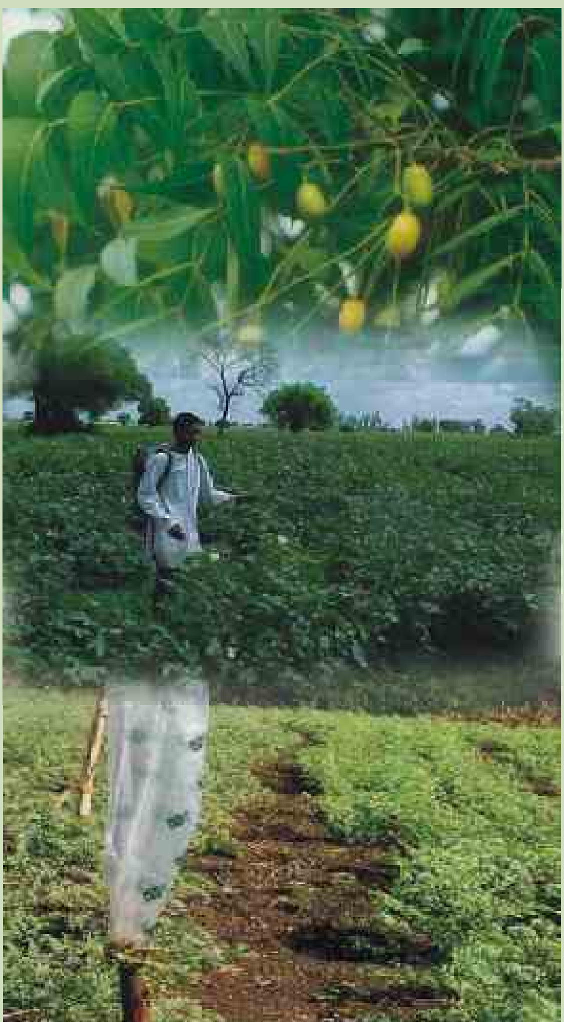
भाकृअनुप
ICAR

POLICY PAPER 18

Economic Potential of Biological Substitutes for Agrochemicals



Pratap S Birthal

राष्ट्रीय कृषि आर्थिकी एवं नीति अनुसंधान केन्द्र
NATIONAL CENTRE FOR AGRICULTURAL ECONOMICS AND POLICY RESEARCH

NCAP has been established by the Indian Council of Agricultural Research (ICAR) with a view to upgrading agricultural economics research through integration of economic input in planning, designing, and evaluation of agricultural research programmes and strengthening the competence in agricultural policy analysis within the Council. The Centre is assigned a leadership role in this area not only for various ICAR Institutes but also for the State Agricultural Universities. With a veiw to making agricultural research a more effective instrument for agricultural and rural change and strengthening the policy making and planning machinery, the Centre undertakes and sponsors research in agricultural economics relating to the problems of regional and national importance.

ECONOMIC POTENTIAL OF BIOLOGICAL SUBSTITUTES FOR AGROCHEMICALS

Pratap S Birthal

February 2003

Policy Paper 18

**NATIONAL
CENTRE FOR
AGRICULTURAL ECONOMICS AND
POLICY RESEARCH (ICAR)
NEW DELHI, INDIA**

Policy Paper 18

Economic Potential of Biological Substitutes for Agrochemicals

Published
February 2003

Published by
Dr Mruthyunjaya
Director, NCAP

Printed at
Chandu Press
D-97, Shakarpur
Delhi - 110 092

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ANNEXURES

FOREWORD

Pesticides, together with the high yielding seeds, fertilizers and irrigation, have made substantial contributions towards making India food self-sufficient. But in recent years, they have come under severe criticism because of their negative externalities to the environment and human health. Besides, the pest-induced losses have been increasing, despite increasing use of pesticides. Biological alternatives to pesticides have been proposed since long, and are claimed to provide effective solutions to the pest problem. Their use, however, has remained extremely low due to a number of technological, socio-economic and institutional constraints. Nevertheless, with rising public awareness of the negative externalities of the chemical pesticides, coupled with the increasing demand for chemical-free food, the biological pest management is going to occupy an important place in the future plant protection strategies. This study makes an important contribution towards understanding the economics of biological pest management vis-à-vis chemical pest management under the experimental as well as the field conditions, and the problems/constraints in the adoption of biological pest management technologies by the farmers, besides providing a critical review of the plant protection policy. The general conclusion is that the biological pest management technologies have the potential to substitute the chemical pesticides without demanding additional resources, and with no adverse effect on agricultural productivity, given the adequate technological, economic and institutional support.

