

INTEGRATED PEST MANAGEMENT

Ki-Baik Uhm
Entomology Division,
National Institute of Agricultural Science & Technology
Rural Development Administration
250, Seodun-Dong, Kwonseon-Ku, Suwon
Kyungki-Do 441-707
Republic of Korea

ABSTRACT

Integrated Pest Management (IPM) is accepted world-wide as the best way to protect crops with reduced pesticide use. However, IPM has several weak points with regard to ambiguous definitions, as well as difficulties in implementation. Several national IPM programs are discussed as case studies, and the needs of IPM in terms of policy, organization, research, extension, and evaluation. Case studies of successful IPM programs showed they were all good at defining their objectives and problems, and were able to harmonize policy, research, and extension in their implementation. To develop IPM programs for the 21st century, directional research and extension seems to be needed, rather than the development of new technology.

INTRODUCTION

For several decades, chemical pesticides have been considered the only reliable method of controlling pests. This was because most pesticides proved effective, while the cost of pesticides was only a small proportion of the total production costs. Consequently, growers, consumers and politicians did not pay much attention to an alternative approach — Integrated Pest Management (IPM). As a result, there have been relatively few successful cases of IPM.

Recently, however, the demand for IPM solutions have been increasing, rapidly due to the limitations now evident in chemical pesticides. First, the demand for food safety and conservation of the environment has been increasing, as the quality of public life improves with economic development. For example, articles in one of Korea's major daily newspapers dealing with pesticides appeared 134 times, or about once a week, during the period from 1995 to 1997. Of these articles, 70% were related to the adverse effect of pesticides and how to solve this problem (Table 1). Concern about the side effects of pesticides is not a new issue, and is now a global concern. Consequently, the reduction in pesticide

use ranks as a top priority in many countries, including Korea.

Second, the average age of Korean farmers is increasing. Younger farm workers are trying to avoid spraying pesticides inside greenhouses to protect their health. As a result, the labor cost of pesticide applications has increased.

Third, it is not easy to find effective insecticides against new exotic insect pests such as greenhouse whitefly, (*Trialeurodes vaporariorum*), or thrips (*Frankliniella occidentalis* and *Thrips palmi*). There are only five pesticides registered in Korea for the control of greenhouse whitefly, and seven for the control of thrips. This is much fewer than the number of products available to control aphids and mites (Table 2). In 1995, 58 pesticides were tested to find those which were effective against *Thrips palmi*. Of these, only three were effective (Lee *et al.* 1995).

Furthermore, new pesticides are much more expensive, because many of them are extracted from soil-borne microorganisms. This lack of cheap, effective pesticides has led farmers to look for alternative methods to solve their pest problems.

Fourth, some endemic insect pests (e.g. two-spotted spider-mite and aphids) can develop pesticide resistance quickly, so that farmers apply

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Table 1. Number and content of articles related with pesticides appearing in the daily press

Topics	Year			Total
	1995	1996	1997	
Overuse	-	5	7	12
Illegal use	1	12	12	25
Reduction	3	18	9	30
Adverse effects	3	6	15	24
Development	-	7	10	17
Banning	-	2	-	2
Other	3	19	2	24
Total	10	69	55	134

Data from Digital Chosun

Table 2. Number of registered pesticides to control four different greenhouse insect pests in Korea

Target pest	No. of pesticides (Crop)
Whitefly	4 (Cucumber), 1 (Tomato)
Thrips	4 (Gerbera), 3 (Cucumber)
Two-spotted spider-mite	8 (Rose), 3 (Strawberry), 8 (Watermelon) 3 (Carnation)
Aphid	17 (Rose), 23 (Red pepper), 7 (Cucumber) 8 (Watermelon), 17 (Chinese cabbage)

excessive amounts of pesticide.

Finally, the increased use of insect pollinators in greenhouses is another reason why IPM is becoming more popular nowadays. Growers are increasingly using pollinating insects such as bumblebees in their greenhouses, and must be careful about using pesticides in order to protect them. These five reasons are the principle catalysts of change, and are why IPM is increasingly being seen as an alternative system of pest management.

