ 250,000/ha	*H. armigera*	Krishnamurthy and Krishnakumar, 1997
By Nuclear Polyhedrosis Virus			
Cotton	NPV @ 200 LE/ha	Bollworms	Patil, 1996
Tomato	NPV @ 250 LE/ha	*H. armigera*	Krishnamurthy and Krishnakumar, 1997

SUCCESS STORIES

Red-headed Hairy Caterpillar

In Tumkur district of Karnataka during 2001-02, the Department of Agriculture organized mass collection of eggs, larvae and adults. An estimated 341 kg of moths were collected and burnt. Three thousand moths weighed 1 kg. Similarly eggs were collected in 2,000 ha. The eggs were collected and put in a tin coated with grease. Such eggs have been destroyed. During 2000-01, in the same area 65,728 mt of larvae were collected and burnt.

<***Reasons for Success***>

* Government sanctioned special package for the purpose.
* Action plan developed involving farmers, people's representatives, the press, scientists, NGOs, Rotary Club members, merchants, media persons, etc.
* Awareness was created through street plays, video cassettes were shown, colorful wall posters were displayed, wall paintings were done, meetings were conducted in villages, banners were put at popular junctions, publicity was made through mike-systems, visits were made to areas where operations concerning hairy caterpillars were successfully carried out.
* Active groups were formed in each village.
* Distributed 2,300 gaslights under subsidy program for using in light traps.
* Set up 30 monitoring centers.
* Set up 200 mercury lamps for light traps.
* Clear-cut responsibilities were fixed and on works to be done.
* With rainfall, follow-up action were taken.
* Seeds of pulse crops were distributed to be grown as intercrops under subsidy schemes.

Root Grub *Holotrichea serrata* Linn. (Coleoptera:Scarabaeidae)

In Bellary, Dharwad district of Karnataka during 1986-87 and 1987-88 collected 20 mt of root grubs in each place after the receipt of summer showers in May 1986 and May 1987.

The farmers were briefed through meetings about the pest, identified the endemic area with the help of farmers, conducted night campaigns during summer showers rainfall, light traps, bonfires with crop stubbles and bicycle waste tires were set up at night. The adult root grubs were attracted to light traps and fire. The beetles were collected and put in water mixed with kerosene.

Farmers Field School (FFS)

1. ***FFS in Cotton***

During 2000-01, with the help of Food and Agriculture Organization (FAO) technical assistance, 22 agricultural officers were trained as IPM facilitators. The training of facilitators was held at the Regional

Research Station, Raichur, in Karnataka, South India. During 2000-01, 20 FFSs were conducted with the help of above IPM facilitators. The school was conducted in the farmer's field only for 20 weeks. Every week, the farmers gathered for the field school and learned to analyze the cotton agro-ecosystem, determine the population levels of parasitoids and herbivorous insects. They carried out experiments and understood the function of useful insects. Based on their understanding of the ecosystem, farmers were able to make informed decisions on growing a healthy crop.

The following suggestions were evaluated by farmers to determine if they are useful:

i. Okra, marigold, pigeon pea and cowpea were grown as trap crop to control sucking insects, *H. armigera* and *Erias* bollworm.
ii. Seed treatment with *Trichoderma* at 4 g/kg and with imidachloprid 7.5 g/kg.
iii. Stem pasting with imidachloprid @ 1:20 ratio to control sucking insects.
iv. *Trichogramma* released 100,000/acre to parasitize eggs of *H. armigera*.
v. NPV spray @ 200 LE/acre.
vi. Set up 25 bird perches/acre for control of small larvae of *H. armigera*.
vii. Caterpillars were collected and destroyed.
viii. In 40 days old cotton crop, pheromone traps at 2/acre were set up to monitor the intensity of *H. armigera* and *Earias* bollworms.
ix. Twenty-five yellow sticky tins were set up to control whiteflies.

Farmer would usually apply 19 chemical sprays to control pests and diseases in their fields and spend Rs.9,000 whereas the cost of protection was only Rs.2,097 in IPM plots. The yield obtained in farmer's plot where IPM was not practiced was 600 kg/acre, earning Rs.9,000 at the cost of Rs.12,936 whereas in IPM plots, the farmers were able to get 1,100 kg of yield by investing Rs.6,043 and fetch the net returns of Rs.10,468 as profit.

2. ***FFS in Paddy***

In Tumkur district, Karnataka during 1995, one officer participated in a season-long training to become an IPM facilitator with the technical assistance of the FAO.

Four FFSs were conducted for 10 weeks in which 20 officers and 120 farmers participated. Every week the farmers would assemble for half a day in the study field. They researched on parasitoids and other useful insects including pests using insect zoos.

From the research conducted by farmers, they learned more about useful insects and this helped them to conserve the beneficials by not using insecticides. The farmers after this exercise did not use even a single chemical spray whereas in control plot the farmers had sprayed four times. The FFS concept is being continued in different areas every year.

Nonpesticide Method of Controlling Pests and Diseases in Chickpea

In 2001-02, 50 ha demonstrations were conducted at Chitradurga district, Karnataka, involving 16 farmers.

The farmers were shown the following practices:

i. Seeds treated with 4 g/kg *Trichoderma*.
ii. Sex pheromone traps were put @ 2/acre.
iii. Nipping of tips as soon as eggs were noticed.
iv. Churumuri (roasted rice) spreading at 6 kg/acre to attract birds, which predates on *Helicoverpa* larvae.
v. Erection of 10 bird perches/acre to attract birds that feed on caterpillars in the crop.

This has resulted in 750 kg/ha yield against 500 kg/ha in the control. In addition to regular cost of production, an additional cost of Rs.470 was spent on nonpesticide method for controlling pests and diseases. In farmer practice, Rs.1,200 was the additional cost for purchase of chemicals to control the pests and diseases. Hence, use of nonpesticide methods result in 250 kg of additional yield, which fetched about Rs.4,000 per net profit.

GOVERNMENT POLICIES AND PROGRAMS

Integrated Pest Management

Indiscriminate and injudicious use of chemical pesticides in agriculture have resulted in adoption of IPM as cardinal principle and main plank of plant protection in the overall Crop Production Program. IPM is an eco-friendly approach which focused on farmer education to make farmers more efficient in their production activities.

The IPM concept is being promoted through 26 Central Integrated Pest Management Centers (CIPMC) located in 22 States and one Union Territory aiming at human resource development, these centers are imparting training to extension functionaries and farmers in IPM skill by conducting FFSs. In addition, these centers are engaged in mass-production and field releases of biological control agents.

With a view to provide technical knowledge to the extension functionaries and farmers in the States, IPM approach has been tried out for 51 crops like rice, cotton, vegetables, pulses, plantation crops, spices, fruit crops and oilseeds. A participatory IPM approach based on farmer education is being implemented throughout the State by the extension service.

Towards human resource development, facilitation skills have been developed through continuous education of Agriculture Extension Officers (AEO) and farmers. IPM FFSs are conducted in the States to enhance the skills of farmers.

Aiming at organic farming production technology for biocontrol agents, biopesticides have been evolved which are being used by the private as well as public sector units for production of biocontrol agents to be used by farmers to save their crops from the ravages of pests and diseases. This concept prevents dependence on chemical/pesticides for plant protection.

Since the inception of IPM program, 7,113 FFSs have so far been conducted thereby training 32,786 AEOs and 212,870 farmers in IPM skills. Eleven hundred and thirty-two IPM facilitators have been trained by conducting 35 season-long training of facilitators courses on cotton, rice, vegetables, pulses, oilseeds, etc.

With the background of IPM knowledge farmers are practicing farming with minimum use of pesticides as agrochemicals. Instead they are depending on biological control agents.

As a result of implementation of IPM program, there is a significant reduction in the consumption of pesticides from 61,357 million mt (technical grade) during 1994-95 to 43,584 million mt (technical grade) during 2000-01.

In the case of red-headed hairy caterpillar the government has given sanction to take up effective awareness campaign, providing gaslights under subsidy program, providing funds for catching larvae at Rs.35/kg and moth at Rs.50/kg.

Farmers contact centers have been started at hobli level to deliver the different nonpesticide/IPM methods to farmers.

Government has given permission to grow commercial Bt cotton in farmer fields in March 2002.

ISSUES AND PROBLEMS

a) *Trichogramma* parasitoids and NPV are not available on a large scale.
b) Quality monitoring and testing facilities for bioagents. Parameters and checkup facilities are not adequate.
c) Awareness of people on nonpesticide methods is inadequate.
d) People participation in control of moths, grub on community basis is not up to the expected level.
e) Monitoring of pests and their populations is inadequate.
f) Prevailing method of giving plant protection chemicals under credit directly from the commission agents to the farmers hinders the use of nonpesticide methods.

SUGGESTIONS FOR IMPROVEMENT

a) Large-scale training to agriculture departmental staff/farmers is required.
b) Block demonstrations are to be laid out exclusively on nonpesticide methods to build more confidence in farmers.

c) Availability of parasitoids/NPV on large scale should be ensured.
d) More testing facilities should be created.
e) Large-scale monitoring of pests is required.
f) Farmers should be encouraged to adopt more nonpesticide methods.

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3. INDONESIA

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INTRODUCTION

The staple food demand of Indonesian population that recently counted about 210 million people is rice. Beside rice, there are cereals (soybean, maize, etc.), tubers (cassava, sweet potato, etc.), fruits and vegetables as a complementary food. Indonesian Government carried out an extensive rice intensification program that was launched in 1960s through efforts by mass guidance. Various efforts were implemented through various government agencies and private sectors involved in increasing rice production. The research agencies were encouraged to develop high-yielding varieties, while private sectors were encouraged to distribute rice seed and other production supplies to rice producing areas. Production of rice seed, fertilizer and pesticide was encouraged to increase rice production and the government provided considerable subsidy. Irrigation networks and extension institutions were also extensively developed. Moreover, the implementation of intensification technologies was encouraged and developed throughout the country. As a result, Indonesia was able to achieve self-sufficiency of rice in 1984.

The national production of food "leveled off", thereby the rice import increased. During the last four years, the harvested area of rice was around 11.3-11.9 million ha with annual production of 49.2-51.9 million mt. While for secondary crops, i.e., maize, 3.5 million ha of harvested area with production of 9.6 million mt/year; for soybean, 0.8 million ha of harvested area with production of 1.0 million mt/year; for cassava, 1.3 million ha of harvested area with production of 16 million mt/year; for groundnut, 0.6 million ha of harvested area with production of 0.7 million mt/year; and for mung bean, 0.3 million ha of harvested area with production of 1.8 million mt/year, respectively.

There were some factors that have to be faced in the promotion of food production program, particularly "on farm" level. One of them is the risk of pest infestation. Nationally, some major pests which frequently cause plant damage on rice are rats, stem borers, brown planthopper (BPH), blast, and tungro. Major pests on soybean crop are pod borer, bean fly, army worm, rat, leaf roller, and green semi-looper. Major pests on maize crop are seedling flies, stem borer, downy mildew, rat, ear borer and army worm, while major pests on fruits and vegetables are fruit flies, army worm, and fusarium fungi. Other than these major pests, there are local major pests in some areas, such as gall midge on rice in North Sumatera and West Java, leaf blight on maize in North Sumatera, and migratory locust in Lampung, South Sumatera, Central Kalimantan, West Kalimantan, and East Nusa Tenggara.

During the last five years (1996-2000) the infestation of major pests caused considerable yield losses (Table 1).

Table 1. Annual Average of Infestation of Major Pests and Yield Loss Estimation, 1996-2000

No.	Commodity	Infestation (ha)	Total Damage Area (ha/year)	Yield Loss (mt/year)
1	Rice	309,141	11,722	279,378
2	Soybean	10,722	184	6,243
3	Maize	18,639	957	24,517

Note: Major pests of three commodities are: rice – rat, stem borer, BPH, tungro and blast; soybean – pod borer, bean fly, armyworm, rat, leaf roller, and green semi-looper; and maize – seedling flies, stem borer, downy mildew, rat, earworm, and armyworm.

In line with the policy of integrated pest management (IPM) implementation, some technologies of pest control were developed which are environmentally sound and limited use of chemical pesticides. Nonpesticide methods among others include resistant varieties, cultural techniques, mechanical and biological control. Some policies, laws and regulations are enforced to support IPM implementation. The development of infrastructures, plant protection institutions and also IPM technology recommendations are continuously extended. However, there are some constraints and problems faced in field implementation.

The paper will discuss the policies being implemented by the Indonesian Government, the development and implementation of nonpesticide pest control methods, its constraint, problems and promoting the effectiveness and efficiency of food production.

POLICY OF NONPESTICIDE METHODS

Development of IPM

The promotion of food crop intensification, especially on rice crop was initiated in the 1969 that led to increase in the use of chemical pesticides for controlling pests. However, after several years, the pest problems did not lessen but became more severe and complicated. Some negative impacts of chemical pesticide used are the shifting of secondary pests into major pests (such as BPH, tungro, etc.), pest outbreak occurs were more frequent due to pest resistance and pest resurgence, killing of non-target organisms was detrimental to biodiversity, and caused environmental pollution.

The government has decided to implement an environmentally sound of IPM technology to minimize those negative impacts of chemical pesticide used. The policy significantly indicated by the use of resistant rice to BPH introduced by the International Rice Research Institute (IRRI), i.e., IR 26 to overcome the BPH outbreak that occurred in 1975/76. Since then, together with the development of plant protection technology, various pest control techniques in accordance with IPM concept, were developed as were some supporting facilities for IPM implementation.

The government has issued some laws and regulations specifically for IPM development. The first decree that promoted IPM is INPRES (Presidential Instruction) No. 3 issued in 1986 concerning the promotion of BPH control on rice crop. In the INPRES No. 3 it was stipulated that 57 chemical pesticides especially the organophosphate group were to be banned for use on rice crop. These pesticides were found to cause BPH resurgence by killing non-target organisms in rice field ecosystem. At the same time, the government recruited 1,000 pest observers to strengthen food crop protection in Indonesia. The action of the government and the community in controlling pests, especially BPH, by IPM methods had a great impact on the community.

The second decree is Law No. 12/1992 concerning crop cultivation system, which distinctly stipulated that the principle of pest control is the IPM methods. In IPM concepts, various environmentally sound pest controls are developed and implemented, while chemical pesticides are used as a last resort when all other methods could not overcome pest infestation.

The third decree is the GR (Government Regulation) No. 6 concerning plant protection issued in 1995. The GR No. 6/1995 is the continuation and explanation of Law No.12/1992, which more distinctively stipulated the implementation of IPM for pest control. Furthermore, some Ministerial decrees and guidance of the pest control by plant protection institutions are made for the implementation of the law and the regulation above. Principally, the implementation of IPM is recommended in four aspects, i.e., “healthy crop cultivation, natural enemies’ conservation, regular observations, and farmer as an IPM expert”. Recently, Indonesian Government implements a regional autonomy system, as a united country, and these laws and regulations are still valid and effective throughout the country.

Development of Infrastructure and Institution

Some infrastructures and plant protection institutions are developed to support the implementation of IPM principles, i.e., Pest Observer (PO), Food Crop and Horticulture Protection Center (FCHPC), Pest Field Laboratory (PF Lab), Biological Control Agent Laboratory (BCA Lab), Pest Forecasting Center (PFC), plant protection organization at farmer level, and other human resource development in plant protection.

In 1976, the PO was established with the authorization to observe pest population and to extend pest control recommendation to the farmer through Field Extension Worker (FEW) in the respective working area. Recently, there are 2,896 POs scattered throughout the country of Indonesia, with each working area of one sub district (= *kecamatan*) as one observation area, and there are about 35,000 FEWs. One PO coordinator is assigned in each district (= *kabupaten*) in order to manage the PO activities.

In one agro-ecosystem that covers some districts, a PF Lab/BCA Lab is established. The roles of PF Lab are to coordinate the duties of PO in its working area, to analyze pest observation data by PO, to develop appropriate pest control technology according with local condition. While the role of BCA Lab is to develop technology of BCA usage for pest controls. In some areas, the PF Lab and BCA Lab is in one building compound, recently there are 77 PF Labs/BCA Labs in Indonesia.

In provincial level, FCHPC are established with the authorization to coordinate some functions of food crop and horticulture protection in respective working area, especially on pest observation and forecasting, and development of plant protection technology. Other than FCHPC in provincial level, there is an Agriculture Extension Service (AES) with the mandate to coordinate the operation of pest control. Nowadays, there are 28 FCHPCs and 30 AESs in 30 provinces in Indonesia.

In central level, there is food crop and horticulture PFC, and Directorate of Crop Protection. The PFC is authorized to develop system and method of pest forecasting and environmentally sound pest control, and also as a “training center” of plant protection. While the national policy decision and coordination of plant protection at national level is the Directorate of Crop Protection’s responsibility. The information and cooperation network on plant protection is developed covering throughout the country of Indonesia. There are 38 buildings of FCHPC/PF Lab/BCA Lab and PFC constructed with the financial aid of the Japanese Government through JICA (Japan International Cooperation Agency).

Furthermore, in order to implement IPM concept, human resource development is also carried out; these include the farmers, the officers and the decision-makers. During the year of 1989-2000, some IPM training is carried out through the Farmer Field School (FFS) through the assistance of a World Bank loan (Table 2).

Table 2. Number of Farmers and Officers Attended IPM Training by World Bank Assistance, 1989-2000

No.	Human Resource	Number (persons)	Remarks
1	Pest observers	2,253	FL-I: 45, FL-II: 288, D-1: 2,197, D-3: 35 and S-3: 21
2	Field extension workers	4,912	
3	Farmers	1,048,564	Rice: 921,282; secondary crop: 102,822; vegetable: 24,460 (tutor farmers: 22,580; biological agents training: 4,170)
4	Officers	8	Master degree: 8

Other than the training funded by the World Bank, some IPM training is carried out by the Indonesian Government budget, central and local governments (province, district, and village), also some training funded by farmer and community government. Those trainings are continuously carried out in accordance with the budget availability in each local government.

DEVELOPMENT OF NONPESTICIDE METHODS

Some nonpesticide pest control methods are developed by the availability of various infrastructures and human resources, whether derived from the existing technologies used by farmers or new technology for the farmers. The development of nonpesticide pest control is carried out not only by plant protection institutes but also by the Agency for Agricultural Research and Development (AARD).

Since the occurrence of BPH outbreaks in 1975/76, the AARD is encouraged to develop varieties resistant to major pest problems, such as BPH and tungro disease, and also some nonpesticide pest control methods. The PF Lab is able to develop specific pest control methods suitable in their respecting working area. The BCA Lab is able to explore and develop BCAs in its working area and disseminate them to farmers.

IMPLEMENTATION OF NONPESTICIDE METHODS

There are some nonpesticide pest control methods developed and applied in Indonesia resulting from the research agencies and the universities. Some of these methods were developed by farmers after attending the FFS, and from farmer group or community development as a result of their interaction with their local-specific ecosystems.

Some nonpesticide methods that have been recommended and developed at farmer level and considered to have important role in food production are pest-resistant variety, cropping pattern and growing season regulation, crop and variety rotation, mechanical method, and biological method.

Pest-resistant Variety

The use of pest-resistant variety was first introduced in 1975/76 when BPH outbreak appeared over 500,000 ha. During that time, the local variety and new high-yielding varieties being planted were susceptible and infested by BPH. Therefore, resistant varieties from IRRI were introduced, such as IR 26. The introduction of other varieties from IRRI and development of national resistant varieties follow the successful of IR 26 variety by AARD.

The use of resistant varieties to control BPH is one of the most successful nonpesticide methods and extensively implemented throughout Indonesia. This is due to its acceptability at farmer level because of the ease, inexpensiveness, effectiveness and safety. During the period of 25 years since the introduction of pest-resistant varieties, the planting of resistant varieties covers an extensive area. Based on data of Cropping Season (CS) 2001, the distribution of resistant varieties reached more than 70 percent of rice area (Table 3).

Table 3. Distribution of Rice Varieties during Cropping Season 2001

No.	Variety Group	Area (percent)	Remarks
1	Introduced resistant varieties	42.42	16 varieties
2	National resistant varieties	31.81	32 varieties
3	Susceptible and local varieties	25.77	
Total		100.00	

To support the use of resistant varieties, the AARD was encouraged to develop more pest-resistant varieties, especially varieties that are resistant to BPH, tungro and some fungal diseases. During the period of 40 years since 1961, AARD has produced 150 national high-yielding varieties, in which the varieties produced after 1970s are generally pest-resistant varieties.

In the field, not all the released pest-resistant varieties were widely accepted and used by the farmers. Some varieties were accepted and planted widely by the farmer for long period, such as IR 36, IR 64, Cisadane, Memberamo, Way Apo Buru, etc. The IR 36 variety was dominant in the 1980s. In CS 2001, IR 64 variety was distributed over 34.83 percent, while Cisadane, Memberamo and Way Apo Buru varieties was reported over 3.99, 3.78 and 9.15 percent, respectively. The variety distribution is influenced by the development of BPH biotype that is capable of breaking the resistance, production achievement, and the farmer/market preference. Therefore, the important consideration for release of a new resistant variety is the resistance to major pest, the ability to meet the market/consumer's preference and the productivity.

Regulation of Cropping Pattern and Growing Season

The government consistently recommends the regulation of cropping pattern and growing season to control pests. This recommendation was directed to the endemic area for pest infestation. The synchronized planting in an extensive area is expected to be able to prevent a great yield loss due to pest infestation, because pest population will be "diluted" over a wide area. The pest population buildup will be delayed and pest control management program in an extensive area will be easier. In some endemic area of pest infestation, the local government issued a Local Government Regulation on cropping pattern.

Besides synchronized planting, regulation of growing season is one of the effective control methods for a certain pest. For instance, for gall midge, its population dynamic is significantly influenced by high relative humidity, around 80 percent, and outbreaks only occurred during the vegetative stage of rice crop. Therefore, the recommendation for the endemic area in the northern coast of West Java is to regulate planting to ensure that the vegetative stage is completed before the high rainfall period.

In South Sulawesi, the growing season is regulated in accordance with the population growth of green leafhoppers, which is a vector of tungro virus, local rainfall and variety planted. This cropping pattern has been effective to overcome infestation of tungro. While in the endemic area of white rice stem borer in the northern coast of West Java, the delay of nursery seed sowing in early rainy season for 7-10 days after the first rain is recommended to avoid the infection of newly emerged moth from diapause during dry season. This method is proven to be able to prevent rice stem borer infestation significantly.

The implementation in regulation of cropping pattern and growing season requires an established recommendation, reliable coordination among government institutions (local government, seed supplier, irrigation, PO, FEW, etc.), researchers' support, etc.

Crop Rotation and Variety Rotation

Crop rotation is one of the pest control methods extensively introduced for long time in some countries, including Indonesia, in order to interrupt the pest life cycle, so that its population and its infestation in the next growing season can be controlled.

Indonesia has developed the rotation concept of pest-resistant varieties, especially in rice crop. Some major pests issued in this variety rotation method are BPH and tungro. This method is based on the basis that there are some different resistant genes to the pest. Each resistant variety usually bears certain resistant gene to react specifically to certain pest biotype/strain. The varieties which have the same or equivalent resistant gene planted in an area subsequently will give greater opportunity of pest population growth and infestation, hence causing greater damage. When they plant continuously in the same area, the variety will experience "resistance breakdown" soon. Therefore, variety rotation pattern with different resistant gene is able to overcome the pest population growth and infestation and also to prolong the variety resistance duration.

The variety rotation with different resistant gene has been successful to overcome BPH and tungro infestation in some endemic area for those two pests. The implementation of variety rotation also requires well coordination from various government institutions in the field level.

Mechanical Method

The implementation of pest control by mechanical method has been successful and well developed in controlling rats, wild boars, migratory locusts, weeds, fruit flies, etc. Land preparation is the main mechanical method to control pests, especially pests that live in the soil including weed.

Other mechanical methods have been applied to control white rice stem borer, i.e., collecting the egg masses in rice nursery and collecting the moth by kerosene light trap. These methods have been quite successfully implemented in northern coast of West Java. Besides that, other mechanical method by eradication of infected plant is one of the recommendations to control BPH, grassy stunt, ragged stunt and tungro diseases. This method is able to contribute to the successful control of BPH outbreaks followed by grassy stunt and ragged stunts diseases, as well as in controlling tungro disease in early infection and during outbreak. The massive extension to encourage farmer awareness is important in the success of this method.

Mechanical method to control rats is carried out by catching and killing the rat in mass action over a wide area, known as "*gropyokan*". This method usually is carried out during fallow period. Sometimes this method is combined with biological method using hunting dog or chemical method using phosphoric smoke to fumigate rat holes. This control method is very popular and widely practiced in Indonesia.

The coordination and involvement of community members significantly affect the success of "*gropyokan*". In some areas, the rat skin is utilized for handicraft such as glove, jacket, head cap, and the rat is also utilized for poultry feed. The other rat control by mechanical method recommended and widely applied by farmers is the setting of plastic fence in nursery bed or even in crop plot. This method is frequently combined with installment of "*bubu*" trap, and then the trapped rats are killed. Such methods could be more effective when applied by a group of farmers. Other than these methods, there is another mechanical method being implemented, i.e., setting some bamboo traps around the rice fields.

The wild boar is controlled by mechanical method carried out by direct hunting of wild boar either by using net trap or without net trap. In some endemic areas a farmer or community organization of wild boar hunter is established professionally and is often carried out as a sport. Controlling wild boar by mechanical method is sometime carried out in cooperation with hunting sport organization. In an area with non-Moslem population, the wild boar becomes food supplement.

The mechanical control of migratory locust by using net is considered to be popular and successful, especially in case of a population outbreak.

Mechanical method to control weed by using hand, mechanical tool ("*landak*") or other tools is widely practiced in rice, secondary crop and vegetable cultivation. Chemical trap by using methyl-eugenol has been recommended and implemented to control fruit flies. Another mechanical control that is popular and widely carried out to control fruit flies in Indonesia is wrapping up the fruits with dried banana leaves, papers, etc.

Biological Control Method

Some biological methods have been promoted and have good prospects in the near future, i.e., the use of microorganisms, such as fungi, bacteria or virus. Some PF Lab/BCA Lab are equipped to explore, to develop and to disseminate the technology to the farmer. Some training for the laboratory technician has been held to promote their knowledge and skill in developing BCAs.

Some microbial BCAs that have been developed are parasitic fungi, i.e., *Beauveria bassiana* and *Metarhizium* spp.; antagonistic fungi, *Gliocladium* spp. and *Trichoderma* spp.; and parasitoids. Nuclear polyhedrosis virus (NPV) has been utilized, while bacteria have been registered as biological insecticide formulation through the Pesticide Commission.

Recently, parasitic fungi *Beauveria bassiana* and *Metarhizium* spp. are used to control some insect pests on food crops, such as BPH, rice bug, caterpillar, etc. The NPV is utilized to control armyworm on soybean (SiNPV) and onion crops (SeNPV). Antagonistic fungi are used to control pathogenic fungi (*Fusarium* sp.) on potato and chili crops and "white root fungi" on estate crops (rubber, coffee, etc.) The predator *Diadegma semiclausum* has been used to control *Plutella xylostella* on cabbages.

Presently, some farmer groups use BCAs in some areas such as West Sumatera, Central Java and East Java. These farmer groups are facilitated and guided by PF Lab/BCA Lab and local agricultural institutions. Such farmer groups keep reproducing BCA by simple method, which are then shared with group members and the surrounding farmers. Local PF Lab/BCA Lab extends the provision of pure isolates and technical guidance. PF Lab/BCA Lab accomplishes the mass production by liquid media and then the farmers can apply directly to the fields.

Farmers have learned the use of NPV using simple methods. Dead larvae infected by NPV are ground, then made into suspension and applied to the field. This method is much appreciated because it increases farmers' understanding on the importance of natural enemies in the field and the utilization of nonpesticide methods in pest control.

The use of predatory owl (*Tyto alba*) to control rat was developed in North Sumatera, West Sumatera and Central Java. In North Sumatera, owls are used widely to control rats in oil palm plantation.

To overcome the population growth of white rice stem borer in northern coast of West Java in 1990s, the conservation of egg mass parasitoid (*Trichogramma* sp. and *Tetrastichus* sp.) is employed by collecting egg masses in nursery. The eggs are reared and the parasitoids that emerged from the egg masses are then released into the rice field. The conservation of natural enemies by not using chemical pesticides is also carried out by the government through recommendation to farmers. When it is necessary to use chemical pesticide, they should consider the type of pesticides, how to apply it, so that it will minimize the effect on the natural enemies.

Biological control also requires consistency of the policy, campaign and extension of all institutions and farmers, provision of infrastructures and human resource development, to both officers and farmers.

Another nonpesticide control method has been developed in the use of sex pheromones to control armyworm on soybean crop in East Java. However, supply of sex pheromone was usually limited. Therefore, this method could not be well developed.

CONSTRAINTS AND SOLUTIONS

Constraints

There are some constraints being faced in the development and implementation of nonpesticide methods to control pests, either general or specific in nature. The general constraints include psychological, technical and operational aspects.

The constraint of psychological aspect occurs due to farmer's habit in using chemical pesticide during intensification program for many years. This constraint occurs because nonpesticide method is accepted as a preventive action to control pest population building, while chemical pesticides have knockdown effect shown by the rapid death rate of insect pest.

In technical aspect, there are some technical things that should be developed and understood by farmers. Since some methods of nonpesticide control could not be well understood by farmers such as the use of biological control agents this method is not well appreciated.

In operational aspect, nonpesticide control methods frequently require basic understanding of the science of its method which are often complicated in procedures and also the technologies. While the use of chemical pesticide method is relatively simple, easy to apply by individual farmers as it does not require complicated supporting equipment and procedures for the implementation in the field.

The specific constraints in the implementation of nonpesticide methods include:

1. ***Resistant Varieties***

Even though the use of resistant varieties is easy, inexpensive and safe, however, a researcher requires advance knowledge and skill to obtain certain resistant varieties. This research is time-consuming with high cost requirement. Moreover, there is a difficult fact that a resistant variety with single gene is easily broken down when continuously planted.