The study has been vetted by the peers, and it is expected that the results will guide the researchers, extension workers and policymakers in taking appropriate steps to accelerate the adoption of biological pest management technologies.

Mruthyunjaya
Director

ACKNOWLEDGEMENTS

Several persons have contributed in brining out this study to the present shape. Dr. Mruthyunjaya, Director, NCAP, and Prof. Dayanatha Jha, National Professor at NCAP have been a constant source of inspiration, guidance and academic support right from the conceptualization of the study. I am highly grateful to them. I have been immensely benefited from the academic interactions with my colleagues, Dr. P.K. Joshi, Dr. Ramesh Chand, Dr. B.C. Barah, Dr. Selvarajan and Dr. Suresh Pal. I sincerely thank all of them. My sincere thanks are due to Dr. S.P. Singh, ex-Director, Project Directorate on Biological Control, Bangalore and his colleagues for sharing the experimental data, and for enriching my understanding of the biological pest management. Dr. C. Ramasamy, Vice-Chancellor of the Tamil Nadu Agricultural University, and his colleagues, Dr. Sivanandam, Dr. V. Alagesan and Dr. K. Mahendran provided excellent support during the field visits in Tamil Nadu. I shall remain indebted to them. I am also thankful to my colleagues Dr. P. Adhiguru and Dr. L.M. Pandey for their help and company during the field visits. I am also thankful to Mr. Jabir Ali and Mr. Badruddin for their help in data compilation and computation

Prof. S.S. Johl, Chairman, Chief Minister's Committee on Agricultural Policy, Punjab, Dr. G.S. Nanda, Director of Research, Punjab Agricultural University, Ludhiana, Dr. Amerika Singh, Director, National Centre for Integrated Pest Management, New Delhi, Dr. D.K. Marothia, Head, Department of Agricultural and Natural Resource Economics, Indira Gandhi Agricultural University, Raipur and Dr. O.P. Sharma, Senior Scientist, National Centre for Integrated Pest Management reviewed the manuscript and provided valuable suggestions that helped in bringing out the final product. Mr. B.L. Shahi provided editorial assistance. I express my sincere gratitude to all of them.

The project was funded by the Indian Council of Agricultural Research under its Young Scientist Award scheme. The financial support from the

Council is duly acknowledged. Dr. J.P. Mishra, Assistant Director-General (ESM), Dr. R.C. Maheshwari, Assistant Director-General (TC) and their staff provided administrative support. I am thankful to them.

Pratap S. Birthal

EXECUTIVE SUMMARY

Over the next three decades, the food grain production in India has to increase at least 2 million tonnes a year to meet the food demand of the growing population. In the past, the agricultural production increased through area expansion and intensive use of seeds, irrigation, fertilizers and pesticides. Now the prospects of raising agricultural production through area expansion are remote. The land frontiers are closing down, and there is little, if any, scope to bring additional land under cultivation. The green revolution technologies have now been widely adopted, and the process of diminishing returns to the additional input use has set in. At the same time, the problems of insect pests, diseases and weeds have multiplied causing considerable damage to the potential agricultural production. About 25 percent of rice, 5 to 10 percent of wheat, 30 percent of pulses, 35 percent of oilseeds, 20 percent of sugarcane and 50 percent of cotton production is lost due to pests. Reducing the loss, thus, can make an important contribution towards achieving the required increase in the agricultural production.