DEFINITION OF IPM

There are 64 definitions of integrated control, pest management, or integrated pest management that have been made since the early 1930s (Bajwa & Kogan 1996). In simple terms, IPM can be defined as a procedure to manage pest populations by harmonizing control methods such as natural

enemies, pesticides and cultural practices. The purpose of IPM is not eradication or removal of the pest, but management of pest populations so that economic damage and harmful environmental side-effects are minimized.

Rational decision-making is the basis of the IPM concept to avoid overuse of pesticides. Furthermore, IPM provides a safe environment, sustainable agriculture, and superior agricultural products for world trade. IPM can be a remedy for the problems caused by pesticides, such as increased food prices and increased public costs for water purification and medical services. Thus, IPM can increase the real income of farmers, maintain productivity, improve the environment, and protect the health of consumers and farmers. These are the reasons why IPM is now welcomed by everyone, and called "all things to all people". Nowadays, the IPM approach is the central theme for combating pests

that affect human and animal health.

HISTORICAL REVIEW

The theory and principles supporting IPM have been developed over the last 40 years. Prior to World War II, pest control was accomplished primarily through cultural practices such as tillage and rotation, and mechanical removal of pests. After World War II, DDT and other organic insecticides came into use worldwide to control insect pests. The period from the late 1940s through to the mid-1960s has been called the "Dark Ages" of pest control (Newsom 1980).

The regular use of pesticides was the basis of pest control practices on almost all farms in industrialized countries in the early 1950s. Most early researchers focused on the development and application of pesticides. By the 1970s, farmers had come to rely on pesticides, and other control methods were not even considered. Regular spray programs were developed on a routine preventive basis, which provided a shield of pesticide protection whether the pest was present in damaging numbers or not.

Shortly after the introduction of control programs based on pesticides, however, resistance, resurgence, and residual problems began to emerge. Some farmers experienced disaster because they could not cultivate crops any more, since no pesticide could control the pests on their farms, or the cost became too high. Perhaps the most alarming example of this is the cotton fields in Peru, Egypt, Central America, and Texas (USA). In an effort to control pests in cotton, some farmers increased the application of highly toxic pesticides to 60 applications during the growing season. Under these conditions, the cost of pest control made the production of cotton profitless, and the industry collapsed in some areas.

Integrated control (IC), the term first applied to IPM, was developed and introduced as a concept in the United States in the late 1950s. IC was developed to harmonize chemical control and biological control. It was Smith and Allen (1954) who established IC as a new trend in economic entomology. The early concept was based on the premise that pesticides could have a minimum impact on the natural enemies of the pest if applied at the correct time and under the correct conditions.

"Economic threshold", another important concept in IPM, was introduced at that time. It is based on the knowledge that pest populations fluctuate naturally.

Control measures should only be used to prevent an increasing pest population from reaching the economic injury level. The "economic injury level" was defined as the lowest density that will cause economic damage. These concepts remained the major theme of IPM throughout much of the 1970s.

The focus of IPM began to shift to non-pesticidal tactics in the 1980s, including expanded use of cultural controls, introduction of resistant plants, and biological control. Although a mass of research results on the effectiveness of IPM were published during the 1970s and 1980s, IPM was not implemented by farmers on a large scale before the 1990s. One of the major reasons was the lack of extension support.

In the 1990s, extension techniques and policy have been emphasized strongly in the development of IPM. The characteristics of IPM in each decade are summarized in Table 3.

DEVELOPING AN IPM SYSTEM

The IPM process begins with finding current pest problems in the local cropping system, and seeks to develop a solution to these. Next, IPM is systematically combined with other tactics, extension plans and implementation programs to provide an integrated system of pest control. Some might say that IPM is more likely to succeed early if countries import and adopt IPM models which have worked well elsewhere. However, an IPM model from abroad cannot necessarily be applied directly, because each IPM system is developed to solve problems specific to local conditions. Thus, an IPM system should be set up for a specific area, and developed in target fields by trial and error. Other IPM systems cannot be a solution, merely a good reference.