The experience in Indonesia has shown that resistant varieties to BPH sometimes undergo this constraint, for example, IR 26 contains resistant gene BPH-1 (BPH biotype-1) is only able to sustain in some cropping seasons. The other resistant varieties such as Cisadane and IR 42 (gene resistance BPH-2) also experienced "breakdown" of its resistance. In addition, field studies indicate that BPH population from different area will show different reaction to resistant gene of the varieties. Therefore, Indonesia holds not only BPH biotypes 1, 2 and 3 but also specific BPH population such as North Sumatera, Jatisari, Yogyakarta, and Klaten population. Moreover, at farmer level there is a preference for certain varieties according to their expectations, hence it is difficult to replace it with other varieties.

The other constraint is the farmer expectations on high level production, pest resistance, preferable taste, and high selling price, whereas the consumer taste varied from one area to another area. Furthermore, it is difficult to combine various resistant genes into one variety to obtain resistant variety to several major pests. Therefore, this constraint is considered to be a serious constraint.

2. ***Regulating Cropping Pattern and Growing Season***

The constraint faced in the development of this method is water availability year round. In such areas, farmers always want to plant continuously at any time, hence various stages of plant growth are available in the field, and create a favorable condition for pest population.

3. ***Crop Rotation and Variety Rotation***

The constraint in the implementation of crop rotation is water availability year round. Variety rotation is constraint by farmers' knowledge, field officers and decision-makers on gene resistance for each variety.

The principle of variety rotation is based on gene resistance, variety reaction to local pest biotype/strain, and timely supplies of seed in accordance to required variety in sufficient amount. It requires continuous advanced knowledge, research support and good coordination among stakeholders.

4. ***Mechanical Method***

The constraint faced in the implementation of mechanical method in the form of "*gropyokan*" (mass action) in rat control, wild boar hunting, catching migratory locust by net is participation during implementation. This constraint affects farmers or community members affected by pest infestation hence it requires farmers' awareness to encourage collective action. Since the development of pest population is unknown, the number of pest being caught and killed during the control action could not reflect the success of control measures. This control action should be done in an extensive area to reduce pest populations significantly, and is difficult to implement.

The installation of fence combined with rat trap "*bubu*" requires correct and precise setting to avoid pest escape is often neglected by farmers. Furthermore, fencing is only a basic control to delay rat infestation, not to reduce rat population. This kind of control method should be applied in an extensive area during the whole growing season; therefore, it is quite difficult to be implemented.

5. ***Biological Method***

The utilization of natural enemies to control pest is a relatively new technology for farmers. It requires more intensive community development, extension and training. The constraint of this method is the killing process of pathogen and parasitoid, which takes relatively longer than the killing process of chemical pesticide, hence farmers find this difficult to accept. Moreover, this method necessitates knowledge and skill of field officers and farmers; therefore, the application of the BCA in the field sometimes does not achieve enough quality.

Solution

The development of nonpesticide methods could not be viewed individually but should be considered as a whole crop protection system in order to overcome various constraints mentioned. In this case, crop protection system consists of four subsystems which are interrelated one to another, i.e., observation and forecasting subsystem, information dissemination subsystem, pest control subsystem and protection supplies subsystem.

The conducive and consistent policy of the government in developing and empowering crop protection system includes laws and regulations. The decision of IPM concept to be a basic principle is a primary action. These government policies are followed by some important actions, i.e., infrastructure provision, institutions involvement, human resource development, budgeting, facilities for crop protection activities, community development and participation of all stakeholders, etc. The government's support to research institutes, cooperation with international agencies, coordination among related institutions and domestic internal information network, and also technical training are among actions to overcome some constraints.

CONCLUSION

Basically, there are nonpesticide methods developed and implemented in Indonesia. However, not all methods are accepted and developed well at farmer level. Some nonpesticide methods that have proven to be successful are pest-resistant variety, cropping pattern regulation, mechanical control methods for rats, wild boars and migratory locust. The biological control method using BCAs appeared to have good prospect for further development.

Some psychological, technical or operational constraints are being faced in the development of nonpesticide methods. However, to solve these problems, nonpesticide methods could not be viewed individually, but it should be done comprehensively as fundamental components of crop production system in the framework of empowering crop protection system.

The conducive and consistent policy of the government has considerable effect on the development of nonpesticide methods. Good coordination and awareness of all stakeholders, the government, private sectors and farmers will determine the success of nonpesticide method development.

4. MALAYSIA

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INTRODUCTION

Agriculture remains an important sector to the Malaysian economy although its role declines compared to manufacturing sector. Presently, it contributes 25 percent to GNP. Two types of agricultural crops are grown, namely; industrial and food crops. The major industry crops are rubber, palm oil, cocoa, black pepper, pineapple and tobacco while major food crops are rice, coconuts, vegetables, and fruits (Fatimah and Mad Nasir, 1997). Total acreage of each crop is listed in Table 1. It indicates a decline in acreage for most of important crops except for palm oil, pineapple, fruit and vegetables. However, the growth rates for palm oil and pineapple are declining. It is expected that this scenario will be continuing due to several problems such as uneconomical farm structure, lack of efficient management and production technologies, limited mechanization and automation, and the rapid growth of non-food industry (Rahman, 1997).

Table 1. Contribution of Various Agricultural Commodities to Malaysian Economy

	Year (acre)			Average Annual Growth (percent)	
	1990	1995	2000	1990-95	1995-2000
Industrial Crops					
Rubber	1,823	1,696	1,400	-1.4	-3.8
Palm oil	2,029	2,479	2,622	4.1	1.1
Cocoa	419	275	250	-8.1	-1.9
Black pepper	11	8	8	-5.6	-1.1
Pineapple	9	11	14	4.9	4.5
Tobacco	10	10	10	0.7	-1.0
Food Crops					
Rice	314	283	219	-2.0	-5.0
Vegetables	31	36	42	2.9	3.0
Fruits	177	244	345	6.6	7.1
Others	57	57	56	-0.1	-0.3
Total acreage	4,880	5,099	4,966	0.8	-1.4

The main challenge for Malaysian agriculture is to become more competitive. Consequently, the Ministry of Agriculture has formulated a number of policies to transformed agriculture sector so that the above problems can be overcome. Most of them revolve around the application of modern technology and the provision of efficient communication services (see http://agrolink.moa.my/amanat/). Therefore, any technology developed to reduce pest damage to agricultural crops has to be revolved around this idea.

Pests – weed, disease and insect – reduce significant proportion of potential crop yield. It is estimated that pest damage may result in more 55 percent yield loss. In 1987, globally, the value of rice losses due diseases was about US$12.5 billion, excluding the cost of pesticides and their application (Teng, *et al*., 1990). In Malaysia, the total value of pesticides used is about RM300 million annually, of which 75-85 percent is for herbicides (U. B. Cheah, personal communication, 2002).

For more than 50 years pesticides have been used to protect the agricultural crops from pest damages. Unfortunately, over-dependence on pesticides for crop protection is increasingly confronted with many undesirable problems that threaten crop production sustainability (Pingali and Roger, 1995). Excessive use of pesticides results in the emergence of pesticide resistance, particularly amongst insect pests; reduction in the efficacy of pesticide and increase the cost of production. Pesticide usage is the root cause in recurring outbreaks due to resurgence of pests resulting in serious crop losses, notably in vegetables and rice (Way and Heong, 1994; and Lim, *et al*., 1997).

It is thus for the crop protectionists to devise effective technologies to manage these pest populations without harming the environment. In lieu with the agenda transformation of agriculture sector, the paradigm of pest control must be shifted from pesticide-dependent method to a multidisciplinary approach of nonpesticide methods. Nonpesticide methods are sound to environment because they are usually based on some ecological principles. The current strategies are to maximize the role of biologically-based technologies for sustainable pest management. The strategy may be developed based on the principles below:

1. <u>To grow a healthy crop</u>: The main approach is to provide favorable environment to crop growth but unfavorable to pests. Some of the available methods are development of superior varieties through conventional breeding or biotechnology, crop rotation, correct time of planting, promote crop vigor (fertilization, water management, pruning or thinning), improve clean environment (sanitation and crop refuse destruction) and reduce pest infestation (mulching and intercropping).
2. <u>To prevent introduction of pests</u>: The main available methods are plant and animal quarantines.
3. <u>To reduce the rate of colonization</u>: These include methods such as:
    * eradication and suppression program
    * mechanical control techniques such as hand destruction, exclusion by screen or barriers, trapping or collecting machines and crushing and grinding
    * physical methods such as heat or cold treatment, humidity manipulation and light trapping
    * disruption of pest searching behavior (mating, locating host)
    * maximize the role of natural enemies, through conservation and encouragement of natural enemies, introduction of specific natural enemies, and application of biopesticides.

In order to improve the effectiveness of these methods, ecologist must understand the ecology of crop and pest in depth. For instance, natural enemies are capable of regulating a host population below the economic threshold (Waage and Hassell, 1982). This regulation process is very effective because the way natural enemies respond to variability in pest populations may contribute to the stability of their interactions (Jones, *et al*., 1993). Stability assures that both populations may coexist in a stable relationship that avoids both becoming extinct. This condition is essential for the success of any biological control program (Murdoch, *et al*., 1984).

HISTORY OF NONPESTICIDE METHODS

The use of nonpesticide methods to control agricultural pests in Malaysia is as old as agriculture itself. The earliest methods of pest control were undoubtedly the physical and cultural methods. Carey in 1902 suggested that termite damage on rubber trees could be stopped by digging 2.5-3 feet for distance of 10 feet in every direction of attacked tree (Ooi, *et al*., 1981). Later techniques emphasized more on creating environment unfavorable to pests. This included the use removing pest breeding sites, healthy seedling and resistant variety. Wood (1971) showed that planting cover crops could eliminate *Rhinoceros* beetles breeding site and thus significantly reduced beetle infestation in coconut plantation. Singh (1976) pointed out the importance of plant quarantine and clean seeds in reducing pest incidences in agricultural systems. Yahaya, *et al*. (1995) recommended removal of crop residue to control tobacco pest.

PAST SUCCESSES

The scientific efforts to maximize the utilization of nonpesticide methods began in the 1900s when pest control managers became increasingly concerned on the negative effects of over-dependence on pesticide usage in crop protection. Research was then directed mainly on development of resistant crop variety and biological control methods. More works were devoted to promote biological control as a foundation of nonpesticide methods to control pest problem. Ooi, *et al*. (1979) had elaborated in detail on the successes and failures of some biological attempts in Malaysia. According to the authors, there were 23 biological control agents imported to control 11 pest problems. Six of them were able to establish (Table 2). The authors also concluded that the strategy to import exotic natural enemies was good for control exotic pests.

Table 2. List of Biological Control Agents that were Able to Establish after Introduction to Their Host

Biological Control Agents	Pest	Obtained From
Schmatiza cordiae Barb. (Coleoptera:Glerucidae) and *Euytoma attiva* Burk. (Hymenopter: Eurytomidae)	*Cordia curassavica* (Jacq) R&S – a noxious shrub of coconut plantation	Trinidad
Ammalo insulata (Walk.) (Lepidoptera:Arctiidae)	*Eupatorium odoratum* L. – a weed in plantation	Trinidad
Thyraella collaris Grav. (Hymenoptera:Ichneumonidae) and *Diadegma cerophagus* Grav. (Hymenoptera:Ichneumonidae)	*Plutella xylostella* L. (Lepidoptera: Yponomeutidae) – pest of cabbage	India, Indonesia, Australia and New Zealand
Bessa remota Ald (Diptera: Tachinidae)	*Artona catoxantha* Hamps (Lepidoptera:Zygaenidae) – coconut leaf moth	Indigenous
Trichogrammatoidae nana Gir (Hymenoptera:Trichogrammatidae)	*Eucosma isogramma* Meyr. (Lepidoptera:Eucosmidae), *Chilo sacchariphagus* Bojer (Lepidoptera:Pyralidae) and *Sesamia inferens* Walker (Lepidoptera:Noctuidae) – sugarcane borers	Indigenous
Granulosis virus	*Darna trima* (Moore) – oil palm nettle caterpillars	Indigenous

Source: Ooi, *et al*., 1979.

Of these, the use of egg parasitoid, *Trichogrammatoidae nana* to manage sugarcane borers and the virus to control oil palm nettle caterpillars were the most successful (Ooi, *et al*., 1979). It is worthy also to note that the suppression of *Rhinoceros* beetles, *Oryctes rhinoceros* (L.) infestation on coconut was due to a biological control agent. Although several importations of biological control agents failed to establish, the pest problem was successful controlled by indigenous disease, *Rhabdionvirus oryctes* (Huger). In fact, the virus was exported to Fiji and Samoa Islands and was successful in controlling *Rhinocerus* beetles infestation (Ooi, *et al*., 1979). In addition, many other natural enemies were exported from Malaysia to other part of the world; six of them were able to establish and controlled their hosts (Table 3).

Table 3. List of Successful Biological Control Agents Exported from Malaysia

Biological Control Agents	Host	Exported to
Bessa remota Ald (Diptera:Tachinidae)	*Levuana iridescens* B&B (Lepidoptera:Zygaenidae)	Fiji
Eretmocerus serius Silv. (Hymenoptera:Eulophidae)	*Aleurocanthus woglumi* Ashby (Homoptera:Aleurodidae)	Cuba
Scelia pembertoni Timb. (Hymenoptera:Scelionidae)	*Oxya chinensis* (Thumb) (Othoptera:Acridiidae)	Hawaii
Tetrastichus brontispae (Ferr.) (Hymenoptera:Eulophidae)	*Brontispa mariana* Spaeth (Coleoptera:Hispidae)	Saipan and Rota
Opius oophilus Full. and *O. vandenboshii* Full. (Hymenoptera:Braconidae)	*Bactrocera dorsalis* Hend (Diptera:Tephritidae)	Hawaii
Selca brunella Hamps. (Lepidoptera:Arctiidae)	*Melostoma malabathrichum* L.	Hawaii

Source: Ooi, *et al*., 1979.

CURRENT STATUS

The success of several nonpesticide methods in reducing pest damage has encouraged more efforts to search for more methods that are able to replace or minimize pesticide usage. Biological-based technologies seem to provide more promising results. Thus, many biological control programs are initiated (Hussein, 1999). Most of the efforts are emphasizing on how to integrate diverse technologies rather than depending on a single component technology. This scenario fits very well to the concept of integrated pest management (IPM). Subsequently, several IPM packages are adopted to manage pest population in many agricultural crops (Chin, *et al*., 1991; Syed, *et al*., 1997; and Mah, *et al*., 2001).

Rice, vegetables and cocoa are three commodities where IPM programs are being implemented. In rice, the main effort is to reduce application of insecticide, especially in the early part of crop stage. Indigenous natural enemy population may build up if no insecticide was applied (Lim, *et al*., 1978).

In vegetable, research is ongoing to increase the effectiveness of available biological control agents. For control of *Plutella xylostella* (L.) (Lepidoptera:Yponomeutidae) on crucifers, local and exotic biological control agents are found effective or partially effective. Examples of local biological control agents are *Cotesia plutellae* (Kurdjumov) (Hymenoptera:Braconidae) and examples of exotic are *Diadromos collaris* and *Diadegma semiclausum* (Ooi, *et al*., 1979). The most recent successful biological control program is the importation of four parasitoids, *Diadegma semiclausum* Helen (Hymenoptera:Ichneumonidae), *Diadromos collaris* (Gravenhorst) (Hymenoptera:Ichneumonidae), *Oomyzus sokolowskii* (Kurdjumov) (Hymenoptera: Eulophidae) and *Macromalon orientale* Kerrich (Hymenoptera:Ichneumonidae) (Ismail, *et al*., 1995). For other pests, effort is ongoing to promote nucleopolyhedrovirus to control *Spodoptera litura* F. (Lepidoptera: Noctuidae) (Mohd Norowi, *et al*., 2002).

In chili system, use of mulching and intercropping are two other successful nonpesticide methods to reduce number of winged aphid, vector of several viruses. Reflective plastic mulch is used to repel winged aphids and prevents from landing and transmitting viruses onto chili plants. In a study, Mohamad Roff and Ong (1991) showed about 85 percent of winged aphids were repelled when reflective plastic mulch was used onto the planting bed of chili. This resulted in nearly 70 percent reduction in virus disease incidences. Other ameliorating effects of reflective plastic mulch are to suppress weeds on planting beds, thus reducing competition with chili plants and cost of weeding; conserve soil moisture which in turn promote the growth of chili crop; reduce soil erosion and leaching of fertilizer; and increase photosynthesis and stomata conductance (Mah, *et al*., 2001). Generally, chili grown using reflective plastic mulch produced yield nearly five times more than that without mulch. The multiple positive effects might account for the success of adopting this method to control aphid population on chili.

In another study, Mohamad Roff and Ho (1991) showed that intercropping chili with maize was able to repel winged aphids from entering into chili growing area, which in turn reduced virus disease incidences and increased yield of chili. Even though at present chili plant resistance against viruses is still not available, it was found that chili varieties with erect and open plant architecture harbored less number of apterous aphids as compared to compact and prostrate plant architecture (Idris, *et al*., 2001). The chili varieties having the erect and open plant architecture were also found to have low incidence of virus disease incidences.

For cocoa, cocoa pod borer is the main problem. Nonpesticide methods are the main trust of pest management. These include cultural, physical, biological control and crop resistant. Some cultural and physical methods used are short harvesting rounds, high harvesting standards, same day harvesting, splitting and bagging and sleeving young cherelles (Shah, 1987). For biological control, several parasitoids and predators are believed to able control the borer infestations (Ooi, 1987; and Wood, 1987). Azhar and Lim (1987) highlighted the importance of crop resistant to reduce borer infestation.

For weed problems, several biological control agents have been introduced. One of the promising programs is the biological control of water hyacinth, *Eichhornia crassipes*. Water hyacinth is a serious weed in water system, i.e., lakes, streams, reservoirs and rivers (Anwar, *et al*., 1997). Since herbicide application is not advisable, manual removal of it is the only option left. However, this method of removal is labor-intensive and thus unsustainable. Recently, biological control agents *Neochetina bruchi* (Hustache) (Coleoptera:Curculionidae) and *Sameodes albiguttalis* (Waren) (Lepidoptera:Noctuidae) were introduced. *N. bruchi* had established in all the sites where they were released while *S. albiguttalis* was recovered only in two out of three sites. Although the impact of these biological control agents has yet been measured, their potential is great. It has been observed that even under favorable conditions destruction of 90 percent of host population can only been observed in about three years.

GOVERNMENT POLICIES

The Malaysian Government considers seriously the promotion of nonpesticide methods of pest management. Several acts and policies have been enacted and formulated to provide the framework of achieving the objective.

Pesticide Act

The Act, passed in 1974, is aimed to register and regulate pesticide usage in Malaysia. This Act together with Food Regulation 1985 reflects the seriousness of the government to ensure the pesticide usage is not abused.

Plant Quarantine Legislation

Quarantine laws provide an important arsenal to control pests and diseases. In Malaysia, two quarantine laws were enacted, namely; Plant Quarantine Act 1976 and Plant Quarantine Regulations 1981. The Act consolidates the law relating to control, prevention and eradication of agricultural pests. It also provides cooperation with other countries in the control of the movement of pests in international trade. The Plant Quarantine Regulations 1981 enable to regulate the importation of plant, plant products, growing media/rooting compost, beneficial organisms, plant pests and carriers of plant pests to Malaysia. The strength of the regulation is that all materials imported to Malaysia are subject to quarantine inspection at the port of entry.

Third National Agriculture Policy (1998-2010)

The policy emphasizes the importance of agroforestry approaches in agricultural system. Agroforestry approaches focus on the prudent management and utilization of biological diversity in agricultural production system.

National Biological Diversity Policy

The policy aims to conserve Malaysia's biological diversity and to ensure that its components are utilized in a sustainable manner for continued progress and socioeconomic development of the nation.

Among the objectives is to ensure long-term food security for the nation. To achieve the objective, one of the agenda is to utilize beneficial organisms viz. natural enemies and pollinators in a sustainable manner.

National Council for Biological Control

The main objective of the Council is to coordinate the biological control works in Malaysia. The initiative taken by the government is a testimony of the seriousness and commitment of the nation to promote nonpesticide method of controlling agricultural pests.

Farm Accreditation Scheme

Presently, the Malaysian Government has formulated a scheme to promote the production of safe agricultural products from pesticide contamination. The scheme is known as Malaysian Farm Accreditation Scheme. The main objective of this scheme is to accredit farms that adopt Good Agricultural Practices (GAP) and produce agricultural products that are safe and wholesome for the consumers. Farm accreditation scheme gives recognition to the farms that comply with the GAP requirements, and thus their products are of higher value and perhaps can fetch higher price. GAP is farm management practices which are environment-friendly, enable sustainable agriculture and ensure agricultural products from the farm do not contain pesticide residues, heavy metals or microbial contamination higher than the allowable level, based on standards which are already accepted internationally and also according to Malaysian standards.

ISSUES AND PROBLEMS

Lack of Appreciations

Lack of appreciation towards nonpesticide methods, especially the use of biological control agent, lies in its nature. As these methods are generally self-sustaining, it does not provide interest from private sector to promote these methods of pest control. In addition, the community did not realize or understand the importance of conserving diversity and maintaining endemic pest below the economic damage. To overcome this issue, the public need to be well informed on the benefits of the methods especially on issues relating to food safety and the effect to the environment.

Lack of Biological and Ecological Research

The success of biological control depends on the stability of natural enemy-host interactions (Murdoch, *et al*., 1984). The stability of an interaction is a favorable outcome for crop protection because a low level of both host and natural enemy is preferable to the violent population changes and large pest growth rates that may occur following a re-colonization by a host to an area devoid of natural enemies. Nevertheless, this interaction is very sensitive to human activities. For instance, the application of insecticide may harm this interaction and result in a resurgence of the host population (Doutt and Smith, 1976). In addition, habitat fragmentation can affect the parasitism rate of large and small parasitoids, depending upon the size of their foraging areas (Roland and Taylor, 1997). Unfortunately, details ecological study is still lacking. Most of the information regarding this matter is obtained from outside of Malaysia. The participation with existing network may overcome this shortcoming.

Lack of Proper Observations

Proper observation (time and space) is crucial in order to minimize dependency on pesticide. Less dependent on pesticide shall increase the effectiveness of natural enemies to control pest infestation. The bases for making accurate decisions on whether or not to apply any insect control tactic or for determining the status of plant and pest should depend on the density of pest and its major natural enemies. The only way to determine these factors is through field monitoring. Unfortunately, field monitoring is a tedious job. Computer simulation may be used to predict the future outcome of plant-pest-natural enemy interactions, and this may reduce the time spend for field monitoring (Mohd Norowi, 2001).

Over-dependent on Pesticide

Despite increased in awareness of pesticide effects on environment (Pingali and Roger, 1995), pesticide usage is likely to increase. Projections indicate that labor shortage will trigger farmers to depend more of pesticide (Schoenly, *et al*., 1998). For example, shortage of labor in rice industry compels rice farmers to substitute direct seeding for traditional transplanting, a change in practice that will encourage higher herbicide usage for early season weed control. This additional chemical input will likely affect non-target species in similar way of insecticides, thus disrupting the delicate interaction of natural enemies and their host.

FUTURE DIRECTION

The demand for nonpesticide method to reduce yield loss due pest infestation needs to be aligned with the concept of sustainable agriculture. The methods must be economically viable, ecologically sound and socially equitable and balance present with future needs. Pest problems are complex, dependent on climate, crop agronomy, technology and various ecological processes, as well as political, social and economic forces. The anticipated pest control technology must have access to apply advance technology. Information technology and biotechnology, the twin technology pillars of the world of crop protection, must be relied on (Rabbinge, 1997).

In Malaysia, the embracing of information technology and biotechnology into crop protection technology is progressing very well although it is at the infancy stage. There are several projects initiated to formulate crop protection technologies to reduce the dependent on pesticide. Examples of projects that are relevant to information technology approach are rice-pest interactions (Mohd Norowi, 2001) and host and parasitoid movement (Mohd Norowi, 2000). Examples of biotechnology approach are the development of transgenic rice resistant to tungro disease, transgenic papaya resistant to papaya ring spot virus and chili resistant to chili veinal mottle potyvirus and cucumber mosaic cucumovirus (Ong and Hassan, 2000).

Modeling Pest-Plant Interactions

To understand how pest problem arise and how they may be tackled, a system view is required. The modeling approach provides a framework for systematic analysis and synthesis of agricultural systems at different level of aggregation, i.e., field, farm and region. By evaluating alternative development options, the modeling approach provides a holistic view of plant-pest interactions, helps in understanding pest problems, targeting research efforts and communicating results. For examples, Mohd Norowi (2001) applied computer simulation predicts the dynamic interactions of *Nilaparvata lugens* (Stål) (Homoptera:Delphacidae) and rice. The similar model was developed to predict the impact of yield loss due to weed-crop competition (Kropff and van Laar, 1993). All these simulation models indicate that plant able to compensate pest damage. In most cases, no intervention (i.e., application of insecticide) is necessary.

Host-Natural Enemy Movement

Biological control method is the most potential nonpesticide method to control pest populations. To be successful, it is a necessary to thoroughly understand biological and ecological aspect of control agent (Longely and Izquierdo, 1994). One of the important ecological aspects is the movement of host and its natural enemies within agricultural land (Dempster, *et al*., 1995; and Perry, 1995). Insect hosts must move regularly to avoid attack from natural enemies. Perry and Taylor (1986) pointed out that the presence of a parasitoid might affect the spatial pattern of the host, which will attempt to relocate in refuges. This escape response by the host may then cause alteration in the spatial pattern of the parasitoids, which strive to seek out the new locations of the host aggregations. A study is in progress to determine the impact of spatial heterogeneity on the interactions of *N. lugens* and its major predator, *Cyrtorhinus lividipennis* Router (Hemiptera:Miridae). In this study, the effect of non-rice habitat (a form spatial heterogeneity in rice ecosystem) on the initial spatial pattern of *N. lugens* colonization in rice ecosystem will be quantified.

Preliminary result indicated that counts were higher in plots located further to non-rice habitat area. There was no detectable trend for density of *Cyrtorhinus* with distance to non-rice habitats. It was suggested that non-rice habitats may serve as a refuge for natural enemies of *N. lugens*. Thus, their predation was higher in plots near non-rice habitats (Mohd Norowi, 2000). This study emphasize the importance of non-rice habitat in rice ecosystem as it might serve as a refuge for natural enemies (Way and Heong, 1994; and Ives and Settle, 1997).

Our understanding of parasitoid foraging behavior, particularly their responses to semiochemicals, is providing exciting opportunities for the manipulation of parasitoids to enhance their impact on pest populations. However, to develop realistic pest control strategies based on the manipulation of parasitoids with semiochemicals, knowledge of parasitoid behavior gleaned from laboratory studies must be combined with a sound understanding of parasitoid and host ecology.

Biotechnology Methods

The effective application of host plant resistance is known to result in both economic and environmental benefit (Teng, 2000). The economic benefits accrue from the reduction in cost of pesticides, reduction in related costs to apply the pesticide, and the consequential yield increase due to crops expressing more of their yield potential. The environmental benefits accrue from reduce effect on non-target organisms and reduction in potential health hazard to the applicators. Transgenic crops with improved pest resistance, therefore, have great potential in crop protection if used in the framework of pest management systems.

In Malaysia, two transgenic rice lines resistant to rice tungro spherical virus (RTSV) were identified after rigorous screening of several lines using viruliferous rice green leafhoppers (Ong and Hassan, 2000). These lines were genetically engineered using biolistic bombardment with polymerase gene derived from RTSV. Both lines could confer immunity against RTSV. The conferred resistance was broad as the lines were found to be immune to different isolates of the virus. Rice green leafhoppers could not acquire and transmit rice tungro bacilliform virus (RTBV) from transgenic lines infected with RTBV.

CONCLUSION

The acceptance of ecological approaches as a more sustain ways to manage pest populations provides a great opportunity to promote nonpesticide methods in agricultural production systems. Past experiences suggest that this opportunity requires nonpesticide methods be developed in a process that responds to real demand and is sensitive to complex ecology of IPM systems. In addition, it is necessary to consider stakeholder participation. The speed of the development depends on how the technology is formulated and delivered to pest managers. The adoption of modern technology and the provision of efficient communication services are two most important stepping stone toward achieving this goal.

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5. MONGOLIA

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Although livestock raising represents the major economic activity in Mongolia, cereal and food crops play an important role in food production. The increase of crop production is one of the major priorities of the Government of Mongolia, in order to gradually meet the food requirement of the Mongolian population, which is about three million. Mongolia is characterized by long, severe winter seasons and short cropping periods between June-September, which make crop production difficult with low productivity. In addition, pests, such as insect pests, plant diseases and rodents are another major constraint to crop production in Mongolia.

The grass and crop land of Mongolia are prone to damage by 75 species of plant disease causal organisms, 92 species of insect pests, 80 species of weeds and four species of rodents, of them 28 species of plant disease causal organisms, 40 of insect pests, 50 species of weeds are considered most harmful for crops. In order to minimize the damage by pests every year the country uses various pesticides, mostly imported from different country. Although pesticides have been shown to be effective, they contaminate the produce and pollute the environment.

Therefore devising environment and eco-friendly but effective pest management requires avoiding or at least minimizing the use of chemical preparations. In Mongolia, nonpesticide methods are based on some physical and mechanical methods and using microbiological and cultural control.

Within the "Green Revolution" program, several activities were organized to teach farmers on the best ways to manage pests. These often included nonpesticide methods such as trappings and baiting. The main goal of this training was to educate the farmers to organize themselves to minimize use of pesticides in managing pests. The present policies of plant protection activity are actually directed to find and use the best method of controlling pests, and minimizing negative impact on the environment and human health.

In order to protect the environment and to preserve enormously rich biodiversity, the country has to minimize the use of agrochemicals like fungicides, insecticides, rodenticides and herbicides, and encourage the use of nonpesticide method of controlling pests. Research results and experiments have shown the efficacy of physical means such as high temperature and freezing treatments which nature has bestowed on us and the microbiological preparations of *Bacillus thuringiensis, Salmonella enteridis* to effectively control insect pests and rodents of wheat, barley, cabbage, carrot and greenhouse cucumber and tomato, pasture land and fruit crops, particularly the black currant.