In the green revolution era, chemical pesticides were increasingly relied upon to limit the production loss. Though, there are no authentic time series estimates on the pest-induced loss, anecdotal evidences indicate an increase in it, despite increase in the pesticide consumption. The 'paradox of rising loss with rising pesticide use' is explained in terms of rise in the pest problem, the technological failure of the chemical pesticides and the changes in the production systems. Besides, the chemical pesticides have also come under severe criticism from the environmentalists because of their potential adverse effects on the human health and environment.

In order to contain the losses, new pest management strategies, using microorganisms and plant products, have been proposed. A number of species of the microorganisms and plants have been identified for their potential use. Some of these are: Nuclear polyhedrosis virus, *Trichogramma*, *Bracons*, *Trichoderma*, *Bacillus*, and neem products. These, when used in conjunction with other methods of pest management, are claimed to provide better control of the pests. This kind of integration of different methods is referred to as Integrated Pest Management (IPM). But their commercialization as well as use has remained restricted. One of the reasons for this is the lack of a sound economic analysis of technology generation and use. This study, therefore, has looked into the issue of substitution of chemical pesticides by biological technologies from an economic perspective.

Technical and economic feasibility of the biological pesticides was examined at two levels that is, experiments and farmers' fields. Experimental data for three technological options viz., chemical control, biological control, and IPM on cotton, paddy and chickpea were analyzed for the purpose. To supplement the experimental evidences, and to identify the problems in shifting from the chemical to the biological pest management, field investigations were conducted in three districts of Tamil Nadu in 1998-99 with focus on cotton, paddy, and cabbage.

The technical as well as economic performance of different pest management options varied across the crops and the locations. In Gujarat and Tamil Nadu the technical potential, (measured in terms of yield saved) of the biological control and IPM in cotton was better than the chemical control. While in Punjab they performed no better than the natural control. Economically, their performance was better in Gujarat, and to some extent in Tamil Nadu. The economic performance, however, was sensitive to the type of the biological inputs used because of the differences in their application rates and prices. Biological control of the paddy pests did not appear much better than the chemical control both in terms of their technical and economic performance. But, wherever IPM was tried, it proved better than the biological as well as the chemical control. In chickpea also, IPM performed better than the chemical control and the biological control.

Field survey indicated application of IPM on 27 percent of the cotton area, 37 percent of the paddy area, and 24 percent of the cabbage area in the study domain. *Trichogramma chilonis*, NPV and neem products were the main biopesticides used in cotton. Neem products were the only biopesticides used in paddy. *Bacillus thuriengensis* and neem products were used in cabbage. Further, the factors that influence farmers' decisions to adopt IPM were identified. Adopters were better educated and had higher endowments of the land and labour resources, compared to the non-adopters. Farmers, in general, were aware of the negative externalities of the chemical pesticides, but this did not influence their adoption decisions in a significant manner.

Adopters encountered a number of problems in the transition from the chemical pesticides to their biological substitutes. Lack of timely as well as adequate supply of the biopesticides, and the absence of timely expert advice were the main limiting factors. A majority of the non-adopters was also aware of the biopesticides, but did not use these. They wished to adopt the new pest management technologies, provided these were broad spectrum, fast in action, available in the right quantity and time, and cheaper. They also needed more information on the technologies, their target pests, methods of application, etc.

Impact of adoption of IPM technologies was assessed on the pesticide use, crop yield and the costs and returns. Application of IPM technologies could reduce the pesticide use by 66 percent in cotton, 45 percent in cabbage, and almost to nil in paddy. The crop yield was also higher with application of IPM. This was about 4 percent in cotton, 3 percent in paddy, and 5 percent in cabbage. Cost of cultivation was marginally reduced with the application of IPM technologies. Unit cost of production was, however, less by 7 percent in cotton, 4 percent in paddy, and 5 percent in cabbage. In other words, the biopesticides, when used in IPM mode, have the potential to substitute the chemical pesticides in a cost-effective manner and without any adverse effect on the crop yield.