In general, the major components that deserve consideration in preparing any IPM system include:

- Defining the target or goal of the system;
- Setting up a program, including organization and budget;
- Research and development, including a review of knowledge and technology developed previously;
- Extension to farmers and implementation by farmers in their own fields;
- Analysis and evaluation of the impact of the program; *and*

Table 3. Historical changes in the concept and issues of IPM

	1960s	1970s & 1980s	1990s
Goal of IPM	Suppression or eradication of pest	Maximization of yield	- Conservation of ecosystem - Reduction of production cost - Improvement of farmer's technology
Targets to management	Single	Major pests in crop system	All organisms in target ecosystem
Major control methods	Pesticides	Various methods including chemical, biological, and cultural methods.	Systems approach to escape pest outbreaks
Biodiversity	Low	Moderate or fairly low	High
Implementation unit	Individual farmer	Village or community	Individual farmer
Time unit	Short	Single cropping season	Semi-permanent
Research goals	Development and improvement of pesticides	Develop alternative methods to pesticides	- Set up IPM systems - Development of extension methodology

- Feedback to solve any problems appearing during evaluation.

Defining Target and Policy

A reduction in pesticide use is considered to be one of the most important policies in the world, from both the economic and environmental point of view. IPM has now been adopted by most countries as a way of achieving this goal. However, the strategy is different in each country. In general, policies of most countries are aimed at reducing pesticide use by 50% within a certain period of time.

In the Netherlands, the main problem was that the use of pesticides expressed as input per hectare per year was very high compared to other countries. Scientists in the Netherlands concluded that the environment had been polluted and that underground water sources were endangered. Nature had tended to lose its self-regulating capacity, while agriculture itself was wrestling with an ever-increasing number of resistant pests (Baerselman 1991). With this diagnosis, they started to prepare a long-term policy plan for crop protection in 1987. Their Multi-Year Crop Protection Plan was pre-

sented in June 1991. The aim of this plan was to halve the use of pesticides by the year 2000.

In Ontario, Canada, the reduction of pesticides was adopted as policy even though Canada's consumption of pesticides was very low compared to other countries. The motivation was mainly political. Public opinion polls in Ontario had indicated that the public were concerned about pesticides from the perspective of both health and the environment. The electorate made their choice in the late summer of 1987. Quite simply, the party which won the election and became the ruling party had as one of their platforms a promise to reduce pesticides by 50% by the year 2002. Why 50%? It had a nice ring to it, as did other programs. The public doesn't want terms such as 37% or 63%, even if these are logical reductions determined by scientists.

Ten million Canadian dollars were made available for the first five years. Three broad areas of effort were identified. These were: the education of farmers (\$C1 million), research (\$C5.6 million), and infrastructure of pest management and education personnel (\$C3.4 million). The funds were made available at a rate of \$2 million per year (Surgeoner and Roberts 1993).

In the United States, the national goal of implementing IPM methods on 75% of the nation's cropland was announced in September 1993 (Sorensen 1994). This goal represents a commitment by the federal government to work with its state and private sector partners to help farmers implement pest management approaches that rely less on pesticides, are more sustainable, are equally efficient economically, and still provide people with a cheap, safe and plentiful food supply.

Thirteen countries in Southeast Asia have begun national IPM programs with the support of the FAO Inter-country Program. This international IPM program started in 1980, and many countries in this group developed their own programs based on their own national research and extension systems. Commitment and changes in national policies followed. This program has shown that farmers can be trained by extension staff to master IPM field skills, apply them in their own fields, reduce their use of pesticides, increase profits and maintain and increase their yields. It designed widespread training programs in member countries, thereby creating confidence in IPM as a way of improving yields and reducing costs.

Many countries have tried to adopt policies which restrict pesticide utilization. Such rules have stimulated the implementation of IPM and research into alternative methods of pest control. Sweden established a pesticide reduction policy in 1986. This was the first in the world, and was very successful. Sweden's approach was to adopt a more stringent registration policy for new pesticides, and to renew the license for all previously registered pesticides with stricter criteria (Kroeker 1991). This strict registration policy was subsequently adopted in many other European countries, including Denmark and the Netherlands. In Indonesia, the key to the IPM program's success was the banning of insecticides by presidential decree in 1987, following an outbreak of the brown planthopper (Kenmore 1996).

Implementing IPM

National IPM programs can usually operate effectively by harnessing the cooperation of existing organizations such as universities, national research institutes and the national extension system. In some cases, however, new organizations were established specifically to implement IPM programs. An example of this approach is the Center for Tropical Pest Management (CTPM) in Australia. CTPM is a joint venture involving four organiza-

tions: the Queensland Department of Primary Industries, the CSIRO Division of Entomology, the University of Queensland and the Queensland Department of Lands. About 80 staff are involved in this joint venture, providing a range of disciplines to tackle a series of problems (Norton 1995).