This approach will help save foreign currency reserves and Mongolian agriculture may truly represent a sustainable use of our natural resource leading to self-sufficiency in agricultural production, whose foundation will be organic in nature. This will allow eco-friendly, pollution-free environment for healthy coexistence of flora and fauna. Mongolian agriculture is poised to move forward in this direction. But implementations of biological methods require building up of skills and knowledge.

6. PAKISTAN

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INTRODUCTION

Pakistan is an agricultural country and more than 70 percent of its population depends directly or indirectly on agriculture. The main source of foreign exchange earning is the export of agricultural products. It also imports edible oil by spending a lot of foreign exchange. The main problem of Pakistan's agriculture is low yield of crops as compare to advanced countries of the world. There are many factors responsible for it but one of the major reasons is the attack of pests which have devastating effects on crop production. It has been estimated that only insect pests reduce crop production by 25-35 percent annually in spite of a number of pesticide applications (Nuclear Institute of Agriculture [NIA], 2000). Several problems have been observed due to heavy, if not sole, reliance on pesticides. Although pesticides have reduced crop losses and increased crop production but their use often led to increased and unnecessary pest outbreaks due to the destruction of natural enemies of the pests and the emergence of both pest resistance and secondary pests. The farmers have to apply ever-increasing and stronger pesticides to kill mutating pests and thus the problem of resistance is becoming worst day by day. In Pakistan, the classical example of development of high degree of resistance is in *Helicoverpa armigera* (Hübner) (Lepidoptera:Noctuidae) which is a serious pest of cotton and chickpeas. Similar is the case with cotton whitefly, *Bemisia tabaci* Gennadius (Homoptera:Aleyrodidae). Pesticides are not effectively controlling these pests which are a serious threat for cotton and chickpea growers. Moreover, the farmers do not follow instructions in the safe use of pesticides in developing countries like Pakistan due to lack of education and training in pesticide application methods. Pesticide use has also contaminated foodstuffs especially fruits and vegetables. The farmers sell them in the market soon after pesticide application; however, there is no scientific basis to collect such data.

The attention is now being shifted from sole dependence on chemical control to Integrated Pest Management (IPM) strategies and the high prices of pesticides are one of the main reasons responsible for this change. The farmers are now also using cultural, mechanical, physical and biological control methods of pest control. Moreover, the concept of economic threshold level is also gaining popularity because of high costs of insecticides. It is hoped that the pesticides use will be minimized due to application of pest management strategies.

NONPESTICIDE METHODS OF PEST CONTROL

Insect Pest Control

1. ***Mechanical Control Measures***

Hand picking: Insects and their egg masses are collected manually and are killed. It is the most practical method and is commonly employed for the control of eggs and larvae of cabbage butterfly, larvae of lemon butterfly, and adults of female mango mealy bugs particularly in home gardening.

Hand nets: It is commonly used for the control of sugarcane leafhopper at the start of sugarcane season in April-May. The method is also being used to collect cabbage butterflies where the cabbage crop is cultivated on small scale.

Hopper dozers: These are big cages with wheels for use in the field to control grasshoppers.

Trapping: This method is used for the control of cutworms. Potatoes, turnips and cabbage leaves are chopped up and placed at different sites in cutworm infested fields at night. The cutworms come out to damage the crop at night and hide under these heaps during the day. Cutworms are collected from these heaps and killed.

Use of collars: The clusters of fruits of dates are covered with bags to protect them from the attack of insects and birds.

Physical beating: Fly flappers are used to kill flies and locust beaters to kill locusts. Hornets are important predators of honeybees and this method is effectively used for the control of the hornets.

Banding: A very common and effective method to control the mango mealy bug is the application of polythene bands at stem of mango trees. The polythene sheet of nine inch to one foot width at four feet height is placed round the tree trunk in December-January. This practice ensures the safety of mango plant against the mango mealy bugs. Gunny bags (made of jute) are used to collect and kill the larvae of codling moth and are an important method to suppress its population on apple trees.

Rope dragging: Small-scale farmers control the population of spotted bollworms by rope dragging. Two men drag a rope over the crop and as a result the infested bolls fall down on the ground. After that the field is irrigated and thus the bollworm present in the bolls are drowned. The method is also used to kill the larvae of cabbage butterfly.

Pressurized water spray: It is used to kill adults of cotton whitefly. In heavily cotton infested fields, the pressurized spray is used six times a month, i.e., at five days interval and found to be effective for the control of whitefly population.

2. ***Physical Control Measures***

Flooding: Soil insects are killed by flooding the fields. Nursery beds of rice are flooded and the rice hispa float up and is killed in water.

Use of low temperature: It is a common practice in Pakistan to store the potatoes in cold storage to protect them from the attack of potato tuber moth.

Use of sunlight: It is a common practice to kill the pests in grains especially wheat by spreading them outside in the sun during summer. The best thickness of the grain layer is one inch or less and best time is 1-4 pm. Cotton seeds are also put in the sun to kill pink bollworm hiding in the double seeds of cotton.

Use of light traps: Termites and moths are collected and killed by installing light traps in the field.

3. ***Cultural Control Measures***

Clean culture: Removal of rubbish from the farm deprives the insects of their food plants for feeding, egg laying and shelter. The common practices of clean culture adopted by the farmers to control the insect pests are:

(a) stubbles of rice, maize and sugarcane are removed with ploughing after harvesting. As a result, the diapausing larvae of rice, maize and sugarcane borers are killed and reduction in population occurs during the next season.

(b) wild growth on the edges of rice crop provides food to insects like rice grasshoppers and rice bug. This wild growth is checked by the farmers to reduce the population of these insects.

(c) the population of red pumpkin beetles is reduced by destroying the creepers which provide them shelter from hot/cold conditions.

Eradication of weeds: The weeds are source of food for many insects. It is a common practice in rainfed areas of Pakistan to remove the weeds manually and fed them to the animals. It not only helps to save their crops from the insects but also solve the problem of food shortage for their animals.

Removal of crop remnants: It is a common practice to remove the cotton sticks two inches below the ground level after the cotton crop is over. The purpose is to prevent the build up of spotted bollworm population on the sproutings of cotton plants.

Removal of affected plant parts and fallen fruits: The infested sugarcane tops are removed and fed to cattle during August-October to suppress the population of top borer. It is a common practice to remove and destroy the egg masses and dead hearts of rice from field to suppress the population of rice borers. The fallen fruits of apple and guava are collected and deeply buried to kill the larvae of codling moth and fruit flies, respectively.

Selection of resistant varieties: The farmers try to sow the comparatively resistant varieties of the crops provided the yield is not affected.

Hoeing: Many insect pests pupate and hibernate in the soil. It is a common practice to control such insect pests of fruit trees by hoeing under the canopy of trees, e.g., guava fruit fly, mango mealy bug, codling moth. The population of *H. armigera* is suppressed by ploughing the field immediately after last picking of cotton. Its larvae pupating in the soil are killed due to ploughing of the field. Similarly, many other insects which pupate in the soil are suppressed effectively with hoeing operations, e.g., brinjal fruit borer, red pumpkin beetle and melon fruit fly, etc.

Pruning of fruit trees: San Jose scale, *Quadraspidiotus perniciosus* Comstock. (Homoptera: Diaspididae) is a serious pest of apple in Pakistan. The farmers remove its heavily infested branches with a pruning knife during winter (January-February) and burn them. It helps to keep its infestation low during the next year.

Biological Control

It is an important method of pest control and has been employed successfully for the control of certain insect pests in Pakistan. The genus *Trichogramma* (Hymenoptera:Trichogrammatidae) is being used effectively as a biological control agent against sugarcane borers in sugarcane growing tract of Pakistan. The trials on small scale were conducted in 1989 by NIA, Tandojam with the collaboration of sugarcane mills of the area. The egg parasitoids, *T. chilonis* Ishii, was mass cultured and released. The performance of the parasitoid was encouraging and, therefore, a laboratory for mass rearing of this parasitoid in the premises of sugar mills was established during 1992 (Al-Noor Sugar Mills, Moro) to meet the requirement of area wide management. An area of more than 50,000 acres (20,000 ha) was treated during 1999-2000 crop season. The use of insecticides in the area has been stopped and excellent control of sugarcane borers has been achieved. The parasitoid successfully suppressed the infestation of the borers as can be seen in Table 1. Parasitoids were also released in sugarcane growing tract of Nawabshah in 60,000 acres (24,000 ha) during 1999-2000. The borer infestation remained below economic threshold level (10 percent) throughout the season (Table 2). The technique was also tried in the sugarcane growing areas of Punjab and NWFP and gave promising results. *Trichogramma* cards are now available commercially and farmers are using them for the control of sugarcane borers in Pakistan.

Table 1. Sugarcane Borer Damage on Internode Basis in *Trichogramma chilonis* Treated Area

(Unit: Percent)

S. No.	Localities	Mean Borer Damage	Infestation Range	S. No.	Localities	Mean Borer Damage	Infestation Range
1.	Allah Khai	2.36	0.7-3.5	29.	Dairis	2.85	1.7-4.0
2.	Noor Muhammad	2.15	0.9-4.2	30.	New Gachero	4.15	2.4-5.5
3.	Malwah	2.58	1.6-4.4	31.	Raja Wah	5.02	3.9-6.7
4.	Phullet	2.58	1.7-3.7	32.	Pubjo	4.23	2.6-5.4
5.	Shahpur	2.66	1.7-3.8	33.	Sawari	3.82	1.6-5.8
6.	Khalso	2.58	1.6-3.8	34.	Utar Sawi	4.52	2.1-5.7
7.	Mari	2.64	1.6-4.0	35.	Habbery	4.52	2.1-6.1
8.	Doulatpur	2.38	0.8-3.9	36.	Qaim Koor	3.83	2.7-5.1
9.	Holipota	2.29	0.8-4.0	37.	Talhi	3.87	1.7-5.5
10.	Chario	2.72	1.6-4.2	38.	Sarmand Kandi	5.05	2.9-7.8
11.	Khar	2.31	0.8-4.0	39.	Kundah Nanda	4.73	1.7-7.9
12.	Dumberjee Wah	2.01	0.7-3.7	40.	Kundah Wadda	7.00	0.0-6.6
13.	K.K.-4	2.34	1.4-3.1	41.	Saeed Kando	4.56	2.1-6.5
14.	Karip	2.23	1.4-3.6	42.	Old Gachero	4.10	3.1-5.1
15.	K.K.-1	2.50	1.5-3.6	43.	Sultan Behan	4.60	2.2-6.1
16.	Manahro	2.39	0.7-4.3	44.	Sadhuja	5.06	3.6-6.3
17.	Sahib Khan	2.18	0.8-3.8	45.	Mubejani	5.86	3.4-7.4
18.	Dal	2.07	0.8-3.4	46.	Noor Pur	5.90	4.1-7.1
19.	Bhelahro	2.20	0.8-3.6	47.	Jark Yaro	4.21	2.0-5.8
20.	Makhand	2.54	1.5-4.1	48.	Mir Rukan	4.78	2.5-7.1

... To be continued

Table 1. Continuation

S. No.	Localities	Mean Borer Damage	Infestation Range	S. No.	Localities	Mean Borer Damage	Infestation Range
21.	Changal	3.34	1.8-4.8	49.	Bogri	4.95	1.7-6.9
22.	Moro	3.51	2.4-4.3	50.	Khair Wah	5.66	2.1-7.5
23.	Doro Behan	3.49	1.5-5.8	51.	Khariro	4.31	2.9-6.3
24.	Lundki	3.37	0.7-5.4	52.	Sun	4.22	1.8-7.1
25.	Wadpagia	2.46	0.8-3.6	53.	J.T.	4.58	3.1-5.5
26.	Qanchi Jageer	3.25	1.7-4.2	54.	Jari	3.67	1.8-4.7
27.	Dalchand	2.95	1.4-4.2	55.	Khandhari	3.69	1.5-5.6
28.	Kopt Satabo	3.00	1.4-4.5	56.	Kharjani	5.41	2.0-7.8

Table 2. Mean Borers Infestation on Dead-heart Basis in Habib Mill Zone Area (Tandojam)

Month (1999)	Weeks	Mean Borer Infestation (percent)
July	4	3.51
August	1	3.70
	2	3.78
	3	3.89
	4	4.06
	5	4.17
September	1	4.26
	2	4.41
	3	4.55
	4	4.63
October	1	4.73
	2	4.84
	3	4.97
	4	5.01
	5	5.17
November	1	5.25
	2	5.27
Overall mean		4.48

San Jose scale is one of the most serious pests of apple in Pakistan. The parasitoid *Encarsia pemiciosi* (Hymenoptera:Aphelinidae) was introduced from U.S.A. in 1986 by International Institute of Biological Control (IIBC) Pakistan Station at Rawalpindi. It was released in Murree hills of Punjab province and is giving excellent control of the pest in this area. Keeping in view the success of the parasitoid in Murree hills, it was also released in Swat valley and the parasitoid has established in this area. Ladybird beetles (Coleoptera:Coccinellidae) are good predators of this pest and some species like *Chilocorus infernalis* and *C. nigritus* (Fabricius) are already existing in this valley. In 1990, conservation and augmentation technique was applied at Kalam area of Swat valley. The ladybird beetles were collected from the orchards where their population was high and released where San Jose scale was serious. The predators have become established in this area and are keeping the pest under control because the farmers are not using insecticides against this pest (Qureshi and Mohyuddin, 1995).

Studies were conducted on the integration of mating disruption technique and the egg parasitoid, *Trichogramma chilonis* Ishii, for the management of cotton bollworms and the experiments have shown good results. An experiment was conducted at Tandojam (Sindh) in a semi-isolated area on 500 acres (200 ha of cotton). The results are given in Table 3 which showed that the bollworms were effectively controlled by mating disruption technique in combination with egg parasitoids. Fruit flies are serious pests of many fruit.

Their control with sex pheromones (methyl eugenol) on fruits like peach, pear and guava is attaining attention of the farmers particularly in NWFP of Pakistan which is an important growing area of these fruits.

Table 3. Mean Percentage Infestation of Pink and Spotted Bollworms in Different Treatments

Treatments	Pink Bollworm		Spotted Bollworm	
	Flowers	Green Bolls	Flowers	Green Bolls
Mating disruption + parasitoid	5.91[d]	4.52[d]	9.11[c]	8.21[c]
Insecticides	6.88[d]	6.97[c]	10.50[c]	9.80[c]
Mating disruption alone	8.90[c]	8.03[c]	11.32[c]	14.12[b]
Parasitoid alone	12.54[b]	11.39[b]	14.64[b]	13.89[bc]
Untreated	22.14[a]	16.25[a]	31.19[a]	23.93[a]

Note: Mean followed by similar letters are non-significant ($P \leq 0.05$).

The infestation data from untreated fields of six localities viz., Serhai, Cheeho, Kalhora, Kango, Pat Peeral and Pir Sadique were recorded which ranged from 7.1 to 28.4 percent with an average 20.23 percent.

Codling moth is an important pest of apple fruit in Pakistan. The Entomology Department of the University of Arid Agriculture, Rawalpindi, Pakistan is running a project for the control of this pest with nonpesticide methods. The experiment conducted to control this pest with mating disruption technique in combination with various cultural practices gave good results. The details are as given below.

The apple orchards were selected at Osia, the main apple growing area of Murree hills, for this experiment. The treatments given were as follows:

* T_1 Hoeing + sex attractant traps
* T_2 Hoeing only
* T_3 No hoeing + sex attractant traps
* T_4 Banding with gunny bags + sex attractant traps
* T_5 Banding with gunny bags only
* T_6 Without hoeing or banding.

Soil under the apple trees selected for cultural practices was ploughed at 20 days interval from March to August 2001. The gunny bag bands, 9-12 inches in width, were applied to apple trees for trapping the sheltering larvae. Five traps baited with sex attractant lures (Codlemone) per acre were installed at different sites in the orchard. The traps were installed from March to first week of September and the lures were regularly changed at three weeks interval. The experiment was replicated thrice and the experimental unit was one acre except in T_4 and T_5 where it was half an acre.

The pest infestation was recorded at harvesting of the fruit by taking a random sample of 10 kg from each treatment. The data were analyzed statistically to find out the effectiveness of various treatments for the control of codling moth.

The findings on the control of codling moth with different methods are given in Table 4. It revealed that the minimum infestation (5.22 percent) was recorded in T_1 where mating disruption technique was used in combination with hoeing under the trees. However, it did not differ significantly from T_4 where mating disruption method was applied along with gunny bag bands, although, the percentage infestation was slightly higher as compared with T_1 (5.69 percent). The percentage infestation of codling moth was 8.78 in apple orchard where only mating disruption was used without hoeing under the trees. The infestation was significantly higher as compared with T_1 and T_4 but lower from all other treatments. It showed that the efficiency of mating disruption technique can be enhanced by reducing the larval population with other means like banding and hoeing.

The treatments where only hoeing (T_2) or banding (T_5) was done, but not supplemented with sex attractant traps for mating disruption, received high infestation of codling moth which was 18.56 and 19.04 percent, respectively. It further revealed that hoeing under the trees (T_2) was slightly better than banding (T_5) but were at par statistically. The maximum infestation (22.32 percent) was recorded in T_6 where neither hoeing nor banding was done. The percentage of infested apple fruits was statistically higher in this treatment

(T_6) than all other treatments. The studies revealed that the lowest percentage infestation was recorded on T_1 and T_4 and the maximum on T_6. The technique is already is being used by the farmers of Baluchistan province which is the main apple growing area of Pakistan.

Table 4. Mean Infestation of Codling Moth in Different Treatments

Treatments	Mean	Duncan's Test
T_1 Hoeing + sex attractant traps	5.22±0.22	a
T_2 Hoeing only	18.56±1.06	c
T_3 No hoeing + sex attractant traps	8.78±0.60	b
T_4 Banding with gunny bags + sex attractant traps	5.69±0.28	a
T_5 Banding with gunny bags only	19.04±0.68	c
T_6 Without hoeing or banding	22.32±1.31	d

It is obvious that hoeing alone or in combination with mating disruption gave better control of codling moth as compared with banding alone or in integration with mating disruption (Table 4). It may be due to the reason that the pest prefers to pupate in the soil in this area. As a result, the hoeing operations under the apple trees kill the insects more effectively than that of banding.

1. ***Insect Pests of Stored Grains***

a) It is a common practice to spread wheat grains in the sun during the summer to dry the moisture contents and kill the insect pests. The wheat is then stored in containers.

b) Neem leaves are kept in the wheat and rice grains to protect them from the insect pests of storage.

c) Rice grains are coated with mixture of ginger and brassica oil to protect them from the attack of rice weevil.

d) Crystals of common salt (sodium chloride) are kept in the rice grains to protect them from the attack of rice weevil.

e) A very effective and safe way to stop insect damage in grain without mixing chemical is used by the people who kept the grains for their consumption throughout the year. This method is very simple. Just take an empty oil drum. Put some soap and water and boil it up and it is absolutely cleaned in this way. If there are any holes they can be filled with appropriate material. The idea behind this exercise is to make the drum completely airtight. Now fill up the drum with dried grain (Pakistan Agricultural Research Council [PARC], 1983) which will remain safe from the attack of insect pests.

f) Gunny bags are spread over the infested grains for trapping the larvae and adults of *Trogoderma granarium* (Everts) (Coleoptera:Dermestidae) and collected insects are then buried deep in the soil.

g) Damage of pulse beetle to pulses is prevented by spreading two-inch layer of sand over the surface of grain when stored in receptacle.

2. ***Miscellaneous Methods***

The problem of drying trees can be solved with a very simple method. The pits of 2-3 feet deep are dug out around the stem of the trees so that their roots become naked. These roots are kept open for 5-6 days for obtaining better aeration. An amount of 1-2 kg common salt is poured in the pits around the stem of each tree and flooded with water. This water is allowed to absorb in the soil and the pits are again filled with sufficient amount of water + formalin solution (16-20 liter water + 100 ml formalin). Pits are then filled with rotten leaves and are covered with soil. The plants will become green and healthy. The month of December is the best period for this treatment.

The chopped leaves of *Calotropis* are placed in the dry water channel to rot for about a week under the clods of soil so that they may not be blown away. The irrigation water is then passed over the rotten leaves which carries extract of the leaves in the field infested with termites. It is very economical and simple method for the control of termites.

Red pumpkin beetle is traditionally controlled by dusting ash on the infested cucurbit plants.

Another traditional method is to apply solution of common salt in combination with lime for the control of aphids.

Weeds and Their Management

Weeds are very serious pests of crops as the requirements of both of them are similar regarding soil space, water, salts, air and light. The development of crop suffers when weeds are present in crop fields to share these necessities. Weeds are generally very hardy, thus, outgrow crops and reduce their yield. It has been estimated that the yields may be reduced up to 30 percent (Jalis, 1987). The herbicides are used for the control of weeds which are not only expensive but are also hazardous to man and his environment. Pakistan can be divided conveniently into 17 distinct crop ecological zones (Rafiq, 1976).

1. ***Zones 2, 3-a: (Hyderabad, Multan and Khairpur)***

The major weed problems in this large area are broad leaved weeds *Chenopodium album, C. murale* and *Convolvulus arvensis. Melilotus alba* and other leguminous broad leaved weeds are present but probably do not cause serious economic losses. *Phalaris minor* and *Avena fatua* are also present but not at levels causing economic loss.

2. ***Zone 3-b: (Jacobabad-Dadu)***

Very little research work has been conducted on weed problems in this area. The two *Chenopodium* species and *Convolvulus arvensis* are present, but of little importance than that of the zone above.

3. ***Zone 4 (Faisalabad)***

This zone is similar to the previous two zones and *Chenopodium* and *Convolvulus* are the major wheat yield reducing weeds. *Phalaris minor* and *Avena fatua* are found important in some fields.

4. ***Zone 5 (Gujranwala)***

Weeds in this zone have been studied extensively. The major problems in this area are the grassy weed *Phalaris minor. Chenopodium album* and *murale* are the major broad leaved weeds. *Avena fatua* and *Lolium* sp. (a new grassy weed) are also important in some fields.

5. ***Zone 6 (Peshawar Valley)***

About 20 broad leaved weeds are the major problem in this area. The grassy weeds are also found in some fields and are becoming important.

6. ***Zones 9 and 10 (Rainfed Areas Gujrat to Rawalpindi)***

Broad leaved weeds are the major weed problems in these zones. None of these annual weeds have serious effect on crops and only cause losses in wet years.

7. ***Zone 12 (Murree-Swat)***

Weeds of this zone are similar to those reported for Zone 6. However, *Ranunculus* sp. and other temperate weeds together with *Poa annua* and other temperate grasses are important. Weeds in this zone are a major hindrance in increasing production.

8. ***Zones 8, 13 and 14 (Dera Ismail Khan and Adjacent Areas)***

Very little information is available on weeds in these zones.

Nonpesticide Methods of Weed Control in Pakistan

Hand weeding: Traditionally, hand weeding and tillage are the major methods of weed control in Pakistan. However, with the increasing cost of manual labor and reluctance of young labor to do this job, it is becoming more costly and difficult to control weeds in field crops. However, the farmers in rainfed areas used the weeds as fodder for their animals. The removal of weeds at least four inches below the ground to kill them and prevent their re-sprouting is a very effective method.

Tillage: It is the safest and most effective method of weed control. The principle is simply to turn the weeds under or bring them to the soil surface where they die of desiccation. It is important not to allow the weeds to set seeds and adding to the soil store of weed seeds. Tillage also leaves a good seed bed that gives the crop a head start in growing and helps in shifting the advantage away from the weed and toward the crop. Tillage is done before or after planting. However, post-germination tillage is not as effective in wheat as in row crops and weeds should be controlled before planting. There are some results in Pakistan that show that the use of a bar harrow is effective in reducing weed population after wheat emergence. Various tillage implements are available for effective secondary tillage and cultivation.

Delayed planting: If moisture is available from pre-sowing rains or irrigation, and planting is delayed a little, weeds are encouraged to germinate and are killed by tillage before sowing. This is an effective method but one must keep in mind the life cycle of the weeds.

Rotation: This is an age-old method of controlling weeds and is still very effective in Pakistan. In Zone 5 (rice-wheat), the use of berseem (*Erifolium alexandrinum*) in the rotation effectively reduces the growth of *Phalaris minor*. This grassy weed grows with the legume fodder and is prevented from flowering since it is cut with the fodder before it can set seed. In Zone 6, berseem in rotation with these crops is also effective for controlling weeds. Rotations are only effective if the *Rabi* (winter) weeds are controlled and not allowed to set seed.

Dabh: The practice of "Dabh", i.e., irrigating the fields and then ploughing in the seedlings when the seeds germinate is very effectively used to eliminate the weeds.

Control of Plant Diseases

Methods of control vary considerably from one disease to another depending on the kind of pathogen, the host, the interaction of the two and many other variables. In controlling diseases, plants are generally treated as populations rather than as individuals, although certain hosts (especially trees, ornamentals and sometime other virus infested plants) may be treated individually.

The various control methods can be classified as regulatory, cultural, biological, physical and chemical depending on the nature of the agents employed.

Regulatory control measures aimed at excluding a pathogen from a host or from a certain geographical area.

Cultural methods aimed at helping plants to avoid contact with a pathogen by creating the environmental conditions unfavorable for the pathogen and thus eradicating or reducing the amount of a pathogen in a plant, a field, or an area.

Biological control methods aimed at improving the resistance of the host or favoring microorganism antagonistic to the pathogen.

In Pakistan, the holdings are small and, therefore, farmers often use the control measures other than chemical except for a few farmers who use fungicides, nematicides and bactericides, etc.

Among the methods mentioned above, the cultural methods are mostly adopted and are highly effective, e.g., crop rotation, removal of alternate hosts and destruction of diseased crop debris.

Cotton is an important cash crop of Pakistan but it has been affected by certain diseases and among these, virus and root rot are important. Some cotton farmers use mixed cropping system with moth (*Vigna* sp.) in between the cotton rows against root rot caused by *Rhizoctonia solani*. Moth crop is a creeper/spreader crop which lower the soil temperature and increase humidity which suppress the pathogenic activity as the casual fungus of root rot require low humidity and high temperature.

Chickpea is another important crop of Pakistan which is affected by two important diseases, i.e., *Ascochyta* blight of chickpea caused by *Ascochyta rabiei* and wilt caused by *Fusarium oxysporium* f sp. *cicero*. For *Ascochyta* blight, farmers use resistant varieties to overcome the disease losses and they control the wilt through cultural means. The causal fungus require high temperature and low humidity and the environmental conditions are favorable at the time of sowing (October-November), so, the farmers delay the sowing in the sick fields and in this way soil temperature is reduced that suppress the pathogen activity. They also harvest premature crop and sell in the market to use its pods as vegetable.

Aphids and whiteflies transmit potato virus X and Y on this crop. To get virus-free material of potato crop in Pakistan, the government is producing seed material in the hilly areas (Gilgit and northern areas) where the population of insect vector is minimal. In this way, government is able to supply disease-free propagating material to the farmers. After harvesting, destruction of diseased crop debris by burring with the help of furrow turning plough reduces the population of the pathogen.

Potato crop was affected seriously by virus X and Y in Kalam area of Swat valley. This problem was solved by crop rotation with radish and turnip.

Pruning in fruit crops particularly pome/stone fruits is effective for the control of dieback, twig blights and cankers.

Earthing up of fruit tree trunks can reduce the soil borne diseases. Burning of diseased leaves, shoots and twigs after defoliation and pruning is very effective for the control of diseases. Use of raised buds for plantation of vegetables/fruits and mulching/soil solarization is used effectively for the control of soil-borne diseases.

The biological control of soil-borne diseases is obtained by application of tricho-pak and aspergo-pak.

GOVERNMENT POLICIES ON USE OF NONPESTICIDE METHODS

Pakistan is importing every year pesticides of worth Rs.12 billion. Much foreign exchange can be saved by reducing the importing of pesticides by encouraging the use of nonpesticide methods of pest control. The government is providing funds through its various functionaries to research institutions of the country for developing insect pest management strategies. Some legislative control measures already exist in the country. These include:

* the Punjab Destructive Insect Pests, Diseases and Weeds Control act of 1959.
* the Sindh Bollworm Act of 1947 to control bollworms.
* the NWFP Sugarcane Pyrilla Act of 1950 to control sugarcane leafhopper.
* the West Pakistan Agricultural Pests Ordinance of 1959 for controlling all serious pests of major crops.

The purpose of this legislation is to control the pests with cultural methods, e.g., removal of crop stubbles like sugarcane, maize, cotton and rice, etc. to kill the hibernating larvae and to suppress the pest population in the next season. Moreover, the farmers are not allowed to sow rice nurseries before 20 May and transplant them after 7 of August.

ISSUES AND PROBLEM IN USING NONPESTICIDE METHODS

Issues

1. Crop losses due to pests are high.
2. Extension services have promoted the use of pesticides as there are easy to apply and give immediate results.
3. The pesticide manufactures and their distributors have aggressive and effective campaigns and demonstrations of the efficacy of their products. The public or private sectors have done much less research on alternatives to pesticides.
4. The small farmers have little or no access to the technologies or services needed for IPM. They are also unable to afford them if are available in the market.
5. How to reduce crop losses while minimizing harmful side effects of pesticides to health and environment.
6. Biopesticides can reduce the need for future pesticides but these are not efficient and cheap as chemicals.

Problems

1. Application of pesticides is easy as compare to nonpesticide methods.
2. The farmers are not properly trained to apply IPM methods of control.
3. Farmers see the immediate gains from using pesticides and are using far greater volume of pesticides than necessary due to lack of education and proper training.
4. Nonpesticide methods are more laborious.
5. Nonpesticide methods are not as cheap as chemicals.

Suggestions for Enhancing Use of Nonpesticide Methods

1. The more realistic approach is to reduce pest losses to socially and economically acceptable levels.
2. There is a need to improve the management of pesticides use rather than to eliminate their use.
3. Government policies have to encourage and support moves toward ecological and management-based approaches like IPM.
4. Public sector have to play a much larger role in promoting IPM through research, development and provision of supporting services such as advice, credit and essential education.

5. IPM training programs are necessary for the farmers. There should be group training programs and frequent discussions among the farmers, field-based instructions, demonstrations and periodic follow-up by trainers for one or two reasons.
6. The government provide funds for development of biopesticides, which are target-specific and can reduce the necessity of pesticides.