Farm level effects of IPM were up-scaled to the regional level to assess the magnitude of social benefits to the producers and the consumers. As expected, adoption of IPM generated considerable economic benefits to the producers as well as the consumers. But, most of these accrued to the producers. Farmers procure biopesticides both from the public and the private sources. The public sector supplies are subsidized, and raising the prices of these inputs to the level market prices would adversely affect the farm profitability, and their adoption, because at present the their use is marginally profitable over the chemical control. Since the biopesticides generate considerable social and environmental benefits, the government should continue with the subsidies on these inputs.

Pest has the characteristic of a detrimental common property resource, and therefore demands common solution. Yet, most of the times, pest control efforts are individualistic, which are less effective in providing protection against pests. However, the collective action assumes greater significance in the context of IPM technologies, because of the sensitivity of the biological inputs to the chemical pesticides. A majority of the farmers was aware of the benefits of the collective action and was willing to participate in it. However, the lack of cooperation among the farmers was the main hindrance. But, the benefits of collective action appear to induce farmers to go for community action. Technology of the pest control also appeared to play an important role, the farmers applying IPM technologies, were more willing to participate in the collective action.

Evidences, from both the experimental data and field surveys, indicate that the IPM possesses the potential to substitute the chemical pesticides without demanding additional resources and without adversely affecting agricultural productivity. India adopted IPM as a cardinal principle of plant protection policy in 1985. Since then a number of policy initiatives such as, ban on use of hazardous pesticides, phasing out subsidies on the pesticides and the appliances, investment in infrastructure for the production of the biopesticides, easing out registration norms for the biopesticides, training of the extension workers and the farmers in tools and methods of IPM, organizing Farmers' Field Schools and IPM demonstrations, etc., have been taken.

The progress in implementation of IPM has been tardy. Hardly about 2 percent of the area under pest control is estimated to be brought under IPM. Supply of biopesticides is extremely limited. The technology dissemination efforts have remained restricted. IPM is akin to a new technology, and is knowledge intensive. It demands extension workers and the farmers alike to have an adequate understanding of the pest management processes. At the national level, on an average, an extension worker has been trained at least thrice in tools and methods of IPM, the benefits of their training did not trickle down, as only 0.2 percent of the farmers have been trained in IPM. But, the use of pesticides has reduced considerably during the 1990s. This, however, has not been accompanied by any reduction in the agricultural productivity. Nevertheless, there is considerable regional variation the rate of reduction in the pesticide use and its impact on agricultural productivity.

Several policy implications emerge from this study. The apprehension, that switching over to IPM might cause a reduction in crop yield is not supported by the study. There might be some reduction in the yield in the transitory phase, but in the long run the IPM can contribute to the sustainability of the agricultural production system, besides yielding substantial social and environmental benefits. However, without appropriate policy support, the use of the biological technologies is likely to remain restricted.

A number of IPM technologies have been generated and standardized for commercial application. But some of these are costly to apply. *Crysoperla carnea* is an example. The high cost of application might act as disincentive to their adoption. This suggests the need for the research to develop the low-cost technologies for their greater commercialization and use. Further, many biological technologies have a narrow host range, are slow in action, have short shelf life, and are sensitive to the chemicals. These characteristics too hinder the pace of their commercialization and adoption. The need is to develop the technologies that provide protection against a range of pests, are fast in action, insensitive to the chemicals and have the better storage life. Biotechnology offers great scope to fulfill these requirements.

Farmers are willing to substitute the chemical pesticides with the biological technologies. Their supply, however, is a limiting factor. The market for the biological pesticides is underdeveloped. Production is low and uncertain. This discourages farmers from adopting these technologies. Increasing the supply would accelerate their adoption. This may require various economic and non-economic incentives to the producers. Support and incentives to the private sector in terms of institutional credit for the establishment of the manufacturing units, insurance cover in the periods of low demand for the biopesticides particularly for those having short shelf life, exemption from the taxes etc. would help improve supply of the biological pesticides. Some biological products such as *Trichogramma*, NPV and neem pesticides can be produced on a small scale at the village/block level in a cost effective manner, because of the local availability of the cheap raw material and labour. Local manufacturers also have the advantage of an accurate assessment of demand for the products. Small scale manufacturing may generate opportunities for income augmentation and employment generation for the unemployed educated youths, and the poor labour households.