In the United States, the National IPM Plan redirects existing and new resources of the Department of Agriculture and its land grant university partners into a single coordinated effort to address important pest control problems for different cropping systems and crop production regions.

In the case of Italy, there are few experimental stations for agriculture. Most of those which do exist belong to the Ministry of Agriculture, while regional governments manage the extension service. Regional governments fund the research done by universities and other institutions. Extension officers are employed by Farmers' Associations, with a contribution from the regional government. Collaboration between these different organizations is the key factor in successful implementation of IPM (Briolini 1991).

The European IPM Working Group was set up in 1992 to strengthen policy and research, and give Europe more impact within the international IPM effort. The activities of the European Group have been sustained by European Commission funding, together with support from participating institutions.

Basically, the common factors in the organization of national IPM programs are planning, research and development, extension, education, and general support. These elements are universal, whether the program has a new organization or not.

Developing of Tactics for IPM

The specific pattern of IPM is dependent on local cropping systems. Any IPM program has to be both practical and highly specific, in order to meet the social and environmental requirements which growers and scientists perceive as important. However, to some extent countries are likely to have much the same general strategy in developing IPM programs. In USA, considerable attention has been given, first to basic research (which is most important for the development of the applied sciences), and secondly to interdisciplinary work, with specific research groups solving problems of implementation and tactical matters. Finally, all the information is compiled into a comprehensive program.

Recently, the National IPM Program provided \$US500,000 to those projects which provide

specific objectives related to technology development (including specific mission-linked or basic research) and transfer, as well as for the demonstration, information management and assessment of the project in economic, social, environmental and public health terms. In addition, funds have been supplied to investigate alternative methods of pest management.

In Canada, the first emphasis has been on a literature review to avoid over-investment at the beginning of the IPM program. Canada has also concentrated on the study of spraying technology, biological control, and environmentally sound cultural practices. Host plant resistance is also an essential component in their research program.

In Italy, emphasis has been placed on developing alternative measures, as well as pest records for every crop, determination of the economic injury level, and optimized pest forecasting models. Monitoring of insecticide resistance is also important, along with the risk assessment of chemicals in the environment.

In general, there has been lot of research into IPM. For example, the number of research articles dealing with IPM which could be retrieved from AGRIS, a literature database, was 699 articles published between 1975 and 1997 (Fig. 1). We should note that the rate at which research articles were published was greatest in the first half of the 1990s. One of the main reasons why there are many research articles in recent years is the increased world-wide concern about the environment.

Most of the IPM research published before 1990 seems to have been conducted independently of IPM implementation. In other words, it lacked an interdisciplinary approach. In the 1990s, research has focused particularly on methods of implementation. To accelerate IPM research in Asian countries, experience and information should be shared more frequently, either by exchanges between scientists or on the basis of national programs.

Extension and Farmers' Use of IPM

The end user of IPM is the crop grower. IPM coordinators, therefore, should be able to develop fine-tuned education programs and keep encouraging growers to adopt IPM techniques. To achieve those goals, IPM experts need to develop dissemination programs that farmers find easy to understand. One way commonly used in many industrialized countries is demonstrations farms that are run by farmers themselves.

Extension services run by Ministries of

Agriculture have also played a major role in the education and dissemination of IPM to farmers. Extension serves as a bridge connecting farmers and researchers. In general, extension staff should be aware of who has a pest problem, where it is, and what kind of problem is involved. Extension workers advise farmers *in situ*, by electronic communication and/or by phone. Therefore, an effective extension service is the most important component on which the success of any IPM program depends.

In the United States, only 165 entomologists were working for the extension service in 1972, before extension IPM programs were initiated on a widespread basis. By 1985, this number had grown to 298 (Allen and Rajotte 1990).

In the greenhouse IPM of the Netherlands and England, a close relationship among researchers, development and extension workers, and growers has resulted in the rapid transfer and use of information about biological control in greenhouses. Commercial producers of natural enemies served as a private extension service, since natural enemies are essential in the greenhouse IPM (van Lenteren 1989, Wardlow 1991).