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7. PHILIPPINES

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INTRODUCTION

Insect pests, diseases and weeds pose a major threat in crop production. Insects and diseases feed/infect on almost all plant parts (roots, stem, leaves, flowers/fruits) throughout its growth stages. On the other hand, weeds are always found associated with crops and they grow more vigorously than our crops. Losses due to these pests are considerably high and may result to complete crop loss when left uncontrolled.

Based on the 1996 National Crop Protection Center (NCPC) nationwide pest survey (NCPC, 1998a), the crop protection practices employed by Filipino farmers can be summarized in Table 1. The survey showed that about 70 percent of the farmers depend on the use of chemicals against pests (Figure 1). It is quite alarming that some farmers used pesticides that are restricted and banned including those that are not registered for use in crops as indicated in the label, use insecticides against diseases, and fungicides against insect pests. In addition, farmers use lower or higher dosage rates and applied more frequently than necessary. Majority of the pesticides are broadly toxic, therefore, they are ecologically disruptive when deliberately used. Realizing the serious problems that may arise from the continued reliance on the use of pesticides (development of resistance, spiraling cost, elimination of natural enemies and pollinators, toxicity hazards to man and domestic animals, contamination of soil water and food chain and general pollution of the environment) the recent trend nowadays is towards the use of nonpesticide methods (NPMs) of controlling pests.

Table 1. Summary of Nationwide Pest Survey of Farmers in 1996

Items	Particulars
Crops covered	Rice, corn, vegetables, mango, papaya, ornamentals
Crop protection practices	* Biological: natural enemies, ducks, botanicals, resistant varieties * Cultural/physical: thorough land preparations, synchronous planting, proper spacing, water management, fertilizer management, crop rotation, intercropping, bagging, trapping, use of attractants, detasseling, etc. * IPM: farmers understanding of IPM (combination of methods) * None: no measures employed against pests * Chemical: insecticides, herbicides, fungicide, rodenticides, molluscicides.

Source: NCPC, 1998a.

Based on the NCPC's survey, about 30 percent of the farmers are using NPMs of controlling pests. Specifically, about 23 percent used physical/cultural methods; 2 percent mentioned Integrated Pest Management (IPM); 1 percent used fertilizer to control diseases; and about 4 percent did nothing to protect their crops from pest damage. Fortunately, with the implementation of IPM/Farmer Field Schools (FFS), majority of the farmers had significantly reduced the frequency of insecticide application by one-third since they applied insecticides only when necessary. This suggests that with proper guidance and education, there is a great possibility to convince farmers to practice NPMs for controlling pests.

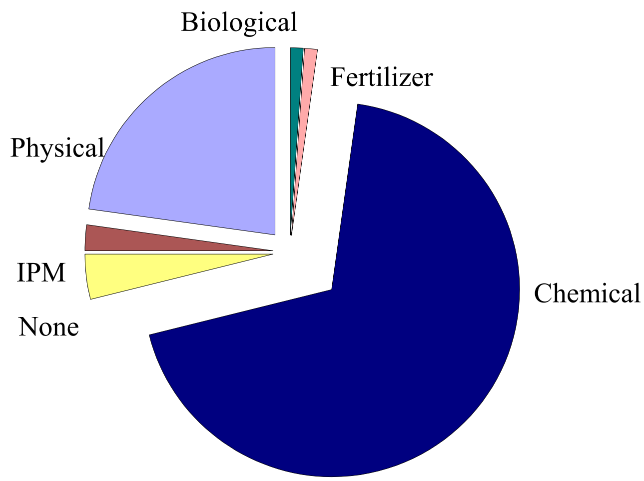

Figure 1. Farmers' Crop Protection Options

Source: NCPC, 1998a.

This paper highlights some of the NPMs that are being successfully employed in various crop production systems including the promising NPMs used in the management of pests in the Philippines.

NONPESTICIDE METHODS FOR CONTROLLING INSECT PESTS

Discussions on the NPMs for controlling insect pests are focused on rice, corn, cabbage and mango. In general, the use of single method of control is ineffective against insect pests hence, farmers are employing a combination of methods.

Rice, in general, is the most important and dominant agricultural commodity in the Philippines because it is the staple food of over 80 percent Filipinos. In 1999, area planted to rice had a total of 4 million ha with a total production of 9 million mt and a 1998 value of PhP (Philippine peso) 69.1 billion (National Statistics Office [NSO], 2001).

Among the NPMs for controlling rice insect pests, a combination of the following are generally employed by majority of Filipino farmers:

1. ***Use of Recommended Varieties Recommended***

In some parts of the country, the Department of Agriculture is encouraging farmers to use new varieties through their program on "plant now pay later" or by subsidizing half the price of rice seeds.

2. ***Conservation of Existing Beneficial Arthropods***

Rice agro-ecosystem in the Philippines had the richest communities of beneficial insects due to long history of rice culture. Barrion (2000) listed a total of 1,522 taxa belonging to 839 genera under 269 families in 23 orders. All the Philippine rice invertebrates belong to four functional guilds: 46.06 percent are predators; 32.00 percent herbivores; 16.82 percent parasitoids; and 5.12 scavengers/tourists. There is a wide array of natural enemies that has been identified (Shepard, *et al*., 1987) and proven to regulate insect pest population in rice agro-ecosystem. In fact, it was estimated that more than 75 percent of the rice fields in the Philippines do not need insecticide sprays. Therefore, the major IPM strategy being employed against major rice insect pests is the conservation of existing beneficial arthropods. In addition, the judicious use of synthetic insecticides minimized the disruptive effect to the possible establishment of natural enemies in the field. Studies showed that the field releases of *Trichogramma japonicum* Ashmead (Hymenoptera: Trichogrammatidae) and the action of existing natural enemies are highly effective in regulating the populations of green leafhoppers, *Nephotettix virescens* (Distant) and *N. nigropictus* (Stål) (Homoptera: Cicadellidae); brown plant hoppers, *Nilaparvata lugens* Stål (Homoptera:Delphacidae); yellow stem borers, *Scirpophaga incertulas* (Walker) (Lepidoptera:Pyralidae) and rice bug, *Leptocorisa oratorius* (Fab.) (Hemiptera:Alydidae). The rice black bug, *Scotinophara coarctata* (Fab.) is the newest introduced insect pest of rice in the Philippines. It was first recorded in Palawan (isolated island in Luzon) in 1979 from Sabah. The insect was recorded in Zamboanga in 1992 then continuously spread throughout Mindanao. Recently, the pest is causing heavy damage in the provinces of Negros and Bohol in the Visayas (Santiago, 2000). To date the insect can be controlled by an egg parasitoid *Telenomus triptus* (Nixon) and by an insect pathogenic fungus *Metarhizium anisopliae* (Metsch.) *M. anisopliae* can be successfully mass produced at a very low cost; the spores can be harvested efficiently and formulated as wettable powder or suspension able oil preparation (Santiago and Gabriel, 1998).

3. ***Synchronized Planting***

Farmers are aware that synchronized planting could significantly contribute in lowering pest population. However, synchronized planting is impractical when water and labor supply is limited.

Light trapping is primarily employed against black bug which is strongly attracted to white lights during full moon. Light trapping and collection of adults are done three nights before and up to three nights after the full moon (Santiago, 2000).

Majority of rice farmers have undergone training at FFSs, a season-long (16 weeks) participatory and discovery-based learning process where they meet weekly from planting until harvest. A group of 25-30 farmers worked as a group, perform agro-ecosystem analysis, team building activities and they are taught on how to conserve existing natural enemies to suppress pest populations. FFS is designed to develop farmer’s ability to make critical and informed decisions that make crop production systems more productive, profitable and sustainable.

The yield of rice farmers who attended the FFS was compared with existing farmers’ practices based on 10 sites. Rice yield increased by 4.7 percent in Cauayan, Isabela and as much as 62 percent in Urdaneta, Pangasinan. The pesticide usage which constitute as much as 15 percent of the total production cost among farmers who had not yet undergone training on IPM had almost been totally eliminated after farmers had attended the FFS.

Corn (*Zea mays* L.) is the second most important crop in rice-deficit areas of the Philippines. White corn varieties served as staple food for 20 percent of the Filipino population while yellow corn is a major component of feeds for livestock and poultry industry as well as source of raw materials for many industrial products (Module, 2001-01). In 1999, corn is cultivated to an area of 2.64 million ha (a 12-percent increase from 2.35 million ha in 1998), with a total production that reached 4.6 million mt (20 percent higher than in 1998). In 1998, the value of corn production was PhP22.8 billion (NSO, 2001).

Studies in corn is primarily directed against the Asian corn borer (ACB), *Ostrinia furnacalis* (Guenée) (Lepidoptera:Pyralidae), the most destructive insect pest of corn in the Philippines and Asia, in general. ACB was found to reduce corn yield by as much as 20-80 percent (Sanchez, 1971; Gabriel, 1971; and Morallo-Rejesus, *et al*., 1982a and b). Basic studies on the biology, ecology, yield loss assessment and on component control tactics which are the prerequisites for the development of rational and sound pest management strategies had already been conducted in corn. The best nonpesticide management practices against ACB includes the following:

1. ***Early Planting***

In this method, the most susceptible stage of the plant to ACB attack does not coincide with the population peak of the pest. Aside from reduction in the amount of insecticides to apply, the effects on the beneficial arthropods are minimized. Experiments conducted in Nueva Vizcaya (Luzon) and Bukidnon (Mindanao) indicated that higher larval population and yield reduction were observed during the late planting (Morallo-Rejesus, *et al*., 1982a and b). However, specific planting dates cannot be recommended since the availability of rainwater differs with locations and with time.

2. ***Biological Control***

Numerous studies have demonstrated the richness of beneficial arthropods attacking insect pests in corn agro-ecosystem. The dominant natural enemies of ACB include *Trichogramma evanescens* (Westwood);

earwigs, *Euborellia annulata* (Fab.) (Dermaptera:Anisolabididae); flower bug, *Orius tantillus* (Motschulsky); spiders; coccinellid beetles, *Menochilus sexmaculatus* Fab. and *Micraspis crocea* (Mulsant) (Coleoptera: Coccinellidae); and lacewing, *Chrysopa* sp. (Neuroptera:Chrysopidae). The effectiveness of the first three species had already been proven, hence if the use of these BCAs will be aggressively pursued, the disruptive effects of pesticides could be avoided and balance between pest and natural enemy complex can be preserved.

There are indications that the presence of wild vegetations around the cornfield could be practical and even necessary in managing insect pests by biological control. It was found that the population of *Orius* and spiders can be enhanced by establishment of spiny amaranth (*Amaranthus spinosus*), a weed species commonly found in cornfields. The population of *Orius* and spiders was considerably higher when *Amaranthus* was planted within and around the corn plants than when corn was planted alone (Javier and Morallo-Rejesus, 2001). A good stand of *Amaranthus* at flowering stage could harbor an average of about 150 *Orius* which is sufficiently high to reduce ACB population. Based on the results at University of the Philippines Los Baños (UPLB), the spiders and *Orius* colonized the cornfield at about 33 and 40 days after planting (DAP), respectively. Peak of *Orius* population was noted at 61-70 DAP which coincide with tasseling stage. At this stage majority of *Orius* transferred to corn tassels but still a greater number of the predator prefer to stay in *Amaranthus*. Therefore, it may be more practical to cut the *Amaranthus* at tasseling stage to force the predator to transfer to corn. *A. spinosus* should be planted along the borders to ensure the continuous presence of *Orius* and spiders.

Another method of conserving natural enemy population is through staggered planting or the successive planting of corn which provide continuity of corn borer and its natural enemies primarily *Trichogramma, Orius* and earwigs. The overlap between plantings ensure that pests and natural enemies can transfer from the crop being harvested to the succeeding plantings.

Minimum tillage or conservation tillage is now becoming popular to corn farmers especially in Mindanao. The practice involves planting of corn without land preparation. In here, weeds are controlled through the use of broad spectrum herbicide which was found to be non-toxic to the earwig (Javier and Morallo-Rejesus, 2001). When the weeds are already controlled, corn seeds are usually planted in furrows or by making holes. Since herbicide is combined with minimum tillage, this strategy cannot be considered an NPM. However, this practice is highly favorable in conserving the *Euborellia* population because it is primarily a soil inhabiting predator. In order to document the effect of land preparation on the predator population, the number of *Euborellia* was determined in a newly-harvested cornfield heavily infested with ACB but without previous insecticide treatment and release of earwigs. Likewise, the population of earwig in the same area was determined after the field had been prepared for the next planting. On per hectare basis, about 124,400 earwigs were collected in the field with 119,424 earwigs found in the soil (96 percent) while about 4,976 were found inside the corn stalks (4 percent). Forty-six percent of the population (57,224) was in the adult stage while 54 percent (67,176) were nymphs. The total population of earwigs at harvest was about 12 times higher than the recommended population of earwigs (10,000 individuals) for release against ACB. After the field had been prepared for the next planting, the earwig population was remarkably reduced by as much as 98 percent (2,667 left). It is highly possible that majority of the earwigs were killed during the land preparation while others might have transferred to the nearby moist area. Obviously, minimum tillage will reduce the harm inflicted to this effective soil-inhabiting predator of ACB (Javier, 1989).

The detasseling technique which is the mechanical removal of tassels from the corn plants proved to be effective and economical in controlling ACB (Morallo-Rejesus and Javier, 1985). The removal of 75 percent tassels immediately after tassel emergence eliminates about 40-50 percent of corn borer larval population. Klitsaneephaiboon (1983) and Sumangil (1984) reported similar findings. Aside from reducing the amount of insecticides at tasseling stage, detasseling also reduces the possible hazards to human beings and beneficial arthropods.

In crucifers particularly cabbage, broccoli, pechay, cauliflower, radish, kale and mustard, the diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera:Yponeumatidae) is the most destructive insect pest. The larva of the insect feeds on the foliage from seedling stage to harvest and could decrease yield by as high as 100 percent if left uncontrolled. Dependence on the use of synthetic insecticides has been the salient feature of crucifer production in the Philippines. Cardona (1992) reported that 100 percent of the farmers interviewed in Atok, Benguet, a crucifer growing area in Luzon, are wholly dependent on the use of chemical pesticides in controlling DBM. Farmers usually practiced 12 insecticidal sprayings per cropping but could go as high as 32 times during the dry season. Mixtures of two or more insecticides ("cocktails") and high dosages are applied more frequently to control DBM. These insecticides are applied based on calendar basis, irrespective of DBM population. Sometimes, insecticides are used up to harvest primarily to preserve the cosmetic value of the crop (Magallona, 1986).

The IPM technology can effectively suppress DBM population and maintain them below damaging levels. The IPM for DBM especially in the lowland involves the field releases of parasitoids supplemented with spraying of microbial insecticides based on an arbitrary action level. The action level from seedling up to mid-vegetative stage is two larvae per plant while five larvae per plant from pre-heading stage until the crop is ready for harvest. The parasitoids *Cotesia plutellae* Kurdj. (Hymenoptera:Braconidae) and *Diadegma semiclausum* Hellen (Hymenoptera:Icneumonidae) which are both imported from Taiwan in collaboration with the Asian Vegetable Research and Development Center (AVRDC), are the natural enemies capable of regulating DBM population. *Cotesia* prefers to parasitize the second instar larva of DBM and sustains therein new eggs of *Cotesia*. It is more effective in low or mid-elevations less than 800 m above sea level, with temperature above 25ºC. On the other hand, *Diadegma* can parasitize all larval instars of DBM, but prefers the second larval instar. More cocoons emerge when parasitism takes place at the second instar larva. *Diadegma* is suited to cool, high elevations more than 800 m above sea level, with temperature lower than 24ºC. There is no doubt regarding the effectiveness of *D. semiclausum* in regulating DBM population. Since insecticide application was significantly reduced, there was a secondary pest outbreak like the cabbage moth, *Crocidolomia binotalis* (Zeller) (Lepidoptera:Noctuidae); common cutworm, *Spodoptera litura* (Fab.) (Lepidoptera:Noctuidae); and aphids, *Myzus percicae* Sulzer (Homoptera:Aphididae) which caused much more serious damage than DBM. This points to the need of a holistic approach in developing biological control against several insect pests.

The efficiency of net covering as an alternative strategy in controlling lepidopterous pests in cauliflower was conducted in Cagayan de Oro, Northern Mindanao. Insect pest damage, curd size and profit were almost similar for cauliflower grown under net covering with releases of *Trichogramma chilonis* and those plants treated with conventional insecticide. In Cavite (Southern Luzon), a farmer is successfully producing organically grown vegetables (without insecticide treatments) under net covering. Profit is considerably high because his produce is being sold at relatively high price in five-star hotels in Metro Manila.

The benefits farmers derived from IPM in crucifers include 75 percent increase in yield and income, 41 percent reduction in cost of production, 86 percent reduction in pesticide application and greatly minimize the hazards to human health posed by pesticide residue on vegetables and the environment.

The major insect pests attacking mango includes the mango leafhopper, *Idioscopus clypealis* (Lithierry) (Homoptera:Cicadellidae); tip borer, *Chlumetia transversa* (Walker) (Lepidoptera:Noctuidae); fruit fly, *Bactrocera philippinensis* and *B. occipitalis* (Bezzi) (Diptera:Tephritidae); cecid fly, *Procantarinia* sp. and mango seed borer, *Noorda albizonalis* Hampson (Lepidoptera:Pyralidae).

NONPESTICIDE METHODS FOR CONTROLLING PLANT DISEASES

Rice Hull Burning (RHB)

In the rice-vegetable farming system in Nueva Ecija, Central Luzon, Philippines, where onion is planted extensively after a rice crop, the most important soil-borne diseases of onion are pink root caused by *Phoma terrestris* Hansen (*Pyrenochaeta terrestris*) and bulb and root rot caused by *Fusarium* spp., *Sclerotium cepivorum* Berk. and *Rhizoctonia solani* (Kuhn.) The rice root knot nematode, *Meloidogyne graminicola*, is also very serious to both rice, onion and garlic.

RHB is a traditional cultural practice of many onion growers in Nueva Ecija, mainly for weed control and was found to increase yield (Gergon, *et al*., 2000). This is done by placing about 15-30 cm rice hull throughout the field and burned them. The resulting carbonized rice hull is incorporated into the soil during land preparation for the onion crop.

For the past three years, a group of researchers involved in the IPM Collaborative Research Support Program (CRSP) evaluated the effects of RHB on the severity of pink root disease. The burning of 15 cm thick rice hull was sufficient to generate heat up to 30 cm depth which also reduced significantly the population of *M. graminicola* in the field (Gergon, *et al*., 2000).

However, the problems associated with RHB are: 1) both beneficial (antagonists, nitrogen fixers, etc.) and deleterious (pathogens, insect pests, weeds) organisms are destroyed that would eventually affect the biodiversity in the area; 2) reduction of soil organic matter; and 3) aggravation of global warming due to increased emission of carbon dioxide into the atmosphere.

Crop Rotation

A three-year rotation scheme was evaluated by the same group of researchers (IPM CRSP) in a demonstration field in Bongabon, Nueva Ecija to determine their effects on the incidence and severity of pink root and *M. graminicola* population. Out of the four crop rotation schemes evaluated, the onion-pepper-rice-onion-peanut-rice rotation sequence significantly suppressed pink root incidence but did not reduce *M. graminicola* population. It was observed that the nematode population remained low in poor host crops such as peanut, mungbean, cucumber and pepper but increased rapidly (within a month) when the preferred host crops (rice and onion) were grown.

Biological Control

The use of BCAs to control important plant diseases in the Philippines was reviewed extensively by Davide (1990). Most of the studies were preliminary in scope and were done under laboratory and greenhouse conditions. Few were evaluated under field conditions but have not progressed beyond pilot testing. Most of the studies were concentrated on *Trichoderma* species and bacterial antagonists.

In an experiment conducted in microplots artificially infested with *Sclerotium rolfsii* Sacc. (80.7 percent incidence), *Trichoderma viride* Pers. was found effective in controlling damping-off of mung bean when applied as seed coating at the rate of 10^9 spores per ml with control efficiency of 38 percent relative to the untreated plants (Maramara and Paningbatan, 1993). It was better than benomyl and maneb with control efficiency of only 12 and 15 percent, respectively.

An unidentified species of *Trichoderma* was also found effective against stem rot of sweet pepper caused by *Sclerotium rolfsii* when applied both as seed treatment and seedling dip (Paningbatan, 1994). The biological control efficacy of 10^9 conidia per ml of this antagonist was about 81 and 76 percent relative to the untreated check when applied as seed treatment and seedling dip, respectively. This is 2-3 times more effective than maneb applied at the rate of 1.5 g a.i. per liter.

Moreno and Paningbatan (1995) evaluated the efficacy of *T. viride* to control mango stem end-rot caused by *Diplodia natalensis* Pole Evans [*Lasiodiplodia theobromae* (Pat.) Griff and Maub]. They applied different concentrations of *T. viride* spores onto newly harvested mango fruits. When the fruits have dried they applied about 500 spores of *D. natalensis* to the exposed pedicel and evaluated disease incidence and severity for eight days. They found that 10^7 spores per ml was comparable to the effect of 600 ppm benomyl. Increasing the spore concentration to 10^8 per ml almost doubled its effectiveness in reducing disease incidence. However, *T. viride* is effective only as a protectant. Complete protection was attained when the inoculum level was 15,000 conidia per ml or less. When the inoculum level was increased to 30,000 conidia per ml, 95 percent reduction in stem end-rot was still attained using 10^8 conidia per ml of *T. viride*.

Efforts toward enhancement of growth, survival and competitiveness of *Trichoderma* spp. in natural soil were made by Cumagun and Ilag (1997). Since *Trichoderma harzianum* Rifai was reported to produce chitinases when grown in a medium supplemented with chitin, they selected an isolate with the highest cellulolysis adequacy index (CAI) and competitive saprophytic ability (CSA) for the study. In laboratory assay, they found that addition of 5 g ground crab shell (as a source of chitin) into a 95-ml coconut water medium enhanced the biological control activity of *T. harzianum* isolate 94-016 as shown by the 56.7-percent growth inhibition of *R. solani* compared with only 19.3 percent growth inhibition in the absence of chitin in the medium. This was confirmed by the results in greenhouse tests, where chitin from the ground crab shells was added at the rate of 5 g/kg soil and used in the formulation of *T. harzianum* conidia into pellets and granules. The pelletized and granule formulations with chitin, applied simultaneously with the pathogen (*R. solani*) were effective in reducing sheath blight infection as measured by the percent real area infected (percent RAI).

The efficacy of a combination of two species of *Trichoderma* (*T. parceramosum* and *T. pseudokoningii*) in controlling pechay damping-off and rice seedling blight caused by *R. solani* was evaluated by Cuevas, *et al*. (2001). The test was conducted in seedbeds which had previously been abandoned due to severe rice seedling blight. *Trichoderma* was as effective as propamocarb hydrochloride in controlling pre-emergence damping-off of *Brassica chinensis* (pechay) but only *Trichoderma* was effective in controlling post-emergence damping-off and seedling blight in rice grown after *B. chinensis*. It was most effective when seeded twice (two weeks and one week before sowing) at the rate of 30 g carrier rice bran pellets of mixed culture of the two species per m^2 of seedbed as shown by the relatively higher percent seed germination and percent seedling survival. The decrease in disease incidence was due to a decrease in percent survival of sclerotial bodies after three successive croppings of *B. chinensis*.

During the 1994 dry season, International Rice Research Institute (IRRI) researchers evaluated the role of two BCAs, *Pseudomonas cepacia* and *P. putida* and their combination, in regulating epidemiological parameters of sheath blight and disease development. The BCAs were applied either as seed treatment or spray at different stages of crop growth. Spread of sheath blight from the initial point was measured weekly to assess BCA suppression of the disease.

All BCA-treated plots showed suppression of sheath blight spread. The effect of BCA on disease suppression at different crop growth stages ranged from 11.4 to 46.1 percent at panicle initiation, 0.2-43.2 percent at flowering and 0.3-17.3 percent at harvest. Plots treated with the mixture of BCA had the lowest sheath blight severity and significantly higher yield than the control. Generally, disease spread in all plots treated with BCA was lower than in check plots where no BCA was applied. The results suggest the importance of seed bacterization and BCA augmentation by spraying at the right time. It was also evident that strains vary in suppressing disease spread (IRRI, 1994).

Ultraviolet Irradiation

Mortuza and Ilag (1997) evaluated the efficacy of UV irradiation as a possible alternative to chemical fungicides in suppressing postharvest rot of banana due to *Lasiodiplodia theobromae*. They found that exposing conidia of *L. theobromae* to UV light (254 nm wavelength) for 15 minutes inhibited the germination of one-celled conidia only. The two-celled conidia were unaffected even if the exposure time was extended to 30 minutes.

Banana fruits of ripening grade 5 were used to test the effect of UV light on disease development. The fruits were cleaned and wounded (two pinpricks) before inoculating with 5 ml spore suspension of *L. theobromae* (2,500 conidia/ml). After 24 hours of incubation the inoculated fruits were exposed to UV light for different duration ranging from 2.5 to 15 minutes. Control fruits were not irradiated. Irradiated fruits were stored in the dark for 24 hours. Lesion size or rotten tissue was measured after two, three and four days of incubation.

The most effective duration of exposure to UV irradiation was found to be 10 minutes as shown by the smallest lesions on the fruits after two, three, and four days of incubation. The effectiveness of UV irradiation was affected by inoculum level of the pathogen and the timing of the UV light treatment relative to inoculation. The treatment was most effective when the fruits were irradiated 12 hours after inoculation and at inoculum level of 1,000 conidia per ml.

Montuza and Ilag (1997) summarized the advantages of using UV light for the control of postharvest diseases of fruits and vegetables as follows: 1) non-radioactive and no accumulation of chemical residues; 2) easier and safer to operate than ionizing radiation such as gamma rays; and 3) known to induce production of phytoalexins in some fruits and vegetables (induced resistance). However, one of the serious problems encountered in the study was the bronzing of banana fruits after prolonged exposure to UV light. Procedural refinements and a more detailed study must be undertaken to solve this problem.

NONPESTICIDE METHODS FOR CONTROLLING WEEDS

Preventive Methods

These pertain to all practices presently used to avoid weeds and its dispersal as well as the build-up of vegetative propagules and weed seed reserves in the soil. Examples of preventive methods include the following: a) use of certified/good seeds; b) use of wire mesh in irrigation inlets; c) maintenance of clean fields, borders, levees and irrigation canals in and out of growing season; and d) removal of long pedicelled-weed inflorescences during the reproductive phase and fallow period.

Cultural Methods

1. ***Good Land Preparation***

This agronomic practice when done thoroughly is a basic weed control strategy in any crop husbandry. In rice production, the thoroughness of land preparation provide greater competitiveness for transplanted rice and a way to provide a head start to direct-seeded rice. Irrigated lowland rice culture is composed of plowing, harrowing (until puddled), rotavation and leveling. In upland rice system, however, puddling is absent. The frequency to perform these operations depends on the type and condition of soil, the presence of weeds and crop residues and the farmers' resources. Deep plowing (15 cm in irrigated lowland and 20-25 cm in upland) allows furrow slice to cover weeds and crop residues left from the previous crop or fallow period. On the other hand, harrowing (2-4 times) destroys weeds not killed by plowing, incorporate them and the crop residues into the lower layers of the mud where they are decomposed, bury weed seeds/vegetative propagules at a depth that prevents germination though germination of weed flush is also allowed in between harrowing when buried seeds are in turn exposed, hasten establishment and tillering of rice for an enhanced growth and competitive ability against weeds. Puddling provides a good seedbed for direct-seeded rice. Leveling the field thoroughly facilitates the control of succeeding weed growth by flooding.

2. ***Closer Crop Spacing/High Seeding Rate***

Transplanted seedlings at 20 x 20 cm, 15 x 20 cm or 10 x 15 cm gives transplanted rice a competitive advantage over the weeds in the use of sunlight through adequate canopy formation. For the same reason, high seeding rate in direct-seeded rice (100-400 kg/ha) is practiced in the Philippines.

3. ***Good Water Management***

Water is essential for optimum crop production. Flooding during the early growth stages (not later than five days after transplanting) at a level of 2-3 cm with corresponding increases (15-20 cm) as the crop develops has a major suppressive effect on emergence, stand establishment, growth and development of weeds; greatly reducing the biomass of grasses. A delay in flooding has less suppressive effect on weeds and deeper flooding is needed to check their growth. Lack of proper water management in transplanted rice increases the need for labor to do hand – or mechanical weeding (Pablico and Moody, 1993). Flooding in pre-germinated, direct-seeded rice, on the other hand, is started by Filipino farmers at six days after seeding (DAS) for optimum rice germination and seedling establishment. When flooded at different length of time from six DAS, Pablico and Moody (1993) found significant reduction in rice seedling stand compared to the saturated check plot. The crop, however, recovered from the initial effect of flooding and at harvest tiller production was similar to that of the saturated check plot. The different flooding duration at six DAS did not reduce weed growth compared with continuous saturated check plot.

4. ***Use of Vigorous Growing Varieties***

Use of varieties released by Philippine Seed Board for irrigated lowland as well as upland rice are recommended for various rice-growing environments in the country because the crop is the most important agent of weed control. Tall, fast and vigorous early vegetative growth, drooping leaves that form canopy, vigorous root system for water and nutrient absorption and high tillering ability are the traits that give rice an advantage when competing with weeds.

5. ***Good Agronomic Practices***

Fertilizer management is critical because fertilizer application may not increase yields in weedy fields for reason that weeds absorb nitrogen more efficiently than rice. For transplanted and direct-seeded rice, split application increases the efficiency of plant's use and the recommendation is to apply part of the needed nitrogen as basal fertilizer which is best just before the final harrowing not only to allow thorough incorporation of the fertilizer with the soil but also to ensure that no weeds are yet established in the field. The second application is recommended just before the reproductive stage (5-7 days before panicle initiation) as top dress fertilizer. Weeds must be removed before topdressing to ensure maximum fertilizer utilization by the crop. In upland rice, Moody (1996) noted that nitrogen application need not be given when the upland rice is small because they neither require nor can use much nitrogen. It should be delayed until the weeds have been removed.