One of the main hurdles in the widespread dissemination of these technologies is inadequate information support to the farmers. Human resource development efforts until now have, by and large, focused on improving the skills of the extension agents. These, however, have not trickled down to the farmers. Henceforth, the priority in human resource development should be to empower the farmers in the use of the new technologies. To make their adoption widespread, the extension system should document success stories and widely publicize their improved benefit-cost ratios.

Economic incentives to the farmers could be a powerful tool for the dissemination of IPM technologies. Input subsidy has been used as a tool in promoting the technologies in the past. At present, the use of the biological inputs is marginally attractive to the farmers, and an increase in the prices of these, might adversely affect their adoption. Since the biological technologies contribute to improvements in environment and human health, provision of 'green box' subsidies, at least in the transition phase, can be thought of.

In the developed countries the market for pesticide-free products is growing fast, and such products fetch premium prices. This, however, is lacking in India. This would require not only the development of low cost certification procedures but also the labeling system to gain confidence of the consumers.

Grassroot level institutions are often overlooked in the technology dissemination process. IPM is a group based approach, and evolving a community approach is a major challenge for its wider dissemination. Yet, there is a latent potential for the community action. But it requires commitment and dedication of the implementing agencies. The role of the extension system needs to be tuned to the requirements of the technology adoption process.

1 INTRODUCTION

1.1 Background

During the last three and half decades of the twentieth century, the productivity of the Indian agriculture increased dramatically. Yield of the main food crops, rice and wheat, almost doubled, and the yield of other food as well as non-food crops too increased considerably. This remarkable increase resulted from an intensive use of high yielding seeds, fertilizers, pesticides, and water. The yield-augmenting technological change led to the self-sufficiency in the food production. Yet, the concerns of food security have not vanished altogether. By 2030, demand for foodgrains is expected to increase to 260-265 million tonnes (Paroda and Kumar, 2000). In other words, foodgrain production in India has to increase at least 2 million tonnes a year to meet the food security needs of the growing population. The incremental production to meet this demand would have to come from the substantial increase in the agricultural productivity, as the scope for bringing additional land under cultivation is limited. Concurrently, a number of biotic and abiotic factors also continue to constrain the growth in the agricultural productivity.

Insect pests, diseases and weeds are the main yield-limiting factors in most of parts of the world. A significant proportion of the potential agricultural production is lost due to pests. Reliable estimates of crop loss, however, are scarce. Amongst the best documented information, Oerke et al. (1995) estimate 42 percent loss in the global output due to insect pests, diseases and weeds, despite use of various plant protection tactics. The loss could have increased to 70 percent if the pests were left uncontrolled. Similar observations have been made by Pimental (1993b) who estimates 40 percent pre-harvest production loss; the post harvest loss adds another 10-20 percent. The loss is higher in the Asian countries (Oerke et al., 1995). In India, the pre-harvest production loss due to insect pests is estimated to be 25 percent for rice, 5 to 10 percent for wheat and 30 percent for pulses (Dhaliwal and Arora, 1993). For cotton, rapeseed-mustard and sugarcane, the loss is estimated at 50, 35 and 20 percent, respectively.

Farmers use a number of pest control strategies to limit the crop loss. Chemical pest control has, however, been the preferred strategy in practice in India since the beginning of the green revolution era in 1965-66. Prior to that, the farmers knew little about chemical pesticides. They relied mainly on the natural, and cultural pest control practices. Use of pesticides was meager, and limited mainly to the plantation crops. In 1955-56, consumption of pesticides in agriculture was about 15 gm/ha (Chand and Birthal, 1997). It increased to 90 gm/ha in 1965-66. Introduction of the new varieties of crops necessitated intensive use of purchased inputs including chemical pesticides for better yield response. Between 1965-66 and 1974-75, per hectare pesticide use increased four-fold (Chand and Birthal, 1997). Concurrently, the pest problem also kept on multiplying. And, the effectiveness of the pesticides was so unambiguous that soon these overshadowed the traditional methods of pest control. A study by the National Council of Applied Economic Research (NCAER,1967) showed that every rupee invested in chemical pest control returned Rs 3 in crops saved. Pesticide use kept on increasing till 1990-91, albeit at a slower rate (Chand and Birthal, 1997). In 1990-91, the pesticide use reached a peak of 405 gm/ha, and has been declining since then (265 gm/ha in 1998-99).