Key to the success of the Inter-country Rice IPM Program was showing how closely outbreaks of brown planthopper are related to overuse of broad-spectrum insecticides. Field demonstrations and training in Farmers' Field Schools used innovative approaches to give farmers the needed IPM skills. By the end of 1995, 35,000 trainers and 1.2 million farmers had been exposed to IPM through these programs (Kenmore 1996).

In Korea, a pilot IPM Program was established in 1993 to promote training, development and implementation of IPM. Since 1993, 92 IPM trainers have been trained in summer field programs which emphasize hands-on training in how to manage pests and diseases. Topics discussed include yield loss impact levels in relationship to infection rates, and weather factors which are favorable for epidemics. Discussions of insect pests cover recognition, migration and development patterns, yield loss impact levels in relationship to pest densities, the role of alternative hosts, and natural enemies. Natural enemies are an important topic, including recognition, predation rates and prey, as well as susceptibility to herbicides, fungicides and insecticides.

IPM training for farmers is conducted in

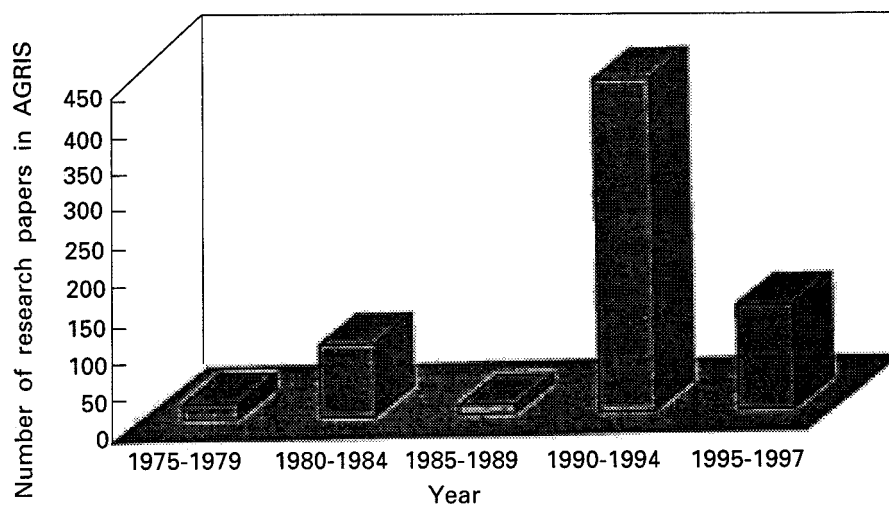


Fig. 1. Number of research papers on IPM in the AGRIS computer data base, AGRIS.

“Farmer Field Meetings” (FFM) that are held in a farmer’s field over the entire cropping season. Defoliation and dettillering studies are conducted in the field. At each meeting, farmers practice field management methods using the agroecosystem method which is re-reforced with specific studies of diseases, insects, and natural enemies predominant at the meeting time. The FFM usually meet four times each season, with each meeting held at a critical control points in the cropping cycle. By the end of the training period, most farmers can evaluate their field in a few minutes, and make appropriate management decisions based on their field’s specific situation. This is a major move away from conventional spray calendars that often include several pesticide compounds in one spray.

So far, the IPM program in Korea has operated under relatively low pressure from immigrating pests. There is still a need for continuous field verification, training, and more data collection over a greater number of years to deal with variations according to annual migrations and temperature conditions. However, we feel confident that the present understanding of the rice ecosystem, plant compensation, role of natural enemies, and migration periods will allow farmers to assess their own fields for appropriate management of pests.

The importance of extension work in IPM has increased since the mid-1980s. There are many techniques that can be used for extension work in pest management. However, they are not all suited to the same situation. It is therefore important to analyze each situation and then to identify appropri-

ate extension objectives, before techniques can be selected and put into practice.

Evaluation of IPM

The economic effects of IPM are realized both by individual farmers and by society at large. Depending on how IPM programs are structured, they can put different emphasis on factors such as the cost of pest control, the level and variability of producer income, and the health of those applying the pesticides. The program can also affect food safety and water quality for human and wildlife, and the long-term sustainability of agricultural systems. IPM programs can be evaluated on the basis of acceptance by farmers, reductions in pesticide use, or economic benefits.