6. ***Crop Rotation***

In some areas, irrigated lowland rice is grown in the wet season (June-November) and upland crops (vegetables or legumes) in the dry season (December-May). By this practice, aquatic weeds that thrive in flooded rice are dried out and killed during the dry season while upland weeds are submerged and killed when flooded rice is grown the following season. This rotation system decreased populations of *Scirpus maritimus* L., an aquatic weed that thrives in flooded rice in the Philippines (De Datta and Baltazar, 1996). Intercropping upland rice with cowpea [*Vigna unguiculata* (L.) Walp] had less weed growth compared to upland rice grown alone due to canopy formation of cowpea.

Physical/Mechanical Methods

1. ***Hand-weeding***

Hand pulling is the traditional direct weed control method in Philippine crop production. Its advantage over other direct weed control methods is that it can remove even those weeds close to the crop hills that are not removed by mechanical weeding/inter-row cultivation (IRC) or those that escape herbicide treatment. In small-sized fields of the country, it remains practical and cost-effective when family labor is available or hired labor is cheaper than herbicides. It is laborious and time-consuming but can be performed only once in transplanted lowland rice when done at the right time within the critical period of rice-weed competition (21-40 days after transplanting). The number of weeding increases when soil is poorly prepared and when water is limiting. Hand-weeding is impractical in broadcast-seeded rice because it is tedious and cause damage by trampling the crop.

2. ***Mechanical Weeding/Inter-row Cultivation***

This use of push-type rotary weeders is recommended in transplanted rice when rice is planted in straight rows at a distance of 20 x 20 cm. This is chosen by farmers when family labor is wanting or hired labor for hand-weeding is more expensive. It is better than hand-weeding in terms of manpower requirement but does not remove weeds close to the rice hills. Additional spot hand-weeding, may be necessary to remove these weeds that can still cause marked yield reductions. In drill-seeded upland rice systems in the Philippines (Batangas), spike-toothed harrow (*kalmot*) is passed diagonally across the rows from 10 to 20 day after emergence (DAE). This is followed by one or two IRCs with a wooden furrower (*lithao*). These operations uproot weeds, and bury them or disturbs their roots causing them to die or be greatly weakened. Consequent crop injury and mortality are countered by using high seeding rates. Survivor weeds are often removed manually using a native trowel (*dulos*).

Biological Control

Biological weed control is the deliberate use of natural enemies (plant-feeding and disease-causing organisms) to suppress the growth or reduce the population of a weed species. Biological control methods include the classical approach (inoculative), the inundative approach (bioherbicide, augmentation) and the herbivore management (Watson, 1994). In the Philippines, biological weed control method is relatively a new approach.

1. ***Classical Approach (Inoculative)***

An aquatic weed of rice, *Salvinia molesta* Mitchell, is the main focus of the biological weed program in the Southeast Asia. This free-floating water fern is confined to the islands of Negros, Guimaras and Panay in the Visayas and is successfully controlled with a weevil, *Cyrtobagus salviniae* Calder & Sands (Coleoptera:Curculionidae). The insect was released in Panay Island, particularly Passi, Iloilo, in 1989 and is already well established in the release site (Watson, 1994).

2. ***Inundative Approach (Bioherbicide)***

This approach is in its infancy in the Philippines, but the prospects are very encouraging (Watson, 1994). A research program was initiated by IRRI in collaboration with McGill University in Canada, and the involvement of the NCPC, UPLB to evaluate the possibility of utilizing indigenous fungal plant pathogens for the control of nine major weeds of rice: *Cyperus difformis* L. (small umbrella sedge), *C. iria* L. (rice flats edge), *C. rotundus*, *Echinochloa colona* (L.) Link. (jungle rice), *E. crus-galli* (L.) Beauv. (barnyard grass), *Fimbristylis miliacea* (L.) Vahl (globe fingerush), *Mimosa invisa* Mart. (mimosa), *Monochoria vaginalis* (Burm) F. Kunth (Monochoria), and *Sphenochlea zeylanica* (L.) Gaertn (goose weed). Virulent pathogens, most with good bioherbicide potential, have been isolated from all target species. Field trials conducted at IRRI, resulted in a 100-percent mortality of *S. zeylanica*, an irrigated, lowland broadleaf weed species caused by a leaf blight pathogen, *Alternaria* sp. (Bayot, *et al*., 1992).

3. ***Use of Azolla***

Azolla, another free-floating water fern, is known for its nitrogen fixing ability through a symbiotic relationship with *Anabaena azollae* Strasburger. In the PhilRice Rice Production Manual, azolla production and utilization is not mentioned in relation to weed management but as an organic fertilizer material recommended to significantly reduce expenses for fertilizer. However, studies at IRRI suggested its role as a weed suppressant in lowland rice culture. It was found that: a) rice yield from azolla-inoculated plots was similar with the hand-weeded plots (one or two hand-weeding) plots and significantly higher than the unweeded plots; b) consistently higher yields and lower weed weights were recorded when azolla was inoculated, there was an inverse relationship between grain yield and weed weight ($y = 3.39-0.01x$, $r = -0.84^{**}$); and c) weed growth was significantly reduced when azolla was inoculated up to seven days after transplanting. Later inoculation did not reduce weed growth significantly.

4. ***Allelopathy***

Allelopathy is any process involving secondary metabolites produced by plants, microorganisms, viruses and fungi that influences the growth and development of agricultural or biological systems (excluding animals) (Narwal, 1999; and Romeo, 2000). The use of this phenomenon to control weeds in food crops could contribute towards increasing yields in sustainable agricultural systems. In the Philippines, research studies on allelopathy in rice were initiated by IRRI. At IRRI rice fields, experiments were conducted in 1995 to assess plant interference potential against *E. crus-galli*. Dry season results showed that out of 111 rice cultivars, 11 cultivars suppressed weed growth by more than 50 percent and 20 cultivars by 40-50 percent. In wet season trial, 21 cultivars suppressed weed growth by more than 50 percent, whereas 22 cultivars by 40-50 percent. Laboratory experiments (using relay seeding assay) showed that cultivars that are able to suppress this weed species in the field were also able to suppress growth in the laboratory suggesting that some rice cultivars have some allelopathic effect against *E. crus-galli* (Navarez and Olofsdotter, 1996; and Olofsdotter and Navarez, 1996). A workshop on allelopathy in rice was even held in the country, at IRRI, in 1996, where scientists around the world gathered to discuss their research (Olofsdotter, 1998).

Weeds are major constraints in corn production causing an estimated 60-percent yield reduction if the crop is left unweeded (Elliot and Moody, 1990). To obtain the best yields, cornfields must be weed-free during the first 4-5 weeks after planting. Weeds that grow after this critical period of competition no longer reduce yield significantly. Weed control has long been practiced by both small- and large-scale corn farmers and the method may be in the form of cultural method (land preparation), physical (hand-weeding)/ mechanical control (IRC, hoeing) or chemical control. Various combinations of cultural, physical/mechanical and chemical control methods have been tried and studied (Talatala-Sanico and Ranchez, 1990; and Elliot and Moody, 1990).

The *Corn Production in the Philippines* was published to facilitate the transfer of relevant technologies developed by various government and private agencies. The following are the NPMs of weed control enumerated in the manual.

1. ***Land Preparation***

Good land preparation provides soil conditions for crop growth and must be done well to give the crop a good start over the weeds. Conventional (full tillage) land preparation in corn production consists of two plowing and harrowing (Modules 2001-01 and -02). This is practiced in Claveria, Misamis Oriental in Northern Mindanao by majority of corn farmers though some farmers plow and harrow as many as four times. Location-specific research results (in this site) showed that increasing the number of plowing and harrowing during the dry season gave slight benefits in terms of reduced weeding time and increased crop yield (Elliot and Moody, 1990). In San Jose, Mindoro Occidental, the farmers' tillage practice to prepare the soil consists of 1-2 plowing and harrowing. In the on-farm trials of corn production after wetland rice, their tillage practice was compared and found inferior to two other tillage methods. The zero or no tillage, a practice of sowing crop seeds directly into the residue of the previous crop (without cultivation) gave the best yields followed by the conventional tillage. In zero tillage, a broad-spectrum herbicide is applied either before corn planting (3-4 weeks after rice harvest) when stubbles have new leaf growth, or a day after planting corn (Labios, *et al*., 2002).

2. ***Inter-row Cultivation***

This refers to the off-barring (shallow cultivation of soil away from the rows) and hilling-up (shallow cultivation which throws soil towards the base of the plants) operations practiced alone or in combination with hand-weeding and/or hand hoeing to make direct control of weeds easier. Off-barring is done 2-3 weeks after planting (14-21 DAP) to remove young weeds while hilling-up follows one week after off-barring (25-30 DAP) when the corn is knee-high. Hand tractor and animal-drawn double moldboard plow are the major sources of farm power to accomplish IRC. IRC does not control weeds within the row. These intra-row weeds are reportedly still capable of reducing yields by 22 and 46 percent in the dry and wet seasons, respectively (Elliot and Moody, 1990).

3. ***Hand-weeding and Hoeing***

These physical weed control methods are done solely or as a follow-up to off-barring and hilling-up operations to remove those weeds left within the rows. Hand-weeding and hoeing after IRC increase corn yield (Elliot and Moody, 1990). The use of hoe shortens the duration of hand-weeding (Elliot and Moody, 1990) and eases its backbreaking effect. NCPC (1998b) reported that hoe weeding 3-4 times (15, 30, 45, 60 DAE) provided high crop relative fresh weight, crop relative height and corn yield. Hand-weeding increases corn yield when field was plowed and harrowed two to three times (Elliot, *et al*., 1993).

4. ***Fertilizer Management***

High-yielding varieties (HYVs) require fertilizer for proper nutrition but weeds are more aggressive and responsive to nutrient application than corn. Large amount of fertilizer are wasted, if weeds are left unmanaged. During the dry season, all the fertilizers are generally applied at planting. However, if the field is irrigated, a second fertilization is done before hilling-up.

5. ***Crop Rotation***

Corn is in the category of soil-destructive crop. It is advantageous if legumes are included in the rotation to maintain soil fertility. Crop rotation also controls the growth of weeds in corn production.

The leading major vegetables in the Philippines based on the 1998 value of production (NSO, 2001) are sweet potato (PhP2.9 billion), onion (PhP1.9 billion), eggplant (PhP1.3 billion), tomato (PhP1.2 billion), cabbage (PhP1.1 billion), and garlic (PhP1.0 billion).

Villanueva (1990), in her review of vegetable production in the Philippines noted that yield losses due to uncontrolled weed growth in some vegetable crops in the Philippines had been estimated at 42-93 percent. To control weeds, land preparation, hand-weeding, hoeing, IRC and mulching are commonly practiced by the vegetable farmers.

6. ***Land Preparation***

The time, degree, and method of land preparation vary widely depending upon farmers' resources and capabilities. In onion, which is produced after rice in the Philippines during the dry season (like tomato and eggplant), land preparation is done by plowing and harrowing once or twice after rice hull burning when rice hull supply is abundant. When rice hull is unavailable, plowing and harrowing is done one to three times (Baltazar, *et al*., 2000).

7. ***Inter-row Cultivation***

Land preparation provides a weed-free start for the crop but inadequate for a season-long control. Off-barring and hilling-up using animal-drawn farm implement provides weed control during crop growth. IRC leaves weeds in the intra-rows and needs an immediate follow-up hand-weeding or hoeing to avoid consequent yield reduction.

8. ***Hand-weeding and Hoeing***

Hand-weeding or manual weeding (using trowels) alone is a common practice in home gardening type of vegetable production, in land with an area ranging from 15 to 50 m^2. This method is very effective in controlling annual weeds but requires much time and labor. In larger areas, hand-weeding or hoeing is done as follow-up operations to IRC. Hand-weeding also reinforces weed control in mulched farming. Hoeing is very effective and less harmful to vegetables planted in rows. Perennial weeds may be controlled by repeated hoeing to starve them of food reserves.

9. ***Mulching***

This cultural practice is a physical means of weed control. Mulching prevents light from reaching the ground and thus suppresses weed growth. Materials used as mulch include rice straw, rice hull, sugarcane bagasse, sawdust, paper and black plastic films. Except for the paper and plastic films, these materials are spread 2-3 inches thick on top of the soil around the vegetables. Mulches control weeds effectively, especially the annuals. Results on tomato showed that rice straw mulch followed by hand-weeding consistently provided adequate weed control and gave yields comparable to hoeing thrice (cited in Villanueva, 1990). Baltazar, *et al*. (2000) confirmed the weed growth suppressing ability of rice mulch even without application of herbicides or hand-weeding in onion grown after rice.

10. ***Rice Hull Burning***

Prior to onion transplanting in Nueva Ecija, Philippines, dry rice hull approximately 15-30 cm deep is laid in the field and seedbed and burned for 24-48 hours. The ash is plowed and incorporated into the soil and the field is harrowed one to two times. The field is then irrigated and seedlings are transplanted. This practice gave 64 percent increase in yield and 55 percent weed growth reduction in comparison with the unburned plots. However, because of the danger of fire spreading, rice hull farming is limited to farms far from roadsides or residential areas (Baltazar, *et al*., 2000).

GOVERNMENT POLICIES ON THE USE OF NONPESTICIDE METHOD

There are government policies which directly or indirectly promote the use of NPMs for controlling pests.

1. Establishment of the Philippine IPM Program in 1993: Biological control and ecological considerations are the program's main considerations.
2. Safety of pesticides: The Fertilizer and Pesticide Authority (FPA) controls the importation, transport, storage, labeling, use and disposal of pesticides.
3. The Agriculture and Fishery Modernization Act (AFMA) of 1997 have five major thrusts, namely; increased productivity, enhancement or saving biodiversity, minimizing environmental degradation, improvement of policies and strengthening of research and development.

ISSUES AND PROBLEMS IN USING NONPESTICIDE METHODS

Biological Control Agents

* In the Philippines, legislations restrict the entry of living organisms and regulate/oversee the implementation of biological control programs.
* The requirements for the importation of biological control agents (BCAs) are strict and very slow.
* Most known BCAs are specific to a single pest species, hence, not attractive to investors for commercialization. Crops are generally being attacked by several pest species, therefore, several species of natural enemies are needed to control these pests.
* Slow or delayed action of BCAs in comparison with the use of synthetic insecticides. Farmers always equate effectiveness of control agents to immediate death of the host.
* Lack of financial and technical support on biological control research.

Cultural Control

* Generally ineffective when used alone but when used in combination with other control tactics may produce convincing results.
* Usually laborious and time-consuming: With labor shortage and high cost of labor, cultural control method may at times be more expensive.
* Suited only for small-scale farming where family labor or hired labor is cheap.
* Flooding is recommended for weed control in lowland rice. However, this method favors multiplication and feeding by whorl maggot and golden apple snail.

* Synchronized planting could significantly contribute in lowering pest population. However, this could not be done when supply of water and labor are limiting.
* Closer plant spacing is recommended to inhibit weed growth but this recommendation favors rapid multiplication of insects and diseases.

Mechanical/Physical Control

* Detasseling technique is a very effective method of controlling corn borer. However, this is time-consuming and the height of corn is sometimes too high for detasseling.
* Net covering served as a barrier to the entry of insect pests. However, construction of these nets are too expensive to resource-poor farmers.

MEASURES FOR EFFECTIVE AND EFFICIENT USE OF NONPESTICIDE METHODS FOR CONTROLLING CROP PESTS

* Financial and technical support on researchers regarding the use of NPMs for controlling pests.
* Demonstrate/show to farmers the effectiveness of non-chemical methods of control and the benefits gained from growing pesticide-free crops.
* Give premium cost to crops grown without the use of synthetic insecticides.
* Subsidize the inputs (e.g., organic fertilizer, seeds, implements) in growing pesticide-free crops.

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8. SRI LANKA (1)

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INTRODUCTION

This paper will focus on the experience of a leading agribusiness company in Sri Lanka, namely; CIC Agribusinesses, in the field of nonpesticide methods of controlling pests and diseases in crop-based agriculture. CIC Agribusinesses is involved in the production of seeds and planting material, vegetables, fruits and cut flowers and operate four farms covering 1,000 ha. The subsidiary CIC fertilizers is the largest fertilizer producer in the country. CIC has exclusive agencies for agrochemicals from leading producers such as Syngenta, Dow Agro Services, Aventis, Nihon Niyoko, etc. in Sri Lanka and are also exclusive agents for Plastro Irrigation Systems, Israel and for Greenhouses, Polytunnels and Accessories for Rovero, Holland.

As a supplier of agrochemicals, it may seem paradoxical that we practice and even promote nonpesticide methods of controlling agricultural pests and diseases. The best response to this question I can give is that we as an agribusiness company would like to see the adoption of pest control methods that are effective, economical and environmentally acceptable. It is only through such an approach that farmers will be able to realize economic benefits and prove that agriculture is a sustainable and profitable industry. In Sri Lanka, we see that many farmers do not utilize their land resources maximally, due to the high cost of inputs. Pesticide costs can be 10-20 percent of the cost of production, depending on the crop. The cropping intensity for the major food crop rice is ca.70 percent. This situation is further aggravated when a scenario arises where a pesticide used is found to be ineffective and therefore, the whole cultivation exercise is negated, with considerable impact on the farmer's purse and his confidence. Such situations have arisen due to development of resistance to pesticides. Farmers in the main vegetable growing region in the central province of Sri Lanka often lament that no chemical is effective against leaf miners (*Liriomyza huidobrensis* Blanchard [Diptera:Agromyzidae]) and therefore, do not grow those vegetables which are affected by these insects. It is our experience that no chemical presently (legally) available in Sri Lanka is effective against red spider mites (*Tetranychus* sp.) on carnation. It is therefore, logical that we explore other solutions to such intractable problems.

AGRICULTURAL RESEARCH IN SRI LANKA

Agricultural research in Sri Lanka is conducted almost exclusively by State institutions. Institutes have been established for research on specific crops such as tea, rubber, coconut, export crops (mainly spices), etc. while research on other crops are the responsibility of the Department of Agriculture. Within the Department of Agriculture, several specific institutes have also been set up, such as the Institutes for Rice Research and for Horticultural Research. Nonpesticide methods of controlling pests and diseases have been investigated in the various State institutes for various crops and several effective methods have been identified and recommended. In the last two years, research activities have been initiated by the private sector as well and research and development (R&D) departments are increasing in several companies.

However, the legal infrastructure for several R&D activities is heavily weighted in favor of the State sector. A good example is in the field of biological control, where only the State institutes can introduce and study the effectiveness of biological control agents. There is no dispute that this is a necessary quarantine control, in the national interest of protection against introducing foreign insects that could become pests.

However, in recent years, resources in State institutes have become limiting and consequently, their basic research function too has been severely affected.

Therefore, in a situation where a biological control agent is available outside the country, it will be extremely difficult for a private company to introduce the control organism as the State research institutes will be poorly equipped to evaluate the organism. A solution to this problem may lie in a State institute-private company partnership, where the company pays for the evaluation which is carried out by the State institute. In practice, this marriage of convenience seldom works, because State institutes do not work at the pace required by private companies.

NONPESTICIDE METHODS OF PEST AND DISEASE CONTROL

Insect Pest Problems and Nonpesticide Methods

1. ***Biological Control***

Coconut is a major plantation crop and occupies almost 0.4 million ha. In the 1970s, export of coconut products was a significant (about 20 percent) source of revenue (ca. US$80-100 million a year), in addition to being a vital raw material for a variety of domestic industries. During this period, the coconut leaf miner, *Promecotheca cumingii* (Baly) (Coleoptera:Hispidae) entered the country and became a serious leaf-damaging pest. The height of the coconut tree and the wide extents involved precluded chemical control. After considerable effort by the Coconut Research Institute, three biological control agents were identified. The egg parasitoid *Chrysonotomiya promecothecae* (Yoshimoto) (Hymenoptera:Eulophidae), the larval parasitoid *Sympiesis javanica* (Ferriere) (Hymenoptera:Eulophidae) and the pupal parasitoid *Pediobus parvulus* (Ferriere) (Hymenoptera:Eulophidae) were effective in controlling this epidemic. The importance and potential of biological control received national attention after this experience (Fernando, 1972; and Mahindapala and Pinto, 1991).

Attempts have been made to extend this success to other serious pests. The rice stem borer (*Scirpophaga incertulas* Walker [Lepidoptera:Pyralidae]), a serious pest of rice, is controlled by the egg parasitoid *Telenomus dignus* Gahan (Hymenoptera:Scelionidae). The most recent successful case reported by the Department of Agriculture was the introduction of the larval parasitoid *Diglyphus isaea* (Ashmead) (Hymenoptera:Eulophidae) to control the leaf miner *L. huidobrensis* referred to earlier. This parasitoid was released in 1997/98 and was well established by 2000 in areas with low pesticide usage (Amarasiri, *et al*., 1990; and Wijesekera, *et al*., 2001).

This latter statement focuses on a very important aspect determining the success of biological control, namely; the restrained use of pesticides, which could kill off beneficial insects. Education in this direction is a vital need. In practice, this has been difficult to achieve in Sri Lanka, because landholdings are small and a variety of crops are grown in a small area. For example, it is common for a farmer to be growing leafy vegetables like leeks and lettuce in his plot and for a neighboring farmer to be growing potato or capsicum – each crop will require different pest control methods and nearly all of them would involve pesticides of one type or another. Further, even within a single crop, a biological control agent may be available against one insect pest (such as leaf miner), but not against another (such as aphids), which has to be controlled with pesticides. Hence, it is difficult to envisage a scenario where a biological control agent will be allowed to get established, especially in intensive production areas such as the vegetable growing region in central Sri Lanka.

Biological control has considerable potential in protected agricultural systems such as in polytunnels. This method of production enables year round growing of high value vegetables and flowers. At present, the extent under protected agriculture is small (about 30 ha), but the concept is gaining in popularity and hence the extent is projected to increase rapidly. Due to the isolated environment inside a polytunnel, it is easy for pests to multiply rapidly and reach epidemic proportions. A common problem is the occurrence of whiteflies, *Bemisia tabaci* Gennadius (Homoptera:Aleyrodidae) and *Trialeurodes vaporariorum* Westwood (Homoptera:Aleyrodidae), for which pesticide solutions are limited. Mites too have become problems recently. In a polytunnel, use of pesticides is also undesirable for health and safety of workers. Also, consumer expectations for polytunnel produce are that they are essentially pesticide-free. A polytunnel would be an ideal system for introducing biological control methods. Several organisms such as predatory mites are used in other countries and it is hoped that these organisms will be available in Sri Lanka in the near future.

A non-selective form of biological control of insects is practiced by rice farmers, who place simple perches in their rice fields, to facilitate bird activity and feeding.

2. ***Exclusion***

The principle of exclusion has been used to develop methods of insect pest control. For this purpose, a variety of nets have been used. Most polytunnels have nets covering the sides. The type of net used would depend on the insect pest targeted. Nets that exclude aphids are perhaps the smallest pore size that can be used in the cooler parts of Sri Lanka. Nets with smaller pore sizes, such as mite-proof nets, often cannot be used in a tropical region, because air circulation is seriously impeded, leading to a build-up of heat inside the polytunnel.

Nets fitted onto metal arches are used to protect beds where seedlings are raised. Such a system is also practiced by some producers of seed potato, where aphid-borne virus diseases are prevalent.

An extension of the method of exclusion that is becoming popular is the covering of bunches of banana with polythene bags. The bag protects the developing fruits from a variety of insects that cause (black) spotting as a result of their feeding. Similar methods are used on a home garden scale, where fruits such as guavas, anona, pomegranate, etc. are covered with polythene bags to protect them from insects, birds, squirrels, etc.

3. ***Breeding Resistant Varieties***

Breeding as a means of achieving resistance or tolerance to insects is a common objective in several crop improvement programs. The brown plant hopper (*Nilaparvata lugens* Stål (Homoptera:Delphacidae]) is a serious pest of rice, affecting around 5 percent of the rice growing area. Eight varieties with moderate resistance to the pest have been developed by the Rice Research Institute in recent years. Similarly, rice varieties resistant to stem borer (*S. incertulas*) and gall midge (*Orseolia oryzae* Wood-Mason [Diptera: Cecidomyiidae]) have been developed (Amarasiri, *et al*., 1991). Regrettably, only a few of the major crops have received the attention of breeders and much work needs to be done for other crops such as vegetables.

4. ***Traps***

A variety of traps are used to control insect pests. Pheromone traps are used for the control of fruit fly (*Bactrocera dorsalis* Hendel [Diptera:Tephritidae]), a pest that can be serious in fruits such as mango. For our mango orchards, a simple trap is made by applying ca. 5 ml of methyl-eugenol on the inside of a plastic bottle. The mouth, bottom and insides of the bottle are coated with oil to trap any insects. One such trap is sufficient for about 15-20 trees. Traps have to be remade every 2-3 months.

Sticky traps have been standard devices in our farms and polytunnels for the last three years and we find that usage of this method is increasing among farmers in general. These traps are made of strips of yellow polythene (50 cm x 15 cm; dimensions may vary according to individual situations). In our experience, one such trap is sufficient for ca. 15-20 m^2 bed space inside polytunnels. Aphids and whiteflies are the commonest insects observed on traps, but even moths and small beetles have been observed.

Inside our polytunnels, a light trap is a standard device, effective to control a variety of moths. This trap consists of a light bulb placed over a basin of soapy water.

Nonpesticide Methods of Managing Weeds

1. ***Mulches***

Mulching using a variety of materials, mainly organic, is common in Sri Lanka. Growers of pineapple, vegetables, ginger, etc. use straw or coconut residues as mulches. Mulches also help conserve soil moisture and increase the soil organic matter content.

In our experience with vegetable cultivation, the effectiveness of polythene mulches has been clearly demonstrated. A lightweight polythene, silver-grey on top and black below is placed over the beds. Seedlings are planted in holes cut in the polythene at the recommended spacings. Irrigation and fertilization are provided by drip lines placed under the polythene. However, such an irrigation system is not critical when using polythene mulches, because water can reach the roots via the planting holes in the polythene. In areas without drip irrigation, we apply water directly over the polythene (sometimes with sprinklers) and the water seeps in through the planting holes. Since evaporative losses are minimal with polythene mulches, frequency of irrigation too can be reduced. Labor costs normally expended on manual weeding have been reduced by 30 percent. The lifespan of the polythene with careful use can be at least one year. The problem presently encountered is the availability of the correct type of material, as only one importer carries stocks.

In the plantation crop sector, since land extents are large, labor is scarce and hence manual weeding is a difficult and expensive proposition. Various methods are resorted to, including the use of cattle to graze on vegetation. The most effective method is the use of live mulches or cover crops, such as *Pueraria thunbergiana* and *Desmodium ovalifolium*. Cover crops confer the added advantage of improving and conserving soil. The practice is unfortunately not as widely adopted as it should be, partly because of the difficulty of establishing cover crops and maintenance, but mainly due to an over-reliance on herbicides.

2. ***Mechanical Weeders***

CIC Agribusinesses operates a 500-ha seed paddy production farm, which supplies 45 percent of the country's seed paddy. Weed control in paddy is difficult after the first month and this is more so for seed paddy production, where tolerance limits have been set for the weed seed content. Custom designed mechanical weeders have been used on transplanted/direct seeded fields and have been very effective. The Farm Mechanisation Research Centre of the Department of Agriculture has been an active promoter of mechanical weeders and has developed several types to suit the requirements of farmers. Widespread use has been limited due to a scarcity of labor in some areas.

3. ***Weed Management***

An approach that has been initiated in our farms is to prevent weeds, especially grasses like *Panicum, Imperata*, etc. from flowering. This is done by manual or mechanical cutting every 3-4 weeks. The cut portions are collected and incorporated into vegetable beds as organic matter. The long-term objective is to minimize seed formation and spread of weeds via seed and thereby reduce the weed seed load in the soil. Some form of recycling of nutrients is also achieved by reusing the cut portions. This approach has worked well in our 8 ha vegetable farm over the last three years and the concept is being extended to our larger farms.

4. ***Flooding***

It is relevant to mention here the common practice of flooding rice fields to control weeds. Though this is an effective method, it is not very efficient in terms of water use. Water is becoming an increasingly scarce resource in Sri Lanka as in most parts of the world. Unfortunately, rice cultivation is sometimes not undertaken if there is insufficient water as determined by the farmer, even though there may be sufficient water for the requirements of the plant, but not for flooding the field to control weeds.

Nonpesticide Methods of Managing Diseases

1. ***Breeding***

The method of choice is the development of varieties tolerant/resistant to diseases. Much attention has been given to rice, where resistance to common diseases such as blast (*Pyricularia oryzae*) and bacterial leaf blight (*Xanthomonas oryzae*) are critical selection criteria. Nearly all varieties released for cultivation are considered resistant to these two diseases. In tea, resistance to blister blight (*Exobasidium vexans*), a serious leaf disease, is critical though success has been difficult to achieve so far. Varieties with gradations of resistance together with copper fungicides have been fairly effective in controlling the disease. The Department of Agriculture has promoted use of two potato varieties that are resistant to late blight (*Phytophthora infestans*).

Where resistant varieties are not available locally, it is our policy to source such material from outside Sri Lanka. An example is our vegetable production program. Leaf curl is a serious viral disease in capsicum and bell peppers. We have been able to source varieties of these crops that are resistant to leaf curl and have had considerable success in production.

2. ***Grafting***

Bacterial wilt (*Pseudomonas solanacearum*) is a serious disease limiting cultivation of Solanaceous crops. Some soils have been rendered uncultivable with these crops due to the severity and persistence of the organism. An approach that has been attempted in our farm is to use grafting. Here, a shoot from a commercial hybrid is grafted onto seedling stocks of a local variety that is moderately resistant to wilt. Initial results have been encouraging and larger-scale trials are in progress. We have extended this approach to carnations, where *Fusarium*-resistant varieties have been used as rootstocks to graft floriferous, *Fusarium*-susceptible varieties. This approach deserves wider study for the management of soil-borne diseases.

3. ***Exclusion and Sticky Traps***

This is an indirect method of controlling some virus diseases, by prevention of entry and/or trapping of virus vectors such as aphids. This aspect has been dealt with in detail in the preceding section. An example of such an application is the control of potato leaf roll virus and other aphid-borne viruses in certified seed potato production, where use of aphid-proof polytunnels is a requirement for certification.