Notwithstanding their success in controlling the insect pests, diseases and weeds, pesticides adversely affect public health and environment. The ill effects of pesticides on the public health and ecology are numerous. Direct exposure to the pesticides can induce allergies and affect body organs such as liver, kidneys, nervous, respiratory and gastro-intenstinal systems. Chronic exposure to pesticides can cause cancer, genetic mutations, male sterility, etc. Evidences indicate that though the pesticide-use-intensity is low in the developing countries, most of the pesticide related accidents, such as poisoning and deaths occur there (WHO/UNEP, 1989). Mohan (1987) observed a high positive correlation between per hectare pesticide use and physical disabilities in India. Misuse of the pesticides and lack of awareness about precautionary measures are the main causes of pesticide related accidents (Mencher, 1981). Residues of the pesticides in foodgrains, fruits and vegetables, fish, milk, water and soil have often been reported to exceed their acceptable limits (Dhaliwal and Kalra, 1977; Kalra and Chawla, 1981; Agnihotri, 1983; ICMR, 1993; Marothia, 1997). Empirical evidences suggest that the cost of the measurable negative externalities of the pesticides outweigh their perceived economic benefits (Pimental et al., 1993; Rola and Pingali, 1993).

Pesticides are broad-spectrum toxic chemicals. These, besides limiting the pest populations, also adversely affect the populations of the beneficial insects and the microorganisms, predatory birds and the natural enemies of the insect pests. Information on the economic loss due to destruction of the beneficial species is scarce. Scattered evidences, mainly from the developed world, indicate considerable loss in crop output due to such externalities (Robinson et al., 1987; Pimental et al., 1993b). However, more worrisome is the technological failure of the pesticides. Indiscriminate use of the pesticides has resulted into problems of the pest resistance, resurgence, and the secondary outbreaks A number of insect pests, diseases and weeds have become resistant to pesticides intended to control them. Worldwide, about 504 insect pests are reported to have acquired resistance to pesticides. This figure was 7 in 1938. Resistance in the weeds was non-existent before 1970, but now 273 weed species have developed resistance to the herbicides (Pimental et al., 1993a). Fungicide resistance is reported in nearly 150 plant pathogens. These are serious obstacles to raising the agricultural productivity. Repeated applications of pesticides to overcome these problems increase the cost of pest control.

In India, insect pests such as *Helicoverpa*, white fly, diamond back moth, tobacco caterpillar and mustard aphid have developed resistance to almost all the pesticides intended to control them (Mehrotra, 1989; Kishor, 1997; Pawar, 1998; Saini and Jaglan, 1998; Alam, 2000). Besides, the *Helicoverpa* and white fly have become polyphagus causing considerable damage to the crops like cotton, pigeonpea, chickpea, and tomato. Annual economic loss due to *Helicoverpa* alone is estimated at Rs 2000 crores, despite the use of pesticides worth Rs500 crores (Pawar, 1998). Estimates by Kishor (1997) indicate that outbreak of *Helicoverpa* in 1988 in cotton growing regions of Andhra Pradesh caused loss in cotton production equivalent to 15 percent of state's agricultural gross domestic product.