In Queensland, 80% of citrus growers have adopted IPM in the form of monitoring for insect pests, spraying chemicals and/or releasing beneficial insects when pests are above a threshold, and utilizing classical biological control agents (Smith 1990).

In the United States, 61 economic evaluations of IPM programs in cotton, soybeans, vegetables, fruits, peanuts, tobacco, corn, and alfalfa have been published (Norton and Mullen 1994). These evaluations indicate that pesticide use, on average, has decreased for seven out of eight commodities. Costs of production decreased or remained unchanged in four out of the five commodities. Yields increased for six out of the seven, and net returns increased for all seven commodities. Monetary risks to farmers decreased in all three cases in

which this was evaluated. A national study of IPM programs over the three-year period ending in 1985 reported a total economic benefit of \$578 million per year in nine commodities (Fajotte *et al.* 1987).

The success of IPM programs has often been measured in terms of the overall reduction in the volume of pesticides used to control pests. Although a reduction in pesticide use is a desirable consequence of IPM, it cannot be the only measure of success. There are special circumstances in which, even following IPM guidelines, it may be necessary to use more, not less, pesticide. The issue is pesticide use within the principles of IPM, i.e., selective use after maximizing the effectiveness of natural controls (Kogan 1998).

A study by Pimental *et al.* (1980) provided rough estimates of the environmental and social costs associated with pesticide use in the United States. The implications for IPM benefits are that if pesticide use is reduced by IPM programs, then the benefits may be realized in proportion to the pesticide reduction. They estimated that the environmental and social costs of pesticides in the United States amounted to \$830 million each year. This total was based on the costs of human exposure (US\$184 million), livestock poisoning and product contamination (US\$12 million), a reduction in the number of natural enemies and increased pesticide resistance of pests (US\$287 million), honeybee poisonings and reduced pollination (US\$135 million), losses of crops and trees due to pesticide drift (US\$70 million), fishery and wildlife losses (US\$11 million), and the cost of government pollution controls (US\$140 million).

In general, major factors affecting the success of IPM are:

- A policy environment that encourages IPM;
- The participation of growers and other end users, in the whole research and development process; *and*
- A system that provides research and decision support to facilitate the adaptation of IPM to changes in production practices, pest status and control technology (Norton 1995).

PROSPECTS FOR THE 21ST CENTURY

IPM is widely accepted as being “all things to all people”. It has become an integral part of global policy for the conservation of the environ-

ment. Farmers expect IPM to reduce the costs of their pest control and the danger to their health from pesticides. Environmentalists expect IPM to replace chemical pesticides in agriculture. Chemical companies expect it to permit the continued use of pesticides, under conditions that will reduce their potential hazards to people and environments. Regulatory agencies see IPM as precise prescriptions for pest control actions which can replace present application schedules. Scientists see IPM as a way to integrate the specific information of their individual research projects into a system which increases the predictability of optimum crop production, while reducing the risk to the environment. Politicians welcome the concept of IPM because almost no-one opposes it.

Looking ahead, it is new IPM technology, including both plant and insect products of genetic engineering, which are generally seen as most significant. However, there has been no absolute and exclusive measure for pest management so far, and nothing of the kind is likely to eventuate, even if genetic engineering is emphasized over all other technologies. IPM has proven to be a robust construct. Opportunities to be creative within the confines of the IPM formula are limitless. Success has come mainly from a better understanding of the ecology of crop/pest interactions, and only rarely from a new control method.

Better communication among specialists between regions and countries would not only improve, the efficiency of implementation, but also avoid duplication of research efforts. IPM acts as a unifying force to stimulate interdisciplinary problem-solving, and to promote understanding of the social and economic impact of pest management and the creation of IPM-oriented farmer groups. The ease and speed of information dissemination through the Internet will certainly have an impact on IPM in the next century. The promise of reliable predictive models based on real-time weather data may finally become a reality, as software and weather information become more widely available. Extension information and educational programs via the Web are already available and, when cleverly used, have given positive results.

To conclude, IPM has played a key role in plant protection, and will continue to play a major role in the next century. The development of new tactics is not the only goal we must pursue. Expanding the implementation of IPM farmers by strengthening extension is even more important.

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