Miscellaneous Methods

1. ***Solarization***

Sterilizing of soil by solarization is practiced in our vegetable farm and to a limited extent in tobacco and vegetable nurseries. Beds are first moistened and then covered with black polythene for 5-7 days. If diseases were observed during the previous season, the process is repeated after turning the soil. If soil has to be brought from outside (e.g., to use inside a polytunnel), soil is filled in bags and left in the sun for 5-7 days before filling beds. It has been observed that black polythene works well at high altitudes (e.g., at our vegetable farm), where day temperatures are high (20-32ºC) and night temperatures are low (12-15ºC), with the black polythene probably acting to keep night temperatures sufficiently high to achieve sterilization. At low elevations, clear polythene has been found to be more effective, as sunlight can penetrate the polythene and heat the soil more directly. Consequent to the ban on methyl-bromide and the limited effectiveness of available fumigants, solarization has emerged as a low cost and effective method of controlling soil-borne pests and diseases, especially for areas receiving abundant sunshine. Since solarization cannot be used during rainy/cloudy weather, a program must be planned to solarize the soil requirement during the sunny season. Polythene bags are very convenient for this purpose. In our experience, a saving of about US$0.12/$m^2$ can be realised compared to fumigation with Dazomet.

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9. SRI LANKA (2)

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INTRODUCTION

Agriculture plays a vital role in the economy of Sri Lanka. However, the contribution of agriculture to GDP has declined over the years and has accounted for 16 percent in 2000. Agriculture has provided employment for about 36 percent of 18 million population in year 1998. Sri Lankan agriculture broadly falls into two sectors:

1. Export crop sector where tea, rubber, coconut spices and coffee are the main crops.
2. The domestic sector primarily relating to food crop cultivation.

The main food crop cultivated in the country are rice, horticultural crops and field crops such as grain legumes (green gram, cowpea, black gram), coarse grains (maize and kurakkan) oilseeds (groundnut, gingerly and soybean) and condiments (chilies and onions). The food crop sector contributes to Rs.89,402 million to GDP which accounted for about 8-9 percent of GDP in 2001.

The objective of this paper is to discuss the present status of nonpesticide methods (NPMs) of controlling pests in food crops highlighting constraints and issues related to this method of pest control. Suggestions for the improvement of the application of NPMs are also given.

CROP PESTS AS MAJOR CONSTRAINTS TO INCREASE PRODUCTIVITY

Productivity of most of food crops are low compared to developed countries and some of the developing countries such as India and China. Further, there is a growing domestic as well as foreign market for many of those crops and hence productivity per ha need to be increased since there is only little room for expansion of land area under cultivation. One of the constraints to achieve high productivity is the infestation by pests including insects, nematodes, bacterial, fungal and viral infestation and weeds.

Rice Pests

Several hundreds of species of phytophagous insects inhabit rice ecosystems. However, few insects are considered as pests (Kudagamage and Nugaliyadde, 1995). In the last several decades, the relative importance of these insects has changed. Insects such as the brown planthopper (BPH), rice bug and leaf folders that are relatively specific have become more important. Additionally incidence of black bug (*Scotinophara laurida*), nematodes (*Meloidogyne graminicola*) and rat (*Bandicota bengalensis*) have been reported from localized areas in the country (Nugaliyadde, *et al*., 2000). Among the rice diseases in Sri Lanka rice blast (*Pyricularia oryzae*), bacterial leaf blight (*Xanthomonas campestris*) and sheath blight (*Rhizoctonia solani*) continue to cause significant yield losses depending on varieties grown, environmental condition during the cropping season, agro-ecological zone and agronomic practices adopted. In addition grain sterility and premature senescence of rice crops and yellowing have being frequently reported as important field problems (Nugaliyadde, *et al*., 2000).

Other Field Crops

In chili, the single most limiting factor of cultivation is the infestation by pests that results in a condition popularly known as chili leaf curl complex. The main causal factor is infestation by various thrips species (Wijeratna Banda, 1997). The important reason for emergence of thrips as the most important pest of chili is because of indiscriminate use of pesticides by the farmers (Chandrasena, *et al*., 1997).

Apart from competition from Mysoor dhal, infestation by pests during flowering and podding are the limiting factors for the cultivation of pigeon pea. The population of the most important pigeon pea pest *Maruca testulalis* is very high during *Maha* (November-January) and decline thereafter (Anon., 1998a). However, incidence of pod fly, *Melonagromyza obtuse* remains high during the *Yala* season (Fellowes and Amarasinghe, 1977).

In cowpea and green gram, post-flowering pests are important than seedling pests. The single most important seedling pest is bean fly, *Ophiomyia phaseoli*. Post-flowering pests include legume pod borer, *Maruca testulalis* and two other pod borer species *Helicoverpa armigera* and *Lampides boeticus*. In the recent time, the incidence of flower thrips is on the increase. The storage pests of green gram and cowpea are more cosmopolitan and include various *Callosobruchus* species.

The onion purple blotch is a serious disease in the *Maha* season (wet season) and is difficult to control by fungicides. Hence onion cultivation is mostly carried out in the *Yala* (dry season). Leaf twister disease of onion is another disease of onion of recent occurrence caused by combination of fungi like *Colletotrichum* and *Fusarium*.

Chili is affected by an array of virus diseases vectored by thrips, mites, whiteflies and aphids. Narrow leaf disorder of chili is reported about 15 years back but the exact causal agent is not yet known. This is perhaps a soil- and water-borne disease and possibly related to physiological/chemical factors in the soil.

In green gram and black gram yellow mosaic virus is the most serious disease. Collar rot of cowpea is a common soil-born disease in cowpea if the cultivation is repeated in the same land.

Vegetables, Tuber Crops and Potato

There are over 200 pests recorded from vegetables in the country. However, only 20-30 are economically important. In recent years several new pests have emerged probably due to accidental introductions. A new leaf miner, *Liriomyza trifolii* was recorded in 1993 from vegetable crops while *L. huidobrensis* was identified in 1997 from Nuwara Eliya areas (Wijesekara, 1997). Both species are well established and particularly *L. huidobrensis* cause economic damage to various vegetables and potato crops.

The different pests associated with mushroom and leafy vegetables became important after their wide-scale cultivation.

The sucking pest complex, particularly the incidence of various thrips species, is on the increase. In addition to direct damage, these insects are responsible for the transmission of various virus diseases.

Sweet potato weevils remain the major insect pest of sweet potato since its commencement of cultivation in the country during the colonial times. It can reduce the yield, quality and storage life of tubers. Cocoyam and Dioscorea are relatively free from infestation of insects. Only pest of economic significance is corm and yam beetle.

Bacterial wilt caused by *Ralstonia solanacearum* is one of the most important diseases of solanaceous crops like tomato, brinjal and capsicum in the wet zone of Sri Lanka. Regular spraying of fungicides is necessary to manage early and late blights of tomato especially in the *Maha* (wet) season. Occurrences of virus diseases of tomato are on the increase especially with the introduction of exotic hybrid varieties.

Powdery mildew is a very common disease of all vegetables and severe incidences are experienced in dry and windy climatic conditions in *Yala* (dry season) mainly from June to August. Okra yellow vein mosaic virus spread by whitefly is one of the important diseases of okra.

Club root of cabbage is a common soil-borne disease in the up-country of Sri Lanka. This is kept under low levels by cultural practices as there is no effective fungicide for this disease. This disease does not occur in mid- and low-country areas where temperature is high.

Seedling rot and collar rot of bean is a problem in the early stage of the crop while anthracnose, rust and leaf spots are also considered serious problems in the up-country areas.

Cultivation of potato is restricted to the cooler (up-country) and hot and dry (Jaffna and Kalpitiya) areas of Sri Lanka because of the high incidences of bacterial wilt in mild climatic conditions. Early and late blight are most damaging fungal diseases which need regular fungicide sprays to keep this disease under control. Recently released variety “Hill Star” is moderately resistant to these diseases.

Fruit Pests

Fruits flies are the most important pests of different fruit crops. An island wide fruit fly survey has revealed the presence of 25 species of which, eight species were identified. They are *Bactrocera dorsalis, B. kandiensis, B. correcta, B. zonata, B. nigata, B. versicolor, B. cucurbitae, B. tau, B. caudate, B. nigrotibialis, B. gavisa* and *B. verbasciflolial* (Anon., 1995).

A new pest known as the spiraling whitefly *Aleurodicus dispersus* was identified infesting guava plants. Many crop species were found to be infested by this pest. However, presently no appreciable economic damage is found to be caused by this pest.

Two species of thrips, *Selenothrips rubrocinctu* and *Sciortotrhips dorsalis* have been identified as causal factors of death of mango seedlings in several government farms (Anon., 1998a).

Panama disease is endemic in soils where banana is cultivated and incidences are severe in the wet zone where highly susceptible varieties like Kolikuttu (silk banana) cannot be cultivated continuously. Variety Ambul (Mysoor) is found to be resistant to Panama disease. Two recently found virus diseases viz. banana streak virus and banana bract mosaic have spread fast causing great losses in commercial cultivations.

Papaya ring spot virus is wide spread in the wet zone. Therefore, commercial cultivations are restricted to the dry zone of Sri Lanka.

Anthracnose of mango at flowering and at postharvest stage cause severe losses if uncontrolled. In addition stem end-rot cause great damage in postharvest handling during poor storage and transport conditions. This is one of the obstacles to export of mango.

Powdery mildew has become a serious threat to the rambutan industry. It damages flowers, young leaves and fruits, and became prominent with the occurrence of off seasonal bearing in the past few years.

Apart from pests, weeds also cause significant yield losses. Invasive weeds are much more economic significance as they affect biodiversity.

NEED FOR ALTERNATIVE CONTROL METHODS

There is a need for controlling pests in order to prevent the damage which they cause. Very often, pesticides are used as the first line of defence against pests. Today many who continued to practice chemical farming relaying solely or heavily on pesticide inputs are confronted with many problems and increasing threat to non-sustainability.

Disruption of Natural Enemy Complex

The recent outbreak of leaf miner, *Liriomyza* spp. in the mid-country and up-country areas of Sri Lanka is attributed to disruption of natural enemy complex. The larval parasitoids were more abundant in fields which received few insecticide applications than in fields, which receive more application (Wahundeniya, 2001). Fernando (1970) showed the importance of egg parasitoids on the population control of stem borers. Recommendations made by the Department of Agriculture in 1968 to use insecticides granules instead of foliar sprays for the control of stem borers has led to the conservation of a highly active egg parasitoid *Telenomus dignus*. As a result, except in localized areas, the pest has receded in importance over the last decade (Kudagamage and Nugaliyadde, 1995).

Changes in Pest Status

Prior to the 1970s the presently important pests of rice, BPH was a minor pest. However, use of broad spectrum insecticides for the control of stem borers, then one of the important pests, resulted in the destruction of natural enemies of BPH and as a result BPH has become a major pest of rice.

Insecticide Resistance

There is no comprehensive data for insecticide resistance in agricultural pests in Sri Lanka. However, there are various reports of the failure of insecticidal control of some of the pests. Some of the notable examples are *Liriomyza sativa* and *L. huidobrensis* and diamond back moth, *Plutella xylostella*.

Hazards

There are more than 1,000 registered products used for pest control in Sri Lanka. Among these products, there are about 125 different pesticides. Value of formulated products imported into the country is higher than that of technical grade material. In the last five years there were more herbicides imported than insecticides and fungicides. Generally there is an increasing trend of insecticides imports in the last five years (Table 1). The health and environmental hazards are associated with increased use and 13,000 people were admitted to hospitals annually for acute pesticide poisoning and further, about 1,000 were fatal (Sim, 1989).

Table 1. Volume and Value of Technical Grade and Formulated Products of Pesticides Imported to Sri Lanka, 1995-99

Unit: Imported CIF value = US$000; and volume = mt or 000 ml)

Year	Technical Grade				Formulated Products			
	Insecticides	Herbicides	Fungicides	Others	Insecticides	Herbicides	Fungicides	Others
1995								
Value	1,331.24	2,221.97	274.15	189.34	3,175.92	3,940.18	2,522.9	408.45
Volume	202.58	124.3	8.4	1.19	728.11	1,491.9	697.67	82.12
1996								
Value	1,283.8	2,120.89	168.04	95.32	3,450.45	4,900.2	2,434.63	326.64
Volume	114.6	294.4	5.34	1.08	845.8	1,334.1	553.9	94.2
1997								
Value	1,568.7	2,653.4	219.7	182.9	3,443.3	4,925.89	1,557.88	348.5
Volume	142.4	390.0	12.5	1.6	879.2	1,500.9	464.1	762.4
1998								
Value	1,660.16	1,000.97	173.81	133.85	4,029.63	5,887.64	2,180.89	361.45
Volume	125.76	259.4	8.22	1.47	1,118.85	1,582.1	430.1	95.63
1999								
Value	1,840.13	1,881.04	187.29	121.97	3,704.73	8,771.87	1,691.2	403.6
Volume	153.37	293.9	13.53	1.37	1,071.03	1,863.8	480.0	134.7

High level of toxic substance has been reported not only in drinking water, but also in a range of essential food items such as rice, lentils, vegetables, fruits, meet and milk (Bull, 1982; and Chandra, 1990).

The hazards of pesticides are most often associated with their misuse. The misuse occur in different form as exclusive use, improper selection of pesticides, wrong time of application, non-adaptation of proper postharvest interval and lack of knowledge on health and environmental hazard and safety measures.

ALTERNATIVE PEST MANAGEMENT METHODS

Plant Resistance

Host plant resistance is one of the most economical and environmentally acceptable method of pest management and emphasis has been placed on breeding varieties resistant to pests.

The biggest success in this method has been achieved in rice (Kudagamage and Nugaliyadde, 1995). Several rice varieties resistant to gall midge (GM), BPH, bacterial blight (BB) and blast diseases (BL) has been released (Table 2). Breeding programs for BPH resistance initiated in 1974 has continued to use Ptb 33 (or its derived lines) as donor parents. The first variety resistant to BPH was released in the early 1980s (Kudagamage and Nugaliyadde, 1980). Since then many varieties have been released (Table 2). Most of these varieties have used Ptb 33 as resistant source. The high level of resistance to BPH and its compatibility as a donor variety could be accounted for the extensive exploitation of Ptb 33 as a donor parent. BPH resistance in Ptb 33 was found to be controlled by a polygenic system with at least one major gene and several minor genes. The chemical composition of the surface lipids and phloem amino acid composition was found to be associated with BPH resistance. The amino acid composition of phloem sap of Bg 379-2 was found to be the similar to resistance donor Ptb 33. However, amino acid composition of other resistance variety Bg 300 differed from Ptb 33. BPH fed less on sugar medium containing phloem exudates of Bg 379-2 and Ptb 33 compared to Bg 300. The resistant factor in Bg 300 appeared to be the higher content of surface lipid (Nugaliyadde, 1994). Efforts are underway to utilize a different source of resistance such as IR 543451 which derive its resistance characters from a wild rice *Oryza australiensis*.

Table 2. Improved Rice Varieties Recommended by the Department of Agriculture Resistant to Major Pest and Diseases

Variety/Age Class	Year of Released	Yield Potential (mt/ha)	Attributes
5-6 months			
Bg 407	1981	7.5	Resistant to BB
4-4.5 months			
Bg 400-1	1980	8.5	Resistant to GM-1
Bg 379-2	1980	8.5	Resistant BPH and BB
Bg 380	1982	10.0	Resistant to GM-1
Bg 450	1985	8.8	Resistant to GM-1
Bg 403	1993	8.0	Resistant to BB, BL and BPH
Bw 100	1979	6.0	Resistant to BL and bronzing
Bw 400 (Bw 272-8)	1987		Resistant to BL
Bw 435	1992	7.0	Moderately resistant to BL and GM-1
3.5 months			
Bg 350	1986	6.0	Resistant to GM-1
Bg 352	1992	8.5	Resistant to BL and GM-1
Bg 357	1997	10.5	Resistant to GM-1, GM-2, BL, BB and moderately resistant to BPH
Bg 359	1999	7.0	Resistant to GM-1, GM-2, BL, BB and moderately resistant to BPH
Bg 360	1999	7.0	Resistant to GM-1, GM-2, BL, and moderately resistant to BPH
Bw 267-3	1981	4.5	Resistant to BL
Bw 351 (Bw 288-1-3)	1986	5.0	Moderately resistant to sheath blight
At 353 (At 76-1)	1992	6.5	Moderately resistant to BL and BB
Ld 355	1994	4.5	Moderately resistant to BL and BB
3 months			
Bg 300	1987	8.0	Resistant to GM-1, BL, BB and moderately resistant to BPH
Bg 301	1987	6.0	Resistant to BL and BB
Bg 304	1993	7.5	Resistant to GM-1, GM-2, BL, BB and moderately resistant to BPH
Bg 305	1999	7.5	Resistant to GM-1, GM-2, BL, BPH and BB
At 303 (At 77-1)	1990	5.0	Resistant to BL

Limitation of the utilization of varietal resistance in pest management has been the evolution of resistant breaking biotypes as found in the case of previously resistant (GM) varieties (Kudagamage and Gunawardhana, 1989). Since then five varieties Bg 304, Bg 305, Bg 357, Bg 359 and Bg 360 possessing resistance to new biotype termed as gall midge biotype 11 (GM 11) has been released. With the introduction of varieties possessing resistance to GM 11 an investigation was conducted to determine the variation of GM population within the country from 1994 to 1995. The GM population from different parts of the country reacted similarly to the differential set of varieties used indicating no variation of GM population within the location tested (Nugaliyadde, 1996). However, Katiyar, *et al*. (2000) using ALFP technique showed a variation between GM population from Batalagoda and Bombuwela and indicated that those two population as separate biotypes. The outcome of the breeding program for the development of thrips (TH) resistance is the development of screening techniques and identification of donors of resistance (Kudagamage, 1977). However, breeding programs for TH resistance was not successful due to complicated nature of the factors associated with TH resistance in traditional donor varieties like Dahanala and incompatibility indicated in the from of grain sterility in crosses between the donors and new improved varieties (Kudagamage and

Nugaliyadde, 1995). However, the breeding programs for TH resistance using ARC 13761, which differs from Dahanala as the donor parent, is in progress (Nugaliyadde, *et al*., 2000).

Breeding for resistance to BL of rice has continued since the inception of organized breeding programs of rice as early as 1950. Since then several rice varieties resistant to BB and BL has been released (Table 2). However, due to the occurrence of new races of the pathogen most of these varieties have become susceptible few years later (Wickremasinghe and Dissanayake, 1990). Location differences in resistance are also evident. However, Bg 300, Bg 301 and 62-355 showed broad spectrum of resistance. Another drawback of breeding for BL resistance is the lack of screening methods for adult plants. At present selection is based on seedling BL reaction expecting for resistance at the adult plant stage. Incorporation of resistance to BB was a major objective of the rice improvement program in Sri Lanka for nearly two decades. The donor parent for BB in most of the presently cultivated variety is IR 20.

In other crops, the breeding for insect pest resistance had limited success. Few chili varieties have been bred with moderate resistance to leaf curl complex caused by TH and mites. Several varieties of green gram having resistance to *Callosobruches* spp. were identified (Dharmasena and Subasinghe, 1966).

Moderately resistant varieties for bacterial wilt like KWR, T 245, T 146 of tomato, variety padagoda of brinjal, CA-8 of capsicum released by the Department of Agriculture, Sri Lanka are successful in managing bacterial wilt of solanaceous crops. In okra, the variety Haritha is resistant to yellow mosaic virus. Department of Agriculture has released green gram varieties with moderate resistance to virus disease.

Biological Control

Biological control is the usage of living organism or products thereof to reduce the extent of problems caused by pests. There are three main approaches to biological control:

1. ***Introduction or Classical Biological Control***

This deals with the importation and release of exotic natural enemies with permanent establishment. Two successful examples in the recent times were the control of coconut leaf beetle, *Promecotheca cumingii* by the introduction of parasitoid *Dimmokia javanica* and the control of water weed *Salvinia* by introduction of *Cyrtobagus salviniae*.

Following pilot-scale verification studies on the effectiveness of the weevil on Salvinia, the biological control program was entrusted to the Plant Protection Services of the Department of Agriculture in the early 1990. From 1995 onwards insects were released in 90 Salvinia-infested water bodies in different agro-ecological regions. A study was conducted to evaluate post-release performance of the insect in controlling Salvinia. According to results from 49 locations Salvinia was effectively controlled in 34 locations giving success rate of 60 percent in the dry zone and 81 percent in the wet zone. Resurgence of Salvinia has been observed in 11 locations where initial control had been successful. Out of these locations nine were in dry zone, indicating that probability that re-infestation is very high in the dry zone as compared to the wet zone. Results also indicate that the biological control agent was more effective in the wet zone than in the dry zone. The water temperature and nitrogen content of leaves of Salvinia appears to be the critical factors for the successful establishment of the weevil. Successful control of Salvinia in the wet zone is attributed to low water temperature and high nitrogen content of the leaves (Amarasinghe and Ekneligoda, 1997).

The most recent success story of the establishment of a exotic parasitoid was that of *Diglyphus isaea* (Hymenoptera:Eulophidae). A larval ecto-parasitoid of *L. huidobrensis* was released into the fields in 1997/98. A post-evaluation survey was carried out in 2000 in six locations of Nuwara Eliya district of Sri Lanka where the parasitoid was released. The percentage parasitism ranged from 1.3 to 65 percent and in locations where there was a high parasitism, farmers did not use highly toxic insecticides to control the vegetable pests. (Nugaliyadde et al, 2001).

2. ***Augmentation and Inoculation of Natural Enemies***

In situations where natural enemies are absent or population levels are low to be effective, numbers may be augmented by the release of laboratory-reared insects. Entomopathogenic agents (bacteria, fungi and nematodes, etc.) may be used similar to conventional insecticides. Recently, there is a growing interest in research activities related to multiplication and augmentation of such natural enemies. An internationally-funded project is underway for the development of technologies for mass culture and release of *Trathala* *flavoorbitalis*, endemic parasitoid of brinjal borer, *Leucinodes orbonalis*. Research projects are also underway to develop biological control agents in greenhouse pests such as mites, whitefly and TH.

There has been recent interest in the use of entomopathogenic organism as biological control agents of pests. Limited surveys have been conducted to identify pathogenic agents of insect pests and nematodes (Sivasubramaniam and Kudagamage, 1997a). Some of the promising biological control agents were mass cultured using agro-industrial waste such as tea waste, paddy husks and molasses (Sivasubramanium and Kudagamage 1997b; and Nishantha, *et al*., 2001).

Trichoderma koningii was found to be effective on *Meloidogyne incognita* (De Silva, *et al*., 2001). Crude extract prepared from grinding dead disease larvae of cabbage semi-looper, *Chrysodeixis eriosoma* infected with fungus *Metarhizium* was found to be effective in the field for cabbage caterpillars (Wickremathilake, *et al*., 2000). *Paecilomyces fumosoroseus*, an antagonistic fungi isolated from disease insects was successfully multiplied on boiled rice. In the laboratory it was found to cause nearly 100 percent mortality of *Plutella xylostella* when treated with spore concentrators ranging from 1.8 x 10^9 (Kudagamage, *et al*., 1996).

The efficacy of isolated antagonistic organisms was evaluated in the laboratory and field experiments for the control of plant diseases. In laboratory and greenhouse tests different isolates of *Trichoderma* gave promising results against *Sclerotium rolfsii*, fungal pathogen causing root rot in cocoyam (Anon., 1998b).

3. ***Conservation of Natural Enemies***

In this method, attempts to conserve indigenous natural enemies by manipulating the environment in such a way their activity against a particular pest or pest complex is enhanced. Farmers need to be educated on the role of natural enemies in the control of pests. The FAO Integrated Pest Management (IPM) Program for rice farmers in 10 countries in Asia commenced in 1980 which has continued for the last 20 years has placed much emphasis on ecological approach to rice pest management.

Through the farmers field school (FFS) farmers are trained on ecological principles of IPM in rice-based farming systems. Emphasis is placed on the identification of natural enemies, role of natural enemies in the control of target pests and methods of conservation of natural enemies. Results of a survey carried out in seven administrative districts by Nugaliyadde, *et al*., (1997) has revealed encouraging information on the ability of rice farmers to recognize the role of natural enemies play in the rice agro-ecosystem.

About 53 percent of the farmers recognized the presence of a group of organism called natural enemies in the rice field (Table 3). Higher percentage of farmers knew the role of natural enemies and were able to name some of the important natural enemies in the rice fields. However, only 17 percent farmers agreed that killing of natural enemies will increase pest infestation.

Table 3. Farmers' Perception of Natural Enemies of Rice Pests (Main Season: October 1995-March 1996)

Criterion	District* (farmers responding, percent)							
	Ap	Pol	Kur	Kay	Mat	Rat	Ham	Average
Know the presence of natural enemies	33	68	48	31	50	53	86	52.7
Average number of natural enemies named by farmers	2.5	4.5	4.1	3.3	4.6	2.7	5.2	3.8
Know the role of natural enemies	31	67	40	31	49	52	86	50.8
Know the effect of insecticides on natural enemies	30	65	41	26	48	51	8	49.4
Know that killing natural enemies will increase pest infestations	10	23	33	10	18	11	15	17.1

Source: Nugaliyadde, *et al*., 1997.

Notes: * Ap = Anuradhapura; Pol = Polonnaruwa; Kur = Kurunegala; Kay = Kandy; Mat = Matale; Rat = Ratnapura; and Ham = Hambantota.

Cultural Control

Farmers are using traditional cultural control methods to control pests. Good tillage practices, removal of crop residue soon after harvest, crop rotation, manipulation of planting time to avoid occurrence of high pest densities and use of intercrops are some of the practices adopted by farmers. Proper water management is widely used method of control rice pests particularly that of weeds.

Other Methods

Use of various traps such as pheromone traps, and sticky traps are becoming popular among growers. The male lure methyl-eugenol is available commercially and being used for trapping male fruit flies of mango (Anon., 1997). Banana pseudo-stem traps (transverse stem slices of 7.5-15.0 cm thick) are recommended as a trap to attract banana weevil (Anon., 1997).

POLICIES AND PROGRAMS TO PROMOTE NONCHEMICAL METHODS OF PEST CONTROL

Government policy statement on agriculture clearly states that dependence on chemical fertilizers and agrochemicals will be reduced through adoption of measures such as IPM and other agronomic practices. The increased productivity through employment of new technologies and reduction of cost of cultivation is another objective of the production program of the Ministry of Agriculture (Anon., 1995). Avoidance of indiscriminate use of pesticide can bring down the cost of cultivation increasing productivity.

The main program implemented by the government to promote non-chemical pest management is the IPM program initially implemented for rice. This program launched in 1986 has been continuing for the last 26 years. In the last several years there were gradual changes in the approach of promotion of IPM among farmers.

* At the initial stage of the project training given was based on classroom instruction using flip chart and other training aids. The flow of information followed one way process from extension workers to farmers. However, this method of training did not build enough confidence in farmers to take appropriate decision to adopt control methods in their fields.
* A new training method known as Farmer Field School came into use in 1994. The main emphasis was to develop skills in ecological approach to rice farming recognizing all factors in the rice ecosystem that limit crop growth.
* Short-term training for trainers of IPM was replaced by season-long training.
* Developing required skills of farmers to under take training of fellow farmers.

Various NGOs such as CARE (Cooperative American Relief Everywhere) and Sarvodaya have also embarked on promotion of NPMs among farmers. With the initial success of IPM in rice, it is being extended to other crops like chili, potato and vegetables. However, there is a need for more research on non-chemical control in these crops.

ISSUES, CONSTRAINTS AND PROMOTION OF NONPESTICIDE METHODS

Poor inter-institutional coordination is a major constraint to the dissemination of technology needed for NPMs. Most often there is clear demarcation between research, extension and support services and the efforts are not harmonized to solve the farmers' problems.

The lack of information on the NPM, particularly that of non-rice crops, is another constraint. There is a dearth of trained manpower capable of generating the knowledge required for the adoption of NPM. Presently there is lack of enough extension workers at the village level for the promotion of NPM. Furthermore, there is no timely flow of technical information required. More constraining than the availability of technology is the lack of facilities and support services for the extension workers to carry out their work. In many instances these workers do not have means of travels to farmers' fields to set up FFS.

Most of the farmers have been conditioned to use chemicals by the industry through their powerful advertising campaign. As a result, they think that use of chemicals is easy and simple and fit well into complex production system. Hence they are reluctant to take the risk of adopting NPM.

The positive step in the promotion of NPM is the institutionalizing of IPM as the basis for official national plant protection policy. Much of the credit for this goes to the FAO regional IPM project working in concert with sensitized political and scientific clientele in the national program. However, this is not adequately recognized by lending institution such as banks. There is need for more rational insurance schemes to avert the risks of adoption of NPM.

The presently adopted methods of promotion of IPM including the NPM is the use of FFSs. However, since there is more than 1.8 farm families engaged in farming, reaching all of them through a process of FFS within a reasonable period can be a difficult task. One way to obviate this problem is to operate through farmer organizations. These farmer organizations if well managed become farmer companies. These companies can hire experienced people for monitoring fields for the presence of natural enemies in the fields and undertake appropriate management methods. To reduce burden on the state, another approach is to use farmer trainers to train their fellow farmers as is already carried out in some parts of the country.

The accessibility of materials needed for NPM is often cited as one of the constraints for the promotion of NPM. Usually, well established firms do not sell products such as natural enemies and various traps used for pest control. Giving more incentives to these firms such as free testing of products in government laboratories, reduction of taxes and low interest credits are some of the possibilities to promote NPM among the pest control firms.

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10. THAILAND (1)

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CURRENT STATUS OF USING NONPESTICIDE METHODS FOR CONTROLLING CROP PESTS IN THAILAND

During the past 10-20 years, chemical pesticides have been used as the main pest control methods. Due to the effectiveness, easy application and low cost, chemical pesticides are likely to be selected by most farmers to protect their crops from pest infestation. Unnecessary and heavy usage of chemical pesticides to control crop pests result in several problems, for instance, pest resistance, secondary pest outbreak, pest resurgence, pesticide residue in food, hazard to human's health, destroy natural enemies and other beneficial insect pollinators. In addition, the most serious situation now is environmental pollution.