Many new insect pests, which were controlled by their natural enemies present in the ecosystem, have assumed the status of the major pests in some regions due to the decline in the populations of the natural enemies caused by the indiscriminate and excessive use of the pesticides. The number of important insect pests of cereal crops has increased from 5 in pre-green revolution period to 44 towards late 1980s (Rao, 1988). In fiber crops, their number has increased from 3 to 11, and in oilseeds from 7 to 17. There were no known important insect pests on pulses before 1960. By late 1980s, their number has swallowed to 18. Changes in the production systems (monoculture, reduction in biodiversity, reduction in crop rotations, etc.), intensive cultivation, destruction of the natural enemies of insect pests, increasing insecticide resistance are some of the often cited causes of rising pest problem (Dhaliwal and Arora, 1993).

Obviously, the crop losses due to pests have increased. Information on trend in crop losses though is scarce; scattered evidences indicate considerable increase in crop losses. In traditional agriculture, about 3 percent of rice, 10 percent of wheat, 18 percent of cotton and 5 percent of oilseeds output was estimated to be lost due to insect pests. In early 1990s the loss increased eight-fold in case of rice, three-fold in case of cotton and seven-fold in case of oilseeds. The loss percentage in wheat output has however remained unchanged. If the observed trends in the pest multiplication and the pest resistance were to continue, the losses are expected to increase further.

With rising public concerns about the economic and ecological externalities of the chemical pesticides, the emphasis of plant protection research and development strategies has been gradually shifting from chemical to non-chemical approaches. Research has generated new technologies, using naturally occurring enemies of insect pests (parasitoids, predators and pathogens). Some important commercially available products are: *Trichogramma, Bracons, Crysoperla carnea, Crytaemus montrouzieri, Bacillus thuringiensis, Bacillus sphaericus,* Nuclear polyhedrosis viruses (NPV) and *Trichoderma*. In addition, a number of plant products such as, azadirachtin (neem), pyrethrum, nicotine, etc. are also valuable as biopesticides. In India, more than 160 natural enemies have been studied for their utilization against insect pests (Singh, 1997). Technologies have been standardized for multiplication of 26 egg parasitoids, 39 larval/nymphal parasitoids, 26 predators and 7 species of weed.

Environmental and public health benefits of the biological pest management are well documented. And, most of the biological technologies are claimed to be effective against the insect pests, diseases, and weeds, particularly when applied in conjunction with other methods including chemical pesticides, agronomic practices and mechanical control. Such a strategy is referred to as Integrated Pest Management (IPM). In India, the use of biological pest management technologies is limited and sporadic (Jayaraj, 1989; Alam, 1994). There is no official statistics available on area treated with the biological pesticides; subjective assessments suggest that hardly about 2 percent of the total cropped area is protected with the biological pesticides. This indicates that though technical efficacy is a necessary but not a sufficient condition for their application in the field. It has to meet the other performance criteria such as practicability, economic efficacy and sustainability.

In view of the above, there arise some fundamental questions. Are IPM technologies profitable, compared to the conventional chemical pest control? Are farmers aware of the technologies, their characteristics and method of application? Are the social and institutional conditions at the grassroot level conducive to the adoption of IPM? Is the supply of technologies adequate? Are the institutions, responsible for delivery of technologies, properly oriented to educate the end-users about these technologies? Is the regulatory framework governing these technologies appropriate for their commercialization? Do the government policies encourage farmers to adopt these technologies? These need to be addressed by research and policy.

Profitability is the major concern in any technology assessment exercise. However, as far as the biological pest management technologies are concerned this issue has not been properly addressed to. Empirical evidences are limited and scattered. Alam (1994) indicates that biological pesticides do not possess economic advantage over the chemical pesticides under farmers' conditions. On the other hand, studies by Kumar (1992), Kishor (1997), Unni (1996), Chowdry and Seetharaman (1997) and Birthal et al. (2000a) provide a broad indication that IPM is as profitable as the chemical pest control. Most of these studies are based on the evidences from a limited number of observations collected from the farmers identified for IPM demonstrations. The issues concerning adoption, constraints and impact of IPM are yet to be investigated thoroughly. It is, however, widely conjectured that the adoption of IPM in developing countries could contribute substantially to the intensification of agriculture in a sustainable manner

(Thrupp, 1996). The main aim of this study is, therefore, to examine the economic feasibility of IPM technologies under field conditions, and to identify technological, socioeconomic and institutional problems/constraints in transition from the chemical pest control to IPM.