Presently, due to the increased use and misuse of agrochemicals that cause environmental and health problems, many Thais realize the serious situation and complained about pesticide residue in agricultural production. They have to spend more money to purchase pesticide-free produce in order to improve their quality of life. According to the consumer attitude and marketing needs, the agricultural producers are currently beginning to shift from reliance on chemical control to alternative nonpesticide methods that are practicable for controlling some economic crop pests. In general, nonpesticide method for controlling insect pests including use of mechanical control (i.e., destroy by hand, using mechanical instrument to kill pest and screening), cultivation techniques (i.e., crop rotation), good sanitation practices, biological control of crop pest (i.e., parasitoid, predator, *Bacillus thuringiensis* [Bt], Nuclear Polyhedrosis Virus [NPV] and nematode) and crop resistant varieties become the alternative control methods in many farms. In addition, several nonpesticide methods are encouraged in integrated pest management (IPM) for controlling insect pests which cannot be controlled by any one method. The national research project has a goal of reduction in use of pesticide in agriculture emphasizing IPM as the preferred crop protection practice. According to research and IPM demonstrations, the pesticide use in agricultural protection was reduced approximately 20-50 percent on rice, fruits, field crops and vegetable in the year 2002.

Organic crop production such as rice and golden banana has been exported to many countries in Europe, U.S.A. and Japan since 1992. However, it is now becoming the hot issue because the organic or green products, biological product and ecological product are increasing in the international trade with increasing economic interests in production. During 1999-2002, the Department of Export Promotion, the Department of Agriculture, the Department of Agriculture and Extension, the Thailand Institute of Scientific and Technological Research, Kasetsart University and private sectors have designated a collaborative pilot project for exporting six crops, namely; vegetable corn, asparagus, golden banana, herb and spice crops, okra and pineapple. Those productions are exported as frozen foods and canned products.

The Standard for Organic Crop Production of Thailand is initialized to serve as a general guideline of organic crop production as it will be use in Thailand. The obligatory program for organic crop protection emphasizes the maintenance of nonpesticide for controlling insect pest. After the establishment of the National Organic Crop Production Standard, a national inspection and certification program needs to be defined. A separate guideline on the National Organic Certification Program will be prepared for the management of organic farm certification program in Thailand.

SUCCESS STORIES PERTAINING TO THE USE OF NONPESTICIDE METHODS FOR CONTROLLING CROP PESTS

Mechanical Control

Kongkanjana, *et al*. (1998) reported the mechanical control of the cotton bollworm, *Helicoverpa armigera* Hübner (Lepidoptera:Noctuidae) on super sweet corn was conducted at Damnoen Saduak district, Ratchaburi province. By squeezing the corn ear tip to kill the cotton bollworm larvae at 60 days after planting (DAP) simultaneously the third-fifth instar larvae infesting corn ears was not significantly different to two times application with lambda- cyhalothrin L at the rate of 30 ml/20 liters at 60 and 64 DAP. This technique is beneficial to the farmer rather than insecticide use. Mechanical killing the larvae in the field as compared to collecting them by hand and removing them from the field increased farmer's income 58-59 percent and 16-31 percent, respectively. The more often the larvae were collected the higher the income for the farmer. To avoid using insecticide and its residue the super sweet corn growers are more likely to use this technique now.

Appropriate bagging technique to prevent fruit insect pest: durian seed borer *Mudaria luteileprosa* Holloway (Lepidoptera:Noctuidae), guava fruit borer and rose apple fruit borer *Meridarchis scyrodes* Meyrick (Lepidoptera:Carposinidae). Sudhi-Aromna and Jumroenma (1997) reported that a study of appropriate fruit bagging time using translucent plastic bag as wrapping material to prevent insect pests infesting durian fruit was carried out at the farmer's orchard in Chanthaburi province during March-May 1996. The experiment was aimed at finding out the appropriate bagging time in order to prevent the most important pest of durian, the seed borer, *Mudaria luteileprosa*. It was found that bagging the fruit at six weeks after fruit setting gave a 100-percent of prevention to durian seed borer whereas bagging at eight weeks and un-bagged treatment had 2.86 and 17.14 percent damages, respectively. Plastic bag also had a slight effect on the color of the fruit peel. In addition, by separating durian fruit with any kind of a wood stick or a piece of coconut shell (a local farm technology), can further reduce the fruit borer damage.

Effectiveness of Different Kind of Traps for Controlling Insect Pests

Theoretically, sticky trap is utilized for monitoring the insect pest population. However, they are widely to use as a control material because the farmers obviously see plenty insects caught on them. Many researches has been done by the Vegetable and Ornamental Plants Entomology Research Group, Entomology and Zoology Division in order to verify the effectively control tactic for various insect pest of vegetables (i.e., chili, cabbage, asparagus and tomato). Eighty yellow sticky traps per *rai* (1 *rai* = 0.16 ha) are recommended to be the optimal number traps for controlling the major insect pest of vegetable (e.g., diamondback moth and thrips). Furthermore, one hundred of white or blue sticky traps can be integrated in controlling thrips for the orchid farm.

Tantiyuth, *et al*. (1995) conducted the research at Phrabudhabat Experiment Station from August to November 1994. Four sticky trap colors, namely; blue, white, yellow and an invented yellowish sticky trap were placed surrounding the Tainan 9 peanut field to verify the attracting effectiveness for sucking insect of peanut. The result indicated that thrips and jassids were the only two sucking insects caught on the sticky traps. Thrips were caught on the trap more than jassids. The ready-made yellowish sticky trap color was found the most effective in attracting both sucking insects in 1993. However, for 1994, the new yellowish sticky traps were inferior to the ready-made ones and it was significantly different in catching jassids but not thrips. Piriyapol, *et al*. (1997) conducted the research on efficiency of various color sticky traps (i.e., yellow, blue, orange, green, white and cleared) for controlling watermelon thrips in farmer field, Nakhon Pathom province during December 1995-March 1996. It was found that blue sticky trap was the most effective to catch thrips, the average thrips caught was 1,348 per trap followed by white and green sticky traps in which the numbers of thrips were found at 838 and 685 per trap, respectively.

The yellow, orange and cleared sticky traps had caught the lowest number of thrips. The effect of light traps for attracting of beet armyworm *Spodoptera exigua* (Hübner) (Lepidoptera:Noctuidae) in grape field was investigated from December 1993 to March 1994, under natural conditions at Ratchaburi province (Namruangsri, *et al*., 1993). Results showed that black light F18/w-BLB and FL20T12/350 BL were more effective attractants to the moth than daylight neon. These light-traps caught the moths 13.30 and 11.30 times better respectively, when compared to daylight neon.

Cultural Methods or the Use of Agronomic Practices

The most important insects of sugarcane in the tiller stage are the early shoot borer *Chilo infuscatellus* Snellen (Lepidoptera:Pyralidae), the white top borer *Scirpophaga excerptalis* Walker (Lepidoptera: Pyralidae) and the pink stem borer *Sesamia inferens* Walker (Lepidoptera:Noctuidae). The larvae feed within the growing point of the cane shoot causing dead-heart symptoms. Prachuabmoh, *et al*. (1992) set up an experiment mainly focused on reducing insecticide usage for shoot borer control by cultural method. Paired comparisons were made under burned dry sugarcane leaf after harvesting and unburned (mulching) plots at Cholburi, Suphanburi and Kanchanaburi provinces. Observations carried out over many locations with many cane varieties, showed that in the mulching plot, an average 3.07 percent shoot infestations were found, while in the burned plots 10.65 percent shoot infestations were reported. Most of the mulching plots reduced an infestation to levels below damaging levels. Pitaksa, *et al*. (1988) also confirmed that the mulching plot and no burning plot have low insect infestation, less oviposition and highly significant than those of burning plot. Mulching plots also increased the moisture content and organic matter in the soil. In addition, investment cost such as the cost of using insecticide, herbicide and labor in mulching plots were reduced.

Cultural control of the brown planthopper (BPH), *Nilaparvata lugens* Stål (Homoptera:Delphacidae) was reported in organic rice fields (Ruay-aree, *et al*., 1999). The control of *N. lugens* (BPH) by draining the rice field was found to be an effective method. BPH is a major pest especially of the organic rice cultivation. Therefore, the population of BPH and its control in KDML 105 and HSPR organic rice fields were studied at Chai Nat Rice Experiment Station in the wet season crop. The BPH density in the drained paddy was 24 ± 19.9 times less than that in the flooded paddy. The yield of the organic rice, KDML 105 and HSPR obtained were 508.5 and 333.5 kg/*rai*, respectively. The investigation of natural enemies revealed the occurrences of egg parasitoids *Oligosita yasumatsui* Viggiani and Subba Rao (Hymenoptera:Tricho-grammatidae) and *Tetrastichus* spp. (Hymenoptera:Eulophidae) at 32.1-51.8 percent and 6.8-9.9 percent while those of the predators, spiders and mirid bug *Cyrtorhinus lividipennis* Reuter (Hemiptera:Miridae) were 56.6-83.7 and 14.3-40.5 percent, respectively. The spiders play a more important role than the mirid bug in the control of BPH. These natural enemies were abundant on both vegetative and reproductive rice growth stages. The BPH density in the drained paddy was 24 ± 19.9 times less than that in the flooded paddy. The yield of the organic rice, KDML105 and HSPR obtained were 508.5 and 333.5 kg/*rai*, respectively.

Physical Control

Trials on preservation of corn seed quality in airtight storage were carried out at Uniseeds Co., Nakhon Ratchasima province during October-December 1996 and December 1996-September 1997 (Sukprakarn, *et al*., 1997). The 10-mt sacks of corn seed var. Suwan 1 were stored in tailored polyvinyl chloride (PVC) sheet called “Volcani cube” with 0.8 mm thickness and 15 m^3 in volume. The cubes were placed outdoors for three and nine months, respectively and observations were made at 2-week intervals to determine the temperature, relative humidity and seed moisture contents inside the cube. After three and nine months, the cubes were uncovered to observe grain damaged by insect, number of insects, mould infection, germination percentages, moisture contents of seed, temperature and relative humidity and compared to those before treatment and control. The results of both trials indicated that the cube could preserve corn seed quality. No insect infestation and no live insect were observed. Mould infection percentages were not much increased and aflatoxin was detected in small amount only on the second trial. Seed moisture contents, germination percentages, temperature and relative humidity before and after treatment were slightly different and the corn seed were still in good condition.

Research on cobalt-60 (Co-60)for controlling orchid thrips *Thrips palmi* Karny (Thysanoptera: Thripidae) was conducted by Bansiddhi, *et al*. (2001). The results indicated that orchid kept in a cool room condition at the temperature 15ºC before treating with Co-60 was not significantly different to the one that was treated prior to keeping in the cool room. Five days after treatment with Co-60 at the rate of 0.5 and 0.75 kGY, 80 percent thrips mortality were observed and there was no effect on the orchid shelf life. However, Co-60 at the rate of 1.0 and 1.5 kGY killed almost 90 percent thrips but it shortened the orchid shelf life.

Biological Control

In Thailand, biological control has provided good results. Difficulties are faced in large-scale implementation due to lack of bio-agent productions. NPV and Bt are widely used for controlling major insect pests on various economic crops for instance rice, cotton, sugarcane, asparagus, okra, cabbage, grape, orange, legume crops and vegetables. The NPV pilot plant has been established since 1994 with the main objective of improving the production capacity of two viruses, *Helicoverpa armigera* NPV (HaNPV) and *Spodoptera exigua* NPV (SeNPV) to a semi-commercial scale (Ketunuti, *et al*., 1999). To increase the production capacity, rearing containers for these two host insects as well as their artificial diet have been developed so as to reduce the production cost and duration. However, the limit of rearing space is a major problem for increasing NPV production. The artificial diet costs ฿0.58 and 0.29 per one cotton bollworm and beet armyworm larva, respectively whereas modified diet for virus propagation costs ฿0.13 per larva. A 36-cell plastic tray has been developed for rearing *S. exigua* and *H. armigera* larvae in order to replace 2 ounces plastic cup which has been used for more than two decades. Moreover a 198-cell plastic tray has successfully substituted the plastic cup for propagation of both virus species. The production cost for 1 liter of SeNPV and HeNPV are ฿1,368.42 and ฿1,373.20, respectively. The production capacity of both viruses during October 1998 to December 1999 was quite far away from the production target of 1,000 liters per year.

The well-known predatory stink bug *Eocanthecona furcellata* Wolff (Hemiptera:Pentatomidae) has been utilized for controlling various insect pests on many economic crops. The control of beet armyworm, and American bollworm in asparagus by *E. furcellata* was carried out in the farmer field, Damnoen Saduak district in Ratchaburi province. From December 1997 to July 1998, third and fourth instar of the stink bugs were released at the rate of 3 nymphs/hill when there were infestations of *S. exigua* and *H. armigera*. This was compared with a non-released plot. The populations of both insect pests were checked at 6-8 days interval. The results showed that the stink bug had high efficacy for controlling beet armyworm and American bollworm throughout the experiment. The average decrease of both worms was 74.23 percent in the released plot whereas only 47.83 percent in the check plot (Nachapong, *et al*., 1999).

The egg parasitoid *Trichogramma* spp. (Hymenoptera:Trichogrammatidae) has been released to integrate with other control tactics for major insect pest of cotton and sugarcane. Prathomrat (2001) reported the effective control of different major insect pests such as *H. armigera* on cotton and tomato, sugarcane borer and corn stem borer. This was demonstrated in a cotton IPM plot carried out at Wang Ngam Yen district, Srakeaw province on an area of 60 *rai*. The field experiment aimed at cotton bollworm control by integrated methods, especially the biological control agents. Egg parasitoids such as *T. confusum* were released at the beginning of 1995. The releases were carried out nine times when the cotton plants were 1-2 months old. The release rate was 30,000 parasitoids per *rai* each time. The results showed that in the farmers' plots the parasitism percentage by *T. confusum* were 7, 5 and 12 percent in August, September and October, respectively while in the demonstration plot the parasitism percentage by *T. confusum* was found at 42, 27 and 54 percent in August, September and October, respectively. The release of egg parasitoids can effectively control *Helicoverpa* eggs and the pesticide application can be reduced by 20-30 percent. For controlling the sugarcane borer, *T. chilonis* Ishii caused about 40 percent egg parasitism naturally in the field.

Approximately 20 species of insect pests tested under laboratory conditions were host of entomo-pathogenic nematodes. Three entomopathogenic nematodes were experimented to control subterranean ant *Dorylus orientais* Westwood (Hymenoptera:Formicidae) the most serious insect pest of peanut pod. The result of the first experiment revealed significant differences in the percentages of subterranean ant mortality which were 30, 46 and 34 percent for the infection of *Steinernema riobravis, S. carpocapsae* (Nematoda: Steinernematidae) and *Heterorhabditis* sp. (Nematoda:Rhabditidae), respectively. The highest infection rate was 11.25 percent for *Heterorhabditis* sp. in the second experiment (Satayavirut, *et al*., 1999). However, in the field, the control cost is 10-60 percent higher than chemical control. Somsook (2001) reported that *S. carpocapsae* was very effective for controlling the bark-eating caterpillar *Cossus* sp. (Lepidoptera:Cossidae) on longkong and langsat, flea beetle *Phyllotreta sinnuata* Stephen (Coleoptera:Chrysomelidae) on Chinese radish and beet armyworm *S. exigua* on marigold.

Genetic Method

In order to minimize the adverse effect of pesticides, many attempts have been made to control the cotton bollworm, *H. armigera* by using botanical and microbial insecticides. Recently, Bt-transgenic cotton has been developed to reduce the use of synthetic insecticides against this insect. This could be an alternative control measure farmers can choose to raise the incomes of their products and hopefully lead to the increase of the growing area of cotton.

Study of resistance of Bt-transgenic cotton to infestation of cotton bollworm was conducted under field conditions during July 1997-January 1998 at Nakhon Sawan Field Crops Research Center, Si Samrong Field Crops Experiment Station, Sukhothai province and Loei Field Crops Experiment Station. The Bt-transgenic cotton varieties, NuCOTBN 33^B and NuCOTBN 35^B, were compared with recommended cotton varieties, Srisamrong 60, DP 5415 (non Bt-transgenic) and Sudan. The results indicated that the Bt-transgenic cotton was resistant to the cotton bollworm in all three locations where the experiments were conducted. The least number of cotton bollworm was found on Bt-transgenic cotton as compared to those found on Srisamrong 60 and other cotton varieties tested (Jee-rajunya, *et al*., 1999). Under severe outbreak condition of cotton bollworm in Nakhon Sawan, the yield of the Bt-transgenic cotton was higher than those of Srisamrong 60 and other cotton varieties. Under the low incidence of cotton bollworm the yields of the Bt-transgenic cotton and of Srisamrong 60 were almost the same. At Loei Field Crops Experiment Station where there was an outbreak of cotton leaf curl disease, the average yield of the Bt-transgenic cotton was lower than that of Srisamrong 60. This was due to the resistance of Srisamrong 60 to the leaf curl (virus) disease whereas the Bt-transgenic cotton was more susceptible to this virus.

GOVERNMENT POLICIES AND PROGRAMS ON USE OF NONPESTICIDE METHODS FOR CONTROLLING CROP PESTS

Since 1997, Thailand has faced an economic crisis as well as most other countries all over the world. Although the government had set the 7th National Economic and Social Development Plan (NESDP) to adjust agricultural production structure, improve quality of life, conserve and rehabilitate natural and environmental resources from 1993 to 1996, the economic problems, for instance, the income gap and social problem still remain.

During 1997-2001, in the 8th NESDP, the strategy was to develop human resource and implement alternative agriculture. In this plan, reduction of agrochemical usage is mentioned and conservation of natural and environmental resources. Moreover, alternative agriculture had been introduced for sustainable agricultural development. The plan also mentioned that the alternative agriculture included integrated agriculture, organic agriculture, natural agriculture and agro-foresty. At present, it is the beginning of the 9th NESDP (2002-06). In order to meet the expectations of the NESDP there is a need for restructuring agricultural production and quality improvement. The quality of agricultural production would depend upon the marketing and the consumer demands.

ISSUES AND PROBLEMS IN USING NONPESTICIDE METHODS FOR CONTROLLING CROP PESTS

Problems of using nonpesticide methods for controlling crop pests in Thailand arise as a means to minimize pesticide residues in food. Two pressing questions are: how can we convince the agricultural producer not to use a common procedure but do the complicated one instead?; and how can the government sector compete with the commercial pesticide sector?

As compared to chemical control method, the bio-pesticide is not only slowly effective but also high cost of control. It can not guarantee 100 percent control by using only the bio-agents. The producers do not want to take a risk to lose their investment. They can not be sure when pest will destroy their crops so that they have to rely on the preventive chemical application and always refuse insect pest scouting before making decision to control. Bio-pesticide has some limiting factors, for instance, its shelf life which is effectively in a short period of time. For effectively use of nematode, it is very essential to apply where having humid condition but the hot sunshine and ultraviolet are the limiting factors for applying Bt and NPV (Nanta, 2001).

The cost of control is expensive for bio-agents and could take more time to accomplish. It is very difficult to manage on a large scale and can only be implemented in a small farm. Lack of research support for practicable procedures also pose problems as are controversial issues surrounding Good Manufacturing Practices (GMPs), such as Bt-transgenic cotton. Ineffective technology transfer and demonstration hampers implementation of research findings. Hence, promotions of nonpesticide methods for controlling crop pests requires clear policy and planning, multidisciplinary approach, farmer participation, and strong government support.

SUGGESTIONS FOR EFFECTIVE AND EFFICIENT USE OF NONPESTICIDE METHODS

The effective and efficient use of nonpesticide methods for controlling insect pests in Thailand should focus on using resistant varieties and biological control.

Resistant varieties are effective for disease management and there are only a few that are tolerant to insect damage (Field Crop Research Institute, 2001).

- ***Rice***: Chainat 1, Supanburi (SPR) 1, SPR 90 and Phitsanulok (PSL)2 – resistance to BPH; Ubon 2 resistance to leaf blight
- ***Cotton***: Srisamrong 60 – resistance to leaf roll (virus) disease
- ***Corn***: Suwan 1, 2, 3, 5 and Nakorn Sawan 1 – resistance to downy mildew (DM)
- ***Sugarcane***: Uthong 4 – smut and red rot wilt resistance; K84-200 – smut and red rot wilt resistance and stem borer tolerance
- ***Soybean***: Chiang Mai 60 – rust and bacterial pustule (BP) resistance; Chiang Mai 3 – soybean mosaic virus, DM and BP resistance; Sukhothai 3 – anthracnose and root-knot nematode at seedling stage
- ***Mung bean***: Kampang Saen 2 – highly resistance to Cercospora leaf spot
- ***Black gram***: Phitsanulok 2 –very highly resistance to Cercospora leaf spot
- ***Peanut***: KhonKaen 3 – resistant to rust, leaf spot, leaf miner, thrips and jassid
- ***Sesame***: Ubol-Rachathani 1 – tolerance to *Antigastra* sp., broad mite and opium bug; KKU2 – resistance to *Macrophomina phasiolina*.

Biological Control

- Efficiency of the predatory mite, *Amblyseius longispinosus* to control the two-spotted spider mite on strawberry
- Predatory stink bug, *Eocanthecona furcellata* for controlling cotton bollworm, *H. armigera* in asparagus
- Field trial on egg parasitoid *Trichogramma confusum* Vig., for controlling cotton bollworm, *H. armigera* in cotton, tomato fields
- Use of SeNPV and HaNPV to control beet armyworm, *Spodoptera exigua* and cotton bollworm, *H. armigera* on tomato and grape vine
- Effectiveness of entomopathogenic nematode, *Steinernema carpocapsae* for controlling the bark-eating caterpillar, *Cossus* sp. on longkong and langsat, rose apple fruit borer, *Meridachis* sp., diamond back moth and beet armyworm on Chinese kale and subterranean ant, *Dorylus orientalis* on peanut.

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11. THAILAND (2)

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INTRODUCTION

A comprehensive review on the use of natural enemies for controlling agriculture pests or biological control of insect pests and weeds in Thailand was also made by Napompeth (1982). Since then updates have been made in Napompeth (1988a, 1989, 1990a, and 1990b). Implementation of biological control as one of the key component in the integrated pest management programs of various insect pests in the country appeared in Napompeth (1981, 1987, and 1988b), and a brief review of biological activities in Thailand was made by Napompeth (1992).

This paper will be based mainly on these earlier-mentioned documentation and references together with updated unpublished information of the current activities especially on the utilization of natural enemies for controlling insect pests and weeds in Thailand.

BIOLOGICAL CONTROL OF INSECT PESTS

The strategy for utilization of natural enemies for controlling insect pests and weeds has been started from the exploration and evaluation of natural enemy complex associated with insect pests and weeds. The natural enemies showing potential in biological control were then identified and subjected to further study for possible exploitation in terms of augmentation and promotional campaign for their conservation.

The natural enemy complex associated with endemic key pests of economic crops had been explored and evaluated. The natural enemies showing potential in biological control were then identified and subjected to further study for possible exploitation in terms of augmentation and promotional campaign for their conservation.

The survey and evaluation of natural enemies were carried out on insect pests of cereal crops, field crops, plantation crops, fruit crops and other pests: such as rice stem borer complex *Scirpophaga incertulas* (Lepidoptera:Pyralidae), *Chilo suppressalis* (Lepidoptera:Pyralidae), *Chilo polychrysa* (Lepidoptera: Pyralidae), and *Sesamia inferens* (Lepidoptera:Noctuidae); rice leafhopper and planthopper complex *Nephotettix virescens* (Homoptera:Cicadellidae), *Nephotettix nigropictus* (Homoptera:Cicadellidae), and *Nilaparvata lugens* (Homoptera:Delphacidae); rice leaf folder *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae); sugarcane borer complex *Chilo infuscatellus* (Lepidoptera:Pyralidae), *Chilo sacchariphagus* (Lepidoptera:Pyralidae), *Chilo tumidicostalis* (Lepidoptera:Pyralidae), *Scirpophaga excerptalis* (Lepidoptera: Pyralidae), and *Sesamia inferens* (Lepidoptera:Noctuidae); sugarcane scale *Aulacaspis tegalensis* (Homoptera:Diaspididae); sugarcane whitefly *Aleurolobus barodensis* (Homoptera:Aleyrodidae); sugarcane wooly aphid *Ceratovacuna lanigera* (Homoptera:Aphididae); rhinoceros beetle *Oryctes rhinoceros* (Coleoptera:Scarabaeidae); and coconut slug caterpillar *Parasa lepida* (Lepidoptera:Limacodidae).

Among field crops such attempts were made on Asiatic corn borer *Ostrinia furnacalis* (Lepidoptera: Pyralidae), Bombay locust *Patanga succincta* (Orthoptera:Acrididae), corn thrips *Frankliniella williamsi* (Thysanoptera:Thripidae) and corn earworm *Helicoverpa armigera* (Lepidoptera:Noctuidae) on corn; cotton leafhopper *Amrasca biguttula* (Homoptera:Cicadelidae), cotton bollworm (*H. armigera*) and cotton whitefly

Bemisia tabaci (Homoptera:Aleyrodidae) on cotton; and bean fly *Ophiomyia phaseoli* (Diptera: Agromyzidae), green stink bug *Nezara viridula* (Hemiptera:Pentatomidae), leaf folder *Hedylepta indicata* (Lepidoptera:Paralidae) and leafminer *Aproaerema modicella* (Lepidoptera:Gelechiidae) on soybean.

The natural enemy survey in fruit crops covers the Oriental fruit fly (*Bactrocera dorsalis*) on various tropical fruits; banana skipper *Erionota thrax* (Lepidoptera:Hesperiidae) on banana; various coccids on fruit trees; mango leafhoppers on mango; and lemon butterfly *Papilio demoleus* (Lepidoptera:Papilionoideae) and citrus leafminer *Phyllocnistis citrella* (Lepidoptera:Phyllocnistidae) on citrus.

Other insect pests whose natural enemies are being surveyed and evaluated are:melon fly *Bactrocera cucurbitae* (Diptera:Tephritidae), diamondback moth *Plutella xylostella* (Lepidoptera:Yponomeutidae), *Thrips palmi* (Thysanoptera:Thripidae) and several insect pests of forest.

The natural enemy of these insect pests had been reported by various investigators and summarized by Charernsom and Suasa-ard (1994).

SOME SUCCESSES ACHIEVED IN UTILIZATION OF NATURAL ENEMIES

Some successes achieved in utilization of natural enemies for augmentative biological control of insect pests of economic crops in Thailand investigators were summarized by Napompeth (1990b and 1992) such as the use of egg parasitoid *Ooencyrtus erionotae* (Hymenoptera:Encyrtidae) and larval parasitoid *Cotesia eriorotae* (Hymenoptera:Braconidae) for the control of banana skipper (*E. thrax*); *Anastatus* sp. (Hymenoptera:Eupelmidae), egg parasitoid of the longan stink bug *Tessaratoma papillosa* (Hemiptera: Pentatomidae), was also mass-reared and released to provide satisfactory and long-term control in the longan and litchi-growing areas in the northern highlands. A substantial control of the sugarcane borer (*S. excerptalis*) was also achieved by using the larval parasitoid, *Cotesia flavipes* (Hymenoptera:Braconidae).

In the utillization of trichogrammatid egg parasitoids, *Trichogramma chilonis* (Hymenoptera:Trichogrammatidae) has been used sucessfully for the control of various sugarcane stalk borers. *Trichogramma chilotreae* (Hymenoptera:Trichogrammatidae) has also been used against the Asiatic corn borer, *O. furnacalis*, and complimented *T. chilonis* for the control of sugarcane borers as well (Napompeth, 1992).

The predatory pentastomid bug *Eocanthecona furcellata* (Hemiptera:Pentastomidae) was considered as one of the most important natural enemies for controlling several species of insect pests, and success achieved in augmentative biological control of caster semi-looper, *Ophiusa janata* (Lepidoptera:Noctuidae) (Suasa-ard, 1988). The mass-rearing technique of *E. furcellata* has been investigated and developed (Suasa-ard, 1999). The ongoing mass-rearing program of this predatory pentastomid bug at NBCRC, Central Regional Center, Kamphaeng Saen has made possible the production of a large number of nymphs of this predator for inoculative field releases for control cutworm and several other lepidopterous caterpillar pests in the field.

At present, one of the most serious insect pests of citrus in Thailand is the citrus leafminer, *Phyllocnistis citrella* (Lepidoptera:Phyllocnistidae). The natural enemies found associated with *P. citrella* were *Quadrastichus* sp. (Hymenoptera:Eulophidae), *Citrostichus phyllocnistoides* (Hymenoptera: Eulophidae), *Microbracon* sp. (Hymenoptera:Braconidae), *Ageniaspis citricola* (Hymenoptera:Encyrtidae), *Sympiesis striatipes* (Hymenoptera:Eulophidae) and *Cirrospillus ingenuus* (Hymenoptera:Eulophidae). Among the parasitoids, *Quadrastichus* sp. and *A. citricola* play an important role in controlling the population of *P. citrella* in Thailand (Kern-asa, 2001).

One of the most outstanding success in augmentative biological control in Thailand was the use of parasitoids for the control of sugarcane moth borer complex, *C. tumidicostalis, C. infuscatellus, C. sacchariphagus* and *S. inferens*. Several species of natural enemies of the sugarcane moth borer complex, were studied and it was found that *T. chilotraeae, Telenomus rowani* (Hymenoptera:Scelionidae), *C. flavipes, Xanthopimpla stemmator* (Hymenoptera:Ichneumonidae) and *Tetrastichus ayyari* (Hymenoptera:Eulophidae) were important parasitoids. The egg parasitoid *T. chilotraeae* and the larval parasitoid *C. flavipes* could be mass-reared in large numbers and use as a biological control agents in augmentative biological control of sugarcane moth borers (Suasa-ard, 1982; and Suasa-ard and Charernsom, 1995).

The use of *C. flavipes* for augmentative biological control of sugarcane moth borers was investigated. Field releases of *C. flavipes* were done at three location: Kamphaeng Saen, Sai Yok and Dan Chang. The percent parasitization increased to higher levels than those in the control plots at all locations. In release plots, the percent infestation by sugarcane moth borers decreased (Suasa-ard and Charernsom, 1996) and the success of *C. flavipes* for control sugarcane moth borers was confirmed in 1995-97. The investigation showed that the percent parasitization of sugarcane moth borers by *C. flavipes* were 17.5, 23.7 and 26.5 percent, respectively at Kamphaeng Saen and 17.4, 25.7 and 27.5 percent, respectively at Sai Yok and percent infestation of sugarcane moth borers in release and control plots were significantly different (Suasa-ard and Charernsom, 1999).

For the control of sugarcane stem borer *C. tumidicostalis*, about 2000 adults of *C. flavipes* were release per acre every year during 1998-2000. The population of sugarcane stem borers kept the borer under control and percent parasitization of sugarcane moth borers in release and control plots were different. It suggested a success in releasing *C. flavipes* for augmentative biological control of sugarcane stem borer (Suasa-ard, 2000 and 2001).

The resurgence of secondary insect pests in sugarcane induced by the overuse of insecticides was also witnessed by the sudden outbreak of the sugarcane scale, *A. tegalensis*, in 1976 followed by the sugarcane whitefly, *A. barodensis* in 1979 and the sugarcane bug, *Phaenacantha saccharicida* (Hemiptera: Colobathristidae) in 1981 and widespread occurrence of the sugarcane mite, *Schizotetranychus andropogonii* (Tetranychidae). However, *A. tegalensis* and *A. barodensis* were kept under control without using any pesticide, the former by various coccinellids and endomychids especially *Chilocorus circumdatus* (Gyllenhal), *Coccinella transversalis* (F.) and *Menochilus sexmaculatus* and the parasitoid of sugarcane whitefly had been investigated and found that *Azotus bimaculatus, Encarsia ochai* and *Amitus* were very effective parasitoids and kept the population of *A. barodensis* under control without using any pesticide (Charernsom and Suasa-ard, 1989; and Suasa-ard and Charernsom, 1994).

For classical biological control of insect pests involving introductions of exotic natural enemies, this began in 1963 when *Scolia ruficornis* was introduced from West Caroline Islands for the control of the coconut rhinoceros beetle, *O. rhinoceros*. This was followed by the introduction of *Diadegma insularis* from Canada in 1965 for the control of diamondback moth, *P. xylostella* (Clausen, 1978). Other natural enemies of *P. xylostella* introduced from India in 1965 were *Brachymeria* sp., *Cotesia plutellae, Macromalon orientale, Tetrastichus sokolowskii* and *Diadromus* (=*Thyraella*) *collaris*. A number of generalist predatory coccinellids introduced to Thailand, carried out during the 1970s mainly from Hawaii, include *Azya orbigera* (Coleoptera:Coccinellidae), *Coelophora pupillata* (Coleoptera:Coccinellidae), *Cryptolaemus montrouzeiri* (Coleoptera:Coccinellidae) and *Orchus chalybeus* (Coleoptera:Coccinellidae). In 1982, a coccinellid *Chilomenes lunata* (Coleoptera:Coccinellidae) was introduced from Kenya (Napompeth, 1990b).

Two additional coccinellids, *Curinus cocruleus* (Coleoptera:Coccinellidae) and *Olla abdominalis*, were introduced in 1987 and 1989, respectively. The former was from Saipan and Hawaii while the latter was from Hawaii. They were introduced for the control of the leucaena psyllid, *Heteropsylla cubana* (Homoptera: Psyllidae), which invaded Asia and the Pacific in the mid-1980s (Napompeth and MacDicken, 1989). An encyrtid nymphal parasitoid, *Psyllaephagus yaseeni* (Hymenoptera:Encyrtidae), was also introduced from Hawaii during 1987-88 to control *H. cubana*.

BIOLOGICAL CONTROL OF WEEDS

A number of both aquatic and terrestrial weeds amenable to biological control have been selected and control implementation initiated. The basic strategy is to search and evaluate if there exists any native biological control agents which could be further utilized. If none are found, introductions of exotic natural enemies are sought, especially for the known exotic weed species.

Among the achievements to date were the augmentative releases of the amaranth weevil, *Hypolixus truncatulus*, against the spiny amaranth *Amaranthus spinosus*; the moth borer, *Bactra staminea* against nut grass *Cyperus rotundus*; the pyralid moth *Syngamia abruptalis* against *Hyptis suaveolers; Agallia quadrinotata* against ground bur nut *Tribulus terrestris*; the chrysomelid *Altica foeveicollis* against the water primrose *Ludwigia* spp.; *Parapoynx diminutalis* against *Salvania cucullata* and the hydrilla leafmining fly *Hydrilla* sp. and the curculionid *Bagous subvittatus* against *Hydrilla verticillata* and a success was achieved by using the water lettuce moth *Epipsamnia pectinicornis* to replace all herbicides against water lettuce *Pistia stratiotes*. These cases have become "reversible biological control" when native biological control agents could be utilized for controlling exotic weed species.

Introduction program for biological control of exotic weeds was first carried out in 1977 when the mottled water hyacinth weevil, *Neochetina eichhorniae*, was introduced from Florida, USA for the control of water hyacinth *Eichhornia crassipes*. The chevroned water hyacinth weevil, *Neochetina bruchi*, which is a closely related species was also introduced to increase efficiency from USA via Australia in 1990. Subsequent introductions consisted of the chrysomelid *Agasicles hygrophila* from Australia in 1981 for the control of alligator weed *Alternanthera philoxeroides*. The seed bruchids, *Acanthoscelides quadridentatus* and *A. puniceus*, were introduced from Mexico via Australia in 1983 for the control of the giant sensitive plant, *Mimosa pigra* in a collaborative project with Australian Centre for International Agricultural Research (ACIAR). The tephritid gall fly *Procecidochares utilis* was released for *Ageratina adenophorum*. Almost all biological control agents introduced and released have become established, resulting in substantial control in several cases and complete control in some instances in the country.

CONCLUSION

The review and highlights of biological control activities in Thailand given so far indicated that there are still many tasks remaining to put more effort into the development of biological control activities in the country to a more practical level. Most of the pest problems in our agro-ecosystems are mainly caused by endemic pest species, thus conservation and augmentation should be emphasized. Emphasis should also be given to the evaluation and development of potential and promising biological control agents so that they could serve as the prominent "alternatives" to chemical pest control which is dominating the country sacrificing natural enemies which are valuable but invisible natural resources of the country with undue responsibility.

Cooperation and collaboration between various institutions at the national, regional and international levels are also essential in the basic foundation and future progress of biological control.

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12. VIETNAM

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INTRODUCTION

Vietnam, covering an area of about 330,363 km^2, extending from North to South and wider maritime area which includes the continental shelf and the Hoang Sa archipelago (Paracel Islands) to the North, and Truong Sa archipelago to the South. It is bounded in the north by China, in the west by Laos and Cambodia, and in the east by South China Sea. The conformation of Vietnam is a stretch over 15º latitudes that situated between 8º and 24º north latitude and long more than 3,200 km of coast from border with China to that with Cambodia, and generated the three climate zones. The characters of weather are of mildness and humidity, alternation of monsoon, distinction of four seasons in the north, two distinguished seasons in the south, adverse effect of the mountains in the central and rich rainfall. The annual rainfall varies from 700 to 4,000 mm and average temperature that gradually increased from the north to the south is 23-27ºC. In general the climate is tropical zone with the complicated effect of monsoon and subtemperate weather.

The economy of Vietnam relies basically on agriculture with a small share of industry, including small and handicraft industries. Through innovative steps initiated from 1989, achievements in agricultural production contributed in pulling the economy out of crisis. Rice production reached a growth rate of 51 percent in comparison with those of the whole country production with an average yield of nearly 4.0 mt/ha (Figure 1). The two main rice bowls of Vietnam are Red River Delta (seven provinces), and Mekong Delta (12 provinces), each of which occupied 15.5 percent and 46.5 percent of the total rice area, respectively. Rice is grown in central coast region covering 18.1 percent of the total rice area.

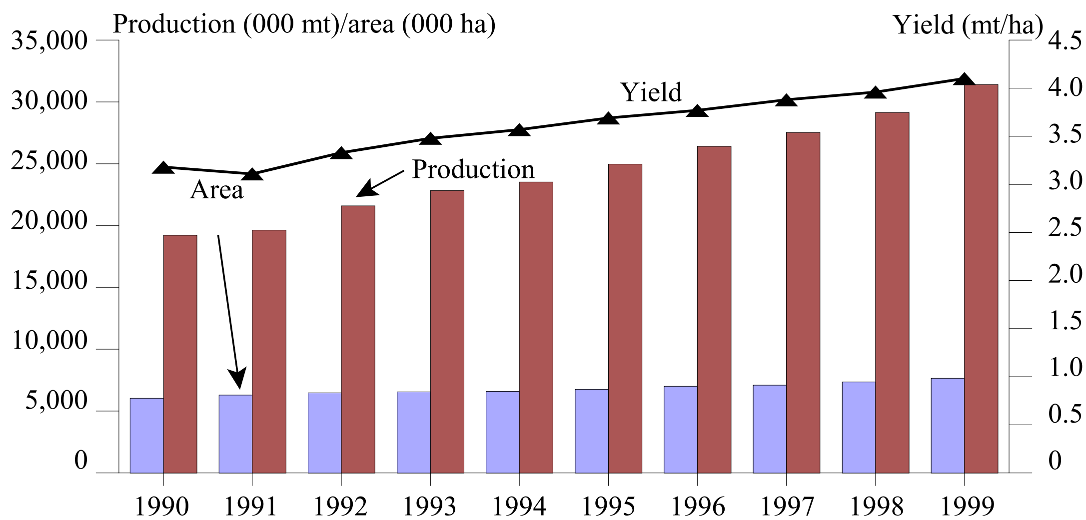

Figure 1. Vietnam National Rice Production, 1990-99

Source: *Statistical Yearbook 2002*, Statistical Publishing House, Hanoi, 2001.

Rice is the most common crop in the lowlands during the raining and dry season. More than 50 percent of cultivated land areas are under rice in Mekong Delta. Other crops grown in the upland areas during the rainy season are corn, sugarcane, vegetables, and orchards and fruit trees. The existing rice ecosystem in Mekong Delta consisting of rainfed lowland and irrigated lowland rice has provided the main rice supply to the market demand and export. Mekong Delta is an intensive rice cultivated area. The total food output in the Mekong Delta has continuously increased and exceeded the national planned target of 4.85 million mt of paddy rice in 1976 to 6.98, 9.5 and 13 million mt in 1985, 1990 and 1995, respectively.

For the past 15 years the Mekong Delta had a difficult condition for agriculture due to the historical background of the nation. The land utilization was under management of the collective agricultural system. In 1978, due to pests and diseases outbreaks and flood, agricultural production was the lowest in past 20 years. After 1980, many projects were implemented, especially with 1) high-yielding rice varieties that were resistant to rice brown planthopper (BPH) and rice blast disease, 2) irrigation system for small (fields) and large scale (area), and 3) changes in cropping pattern and cropping practices; but most important was the departure from collective agricultural system to an individual-oriented contract system of production. From that period individual households were able to cultivate land independently. The agricultural production has been stable and increasing year by year (Figure 1). The cropping pattern had changed year by year contributing to a diversification of crops that still retains a basically rice production system.

CURRENT STATUS OF USING NONPESTICIDE METHOD TO CONTROL CROP PESTS

Since 1978 up to 1992, important pest and disease outbreak recorded in the Mekong Delta included BPH, rice ragged stunt disease (rice stripe virus [RSV]), sheath blight, and red stripe. Besides weedy rice is also a considerable problem because of direct seeding method (Table 1).

Table 1. Infested Rice Areas in Mekong River Delta in Five Years

(Unit: Percent)

Pests	1993	1994	1995	1996	1997
Thrips	4.4	4.9	6.6	4.4	5.8
Case worm	1.9	1.2	2.6	1.4	2.0
Armyworm	0.5	0.2	2.1	1.2	1.8
Leaf folder	10.9	12.4	18.8	18.1	15.5
Stem borer	10.7	8.8	7.9	6.3	6.7
Brown planthopper	28.2	10.0	14.1	13.4	9.1
Rice bug	2.4	1.9	3.3	3.5	2.5
Blast	4.0	5.8	7.4	6.0	5.4
Sheath blight	12.0	13.5	15.1	12.6	10.3
Red stripe	7.1	6.1	5.6	4.3	6.7
Rats	3.3	4.0	2.0	3.4	3.5
Hopper burn	-	18,000	Scattered	Scattered	-
Rice area (000 ha)	3,257	3,357	3,758	3,388	3,700

Brown Planthopper

The biggest outbreak of BPH in 1977-78 caused a great loss to rice production in Mekong Delta (Table 2). The resurgence of BPH that was recorded in 1990 due to breakdown of resistant varieties having BPH2 gene and the misuse of pesticides over an extended period that kill natural enemies of BPH. To control BPH, farmers used broad-spectrum insecticides.

Rice Leaf Folder

Farmers usually spray broad-spectrum insecticides to prevent damage of rice leaf folder (RLF). This practice leads to resurgence of BPH because natural enemies were killed. From 1993, studies on self-compensation of rice plants proved that rice plant can recover and withstand the feeding of RLF.

Table 2. Area Infested by Rice Brown Planthopper in the Mekong River Delta

Crop Season	Total Area (ha)	Infested Area		Hopper Burn Area	
		ha	Percent	ha	Percent
He-Thu, 1977	147,186	17,623	11.97	161	0.11
Mua, 1977	723,000	162,693	22.50	18,496	2.56
Dong-Xuan, 1977-78	277,792	50,522	18.19	2,010	0.72

Rice Blast

Annually, rice blast disease peak in February. In 1989-92 blast epidemics were found on newly released varieties like MTL58, OM 269 in all cultivated areas in Mekong River Delta. In 1999, total infested area was about 146,000 ha comprising 3.6 percent of the cultivated areas, especially in Bac Lieu, Tien Giang, Kien Giang, and Soc Trang provinces. The infested areas followed the increasing of cultivated areas and degree of rice intensification (Table 3).

Table 3. Area Infested by Rice Diseases in the Mekong River Delta

Year	Sheath Blight		Blast		Red Stripe	
	ha	Percent	ha	Percent	ha	Percent
1981	-	-	30,570	1.2	-	-
1982	-	-	26,430	1.0	-	-
1983	70,200	0.3	23,660	0.5	-	-
1984	35,230	1.5	77,850	3.1	-	-
1985	47,210	1.9	23,610	0.9	-	-
1986	40,390	1.7	17,150	0.7	-	-
1987	126,630	5.4	9,690	0.4	-	-
1988	170,630	6.9	5,430	0.2	-	-
1989	100,910	3.9	9,870	0.4	-	-
1990	150,310	4.7	3,560	0.3	66,350	2.2
1991	360,690	11.6	11,690	0.7	244,170	4.6
1992	332,840	10.7	148,130	4.5	148,200	7.5
1993	381,760	12.0	114,630	4.0	169,470	7.1
1994	357,870	13.4	182,700	5.8	189,900	6.1
1995	487,460	14.9	239,320	7.3	163,310	5.0

Sheath Blight

Sheath blight was recorded in rice fields that applied high dose of fertilizer and high planting density. Sheath blight was observed under these conditions and caused serious losses. Sheath blight had a tendency to increase year by year. Farmers also control sheath blight by application of fungicides at least twice per season. Fungicides could control sheath blight; however, the damage will be higher in the next season. This practice obviously is not stable and is harmful to the environment.

Red Stripe

This is a new rice disease that was recorded in 1988 in Tien Giang, An Giang. Red stripe disease (RSD) was recorded for the first time causing heavy damage in a few hundred hectares. Yield losses were estimated to be as much as 50 percent together with typical symptoms of premature development or "*chin som*".

Weedy Rice

Weedy rice is a new pest of rice that was recorded in Tien Giang and other provinces of Mekong River Delta since 1994. The occurrence of weedy rice is at 18 southern provinces. There was 27 designation of weedy rice determined in Mekong River Delta. The estimation of yield losses is at about 10-15 percent.

Rice Field Rats

The rice field rats in the Mekong Delta were dominated by *Rattus argentiventer* (Brown, *et al.*, 1998). In the Mekong River Delta, rice field rats have been chronic pests. Before 1975, rat damages were estimated at about 5 percent of gross products per annum. Annual losses attributed to rats was estimated at US$6 million; particularly, losses due to rat rose up to US$20 million in 1993 and US$30 million in 1996. The area damaged by rats was 245,000 ha in 1999, 22 percent higher than that of 1998. The highest rice areas destroyed by rats were recorded in the winter-spring and summer-autumn crop season (Figure 2). The occurrence of rat damage was in Long An, Kien Giang, Dong Thap, An Giang, Tra Vinh, Soc Trang, Bac Lieu, Can Tho, and some coastal provinces. Farmers in the Mekong Delta now recognized "*chuot dong*" (rice field rats) as the most important rice field pest.

In general farmers in the Mekong Delta like to control rice field rats by using rodenticides. Farmers have also used other innovative physical methods such as living-trap, slippery trap, digging and fumigation of burrows, high voltage electrical trap, flooding, and dogs hunting during and at the end of season crop. Some farmers used the plastic barrier that surrounds individual rice field to protect their fields. However, the rat control of farmers usually is spontaneous and passive, therefore less effective. The gaps in knowledge on rat biology of local government officers, and the ineffective collaboration between local governments also contributed to the damage by rats.

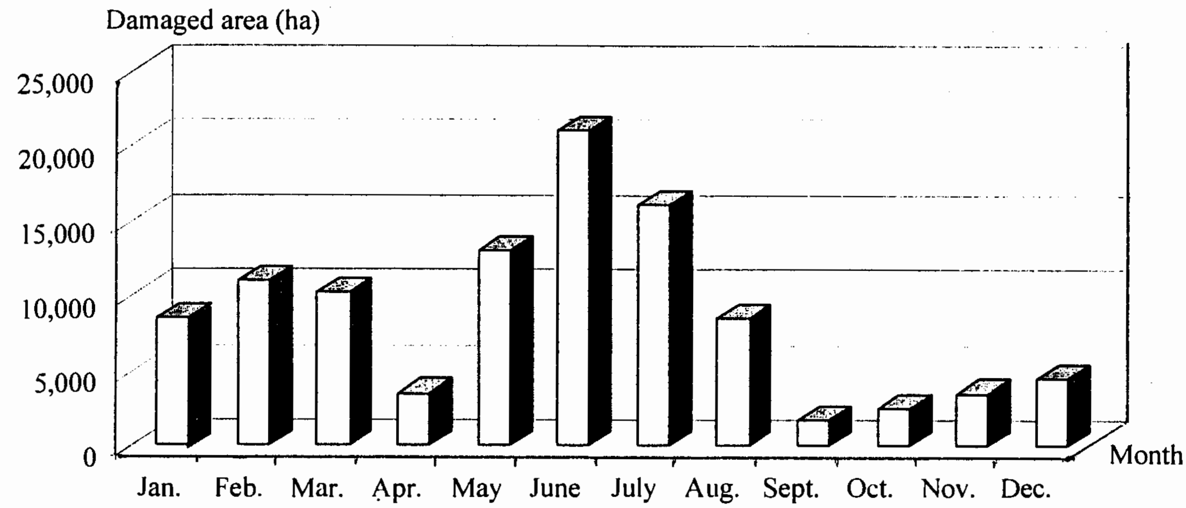

Figure 2. Rice Area Infested by Rats in the Mekong Delta
Based on Average of Reports from 1992-97

PROBLEMS AND RISKS IN CONTROLLING PESTS BY USING PESTICIDES

The application of pesticides has been the most common approach by farmers to control pests. Landell Mills Market Research Ltd. (1995) reported that the pesticides used in Vietnam comprised insecticides, 40 percent; herbicides, 27 percent; and fungicides, 33 percent. The amount of pesticides use has increased year by year. There are more than 600 trade names of pesticides and these are recognized as unsustainable factors for agricultural development. Farmers normally are not interested in the adverse effects of pesticides. An investigation showed that 65 percent of farmers can read instructions on the labels but only 39 percent of them apply pesticides as guided. Besides, more than 60 percent farmers did not use protective cloths except gauze masks. In the first six months of 2000 there were 11 percent cases of food poisoning due to pesticides as reported by Department of Management of Qualification, Safety of Food – Ministry of Public Health. Pesticides use in irrigated rice fields had hazardous effects on aquatic living things, and plankton. The application of pesticides also minimized population of soil fauna in upland crops such that earthworm populations decreased by 71 percent, 30 days after herbicides treatments (Nhat, *et al.*, 2000), and the tremendous decline abundance of soil fauna in orchard gardens (Cuc, *et al.*, 2000). This situation should be changed in the coming years due to effort of agricultural scientists.

CASE STUDIES: ISSUES AND PROBLEMS IN USING NONPESTICIDE METHODS

Some examples of using nonpesticide methods in national programs and foreign collaborated programs, in both research and development are as follows:

- The application of *Trichoderma* in powder formulation into rice straw for decomposition and the decomposed rice straw would be applied in combination with bio-organic phosphorus fertilizer as well as organic fertilizer (Man, *et al*., 1999).
- The use of di-potassium hydrogen phosphate to induce the resistance to rice blast (Du, *et al*., 2000).
- The use of mycoherbicides to control barnyard grass (*Echinochloa* spp.) (Dinh, *et al*., 2000).
- The use of antagonistic bacteria to control rice sheath blight (Du, *et al*., 2001).
- Attempt at management of vegetative diversity to control rice insect pests (Lan, *et al*., 2001).
- The minimum use insecticides in vegetable production through application of plastic sheet cover, the adjustment of planting time, planting densities, fertilizer amounts, monitoring insect pest developments.

Rice Seed Health for Disease Management

This is a collaboration program with International Rice Research Institute (IRRI) scientists that was conducted from 1998 to 2001 in five provinces in the Mekong Delta. The procedure followed the method of farmer participatory research (FPR), one part of farmer's field of about 1,000 m^2 planted healthy seeds, the rest followed farmer practices. The package of Seed Health Program is that clean, healthy rice seeds of common rice variety were distributed to participating farmers, no pesticides were applied to the field except the recommendation by agricultural technicians when it was needed. Eighty percent of participant farmers did not apply insecticides during the three continuous crop seasons. Farmers gained about VND900,000 (Vietnamese dong; US$60) each hectare (Plant Protection Department [PPD], 2000).

In 1999 the implementation of a plan of "non-spraying insecticides, applying low planting density, using low fertilizer-based leaf color chart" was conducted in Long An, Tien Giang under guidance of PPD. Yield of demonstration fields were at 6.5 mt/ha similar to that of control. Farmers gained benefit from saving money through decreasing amount of seeds and fertilizers at about US$100/ha/season.

Rodent Management Using Nonpesticide Methods

The Trap Barrier System (TBS) method was introduced to farmers in the Mekong Delta since 1997 following that organized in Malaysia (Lam, 1988). Some of the strength and weakness in application of TBS had been analyzed (Singleton, *et al*., 1998). Helped by Australian Centre for International Agricultural Research (ACIAR) and Commonwealth Scientific Industrial Research Organization (CSIRO) this device of rice field rats control was introduced to farmers in Tien Giang and Soc Trang provides during 2001-02. The program was conducted as a community-based activity where farmers in village with fields located in the effective range of this device build, maintain the trap, and collect captured rats every day.

The TBS consists of a plastic fence and multiple-capture cage made from strong wire mesh traps. One part of rice field measuring at about 1,000 m^2 with a trap crop planted three weeks in advance of the surrounding crop can provide protection for crops at least 200 m away from the fence (Singleton, *et al*., 1996). The fences are made of heavy plastic 0.7 m wide, supported by bamboo poles interconnected by plastic string. The base of the fence is buried in the mud. Holes are made at certain distances along the fence, corresponding to the position of the traps. Eight multiple-capture cage traps are placed within the fence, facing outwards. There is an opening at one end of a trap, which leads to a funnel that the rats can enter but not exit. At the other end is a door held closed with a pin, by which rats can be collected. Straw is placed over the trap to provide shade to the captured animals. Traps should be cleared of rats as early as possible each day.

The first application of TBS plus trap crop was in Vinh Hung district (Long An province), and then in Tieu Can district (Tra Vinh province) in 1997 (Hung, *et al*., 1998). A total of 1,680 rats caught at five TBS setup at distance 400-500 m from each to another indicated that the TBS plus trap crop provides an area of protection to surrounding crops within 200 m of the fence. The protection is stronger the closer the crop is to the TBS (Table 4).

Table 4. Capacity of Protection (Percentage of Damaged Tillers) of Five TBS in Tap Ngai Village, Tieu Can District, Tra Vinh Province, Summer-Autumn 1997

Day After Seeding	Within Range Effect of TBS	1 km Far from TBS (Control)	7 km Far from TBS (Control)
10	2.4	16.0	11.8
20	0	12.4	0
30	0	0	17.1
40	1.5	15.6	0
50	0.7	17.3	19.9

Source: Hung, *et al*., 1998.

TBS can be modified as a linear barrier established between different habitats to protect rice fields from rats. In Tan An Hoi (Cu Chi) the wild pandanus was considered secondary habitat of rice field rats. During the winter-spring season of 1997-98, a linear TBS 300 m-long was set up along rice fields and wild pandanus area. Some 1,033 rats were caught during the crop stage. Continuously, Sub-PPD of Ho Chi Minh City constructed 76 TBS plus trap crop from 1997 to 2000. Rat damage decreased 30-60 percent comparable to previous season crop. Average number of rats caught was 200 rats/trap/season crop.

In Bac Lieu province, the Sub-PPD established 45 TBS plus trap crop from 1997 to 2000. One TBS attracted 120-140 rats/season and protected 20-25 ha surrounding rice fields. In Tien Giang province, the Sub-PPD conducted seven TBS in seven districts in 1997.

In the year 2001, 26 TBS were conducted in Tien Giang and Long An that protected about 500 ha (Table 5) (Anon., 2002).

Table 5. Yield in TBS Sites and Control Areas in Soc Trang, 2001

Location		Yields	
		TBS Sites	Control
My Tu	1st season	6.28	5.30
Long Phu	1st season	5.47	5.11
	2nd season	5.82	5.52

Note: Averages of 10 samples at each treatment.

TBS is now familiar to farmers in Mekong Delta. TBS also applied in other crop, i.e., corn. Almost all the southern provinces had accepted the concept of rice as a trap crop and developed TBS successfully. Highly effective, TBS kill rats from the early season, saving costs and do not pollute the environment. However the implementation of TBS should be manipulated in accordance with the specific condition of each region. Farmers need to know that the application of TBS on a large scale do not belong to individuals.

ENABLING POLICIES AND PROGRAMS TO SUPPORT NONPESTICIDE METHODS

There is a strong linkage between the plant protection services in provinces and research organizations with rice farmers.

In each province the provincial Sub-PPD which belongs to PPD-MARD (Ministry of Agriculture and Rural Development) had a provisional network reaching to district that include 5-6 technicians; they are responsible to monitor the pest dynamic and development. Often, rice farmers were invited to attend training courses on Integrated Pest Management (IPM) or join FPR programs. The IPM national program under the technical support of FAO has organized thousands of farmer field schools for rice farmers.

For research institutes and universities there are the Institute of Agricultural Science of South Vietnam, Cuu Long Delta Rice Research Institute, Can Tho University, and Agriculture and Forestry University. Most of basic and applied researches for solving the national or provisional problems in conducted in these institutes, providing new varieties and improving practices of rice farmers. Frequently provincial representatives were invited to attend science workshop organized by institutions or universities.

TOWARDS A MORE EFFICIENT USE OF NONPESTICIDE METHODS

The results presented are just initial achievements. Most of programs focused on rice while basic and applied research about methods of pest management need to have more consideration and targeted on agricultural crops including storage products. The interaction of land preparation, water, and nutrient management with chemical and non-chemical pest control should be studied and pest control strategies will be tested. New pest control strategies should be compatible to conventional framers' practices and analyzed together with social economic issues.

Natural biological control agents will be reared in good conditions to enhance their capacity due to improvement of farming management. The application of biotechnology in agriculture should be promoted as part of a pest management strategy. This technology would make many natural biological control agents more effective.

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2. PROGRAM OF ACTIVITIES

(10-17 April 2002)

Date/Time	Activity
Wed., 10 April	
Forenoon	Opening Ceremony Presentation and Discussion on Topic I: *Some Non-Pesticide Methods for Managing Crop Insect Pests – Present Status, Issues and Strategies* by Dr. Peter A. C. Ooi
Afternoon	Presentation and Discussion on Topic II: *Non-Pesticide Methods for Sustainable Crop Disease Management in the Asia-Pacific Region: Present Status, Issues and Strategies* by Dr. D. Hunter Presentation and Discussion on Topic III: *Biological Control of Vegetable Pests with Natural Enemies* by Dr. Eizi Yano
Thurs., 11 April	
Forenoon	Presentation and Discussion on Topic IV: *Non-Pesticide Methods for Managing Crop Weeds in the Asia-Pacific Region – Allelopathic Cover Crops* by Dr. Yoshiharu Fujii Presentation and Discussion on Topic V: *Control of Plant Virus Disease by Cross Protection in Japan* by Dr. Shinya Tsuda
Afternoon	Presentation of Country Papers by Participants
Fri., 12 April	
Forenoon	Presentation of Country Papers by Participants
Afternoon	Presentation of Country Papers by Participants
Sat., 13 April	
Forenoon	Workshop
Afternoon	Free Time
Sun., 14 April	Free Time
Mon., 15 April	
Forenoon	Leave Tokyo for Ibaraki Prefecture
Afternoon	Visit Ibaraki Agricultural Center – Kashima Agricultural Research Station Observe green pepper facility in Kamisu-machi, Ibaraki Prefecture Visit Japanese agricultural cooperatives, Shiosai Production Group
Tues., 16 April	
Forenoon	Visit Ibaraki Agricultural Center – Plant Biotechnology Institute and Horticultural Research Institute, Iwama-cho
Afternoon	Leave Ibaraki for Tokyo
Wed., 17 April	
Forenoon	Summing-up Session Closing Session