1.2 Objectives

The general objective of this study is to examine the economic potential of biological pest management technologies to substitute the chemical pesticides. This is accomplished by an analysis of the costs and benefits at the level of (i) research, and (ii) farmers' fields. The specific objectives of the study are to:

- Examine the status of the biological pest management technologies vis-à-vis chemical pest control.
- Evaluate the profitability of the biological pest management technologies in relation to chemical pest control.
- Identify the problems/constraints in transition from the chemical pest control to the biological alternatives.
- Derive implications of the use of the biological pest management technologies for the sustainability and food security.

1.3 Organization of the Study

The study is organized into nine chapters. The next chapter presents the concept and definitions of Integrated Pest Management. Chapter 3 reviews plant protection strategies and the policies in India, with emphasis on the growth in the consumption of pesticides, its determinants and relationship with the agricultural productivity, policy changes and their effects on the pesticide use, and adoption of biological pest management technologies. Methodological framework for measuring the technical and economic efficacy of different pest management technologies under experimental conditions, and their adoption and impact under the field conditions is presented in chapter 4. Besides, this chapter also describes the data requirements to achieve the intended objectives.

Results of the technical and the economic performance of different pest management technologies under experimental conditions are discussed in chapter 5. Chapter 6 describes the process of adoption of biological pest management technologies (IPM), the farmers' perceptions of problems and constraints in their use, and the technological, socioeconomic and institutional factors influencing their adoption. Impact of the adoption of IPM on the pesticide use, crop yield, costs and returns and the social welfare are examined in chapter 7. Grassroot level institutional requirements for the area-wide adoption of IPM are discussed in chapter 8. The final chapter presents the conclusions and the implications of the study.

2 INTEGRATED PEST MANAGEMENT: CONCEPT AND DEFINITION

Integrated Pest Management (IPM) in agriculture has been practiced in one or another form since times immemorial. Before the advent of the pesticide era, farmers relied mainly on the natural and mechanical methods for controlling the insect pests and diseases. The discovery of the insecticidal properties of DDT and BHC during the World War II, however, revolutionized the pest management. These chemicals soon became a popular means of pest control, and overshadowed the traditional methods of control. Intensification of agriculture gave further fillip to the use of chemical pesticides. Agricultural development policies too encouraged the use of the chemical pesticides. The marginal returns to the investment in the chemical pesticides were attractive enough to justify their increased application.

Negative externalities of the chemical pesticides to public health and environment, however, soon became apparent. Besides, a number of insect pests, diseases and weeds developed resistance to the pesticides, and repeated applications of pesticides to contain these, led to an increase in the cost of control. At the same time, prices of the pesticides too increased. These factors led to diminishing returns to the pesticides use. These developments prompted the scientists and the farmers alike to search for and try alternative methods of pest control that have the potential to ensure farm profitability, and safety to the public health and environment.

2.1 Concept of IPM

As stated earlier, the concept of IPM is not new. Farmers have been applying this since long. But formally, it came into being in 1950s in the United States in response to the failure of the chemical pest control. A group of entomologists coined the term 'Integrated Control', which emphasized the pest control in an ecological context, and identified biological and natural methods as successful foundations of pest control (Stern et al., 1959). Also, by the early 1960s the ill effects of chemical pesticides on the ecology and public health had started attracting public attention. Rachel Carson (1962) in her classic 'Silent Spring' warned that the pesticides were being used indiscriminately and excessively, causing harm to non-target species and human health, and were resulting in the technological failure (pest resistance, resurgence and secondary pest outbreak). These concerns spurred the interest to search for the safer yet profitable methods of pest control.

The term 'Integrated Pest Management' was coined in 1967 by the Food and Agriculture Organization of the United Nations. In 1970s, IPM was promoted as a new technology of pest management, which could replace the broad-spectrum chemical pesticides with alternative management techniques. With further developments in the theory and practice of pest control, the horizons of IPM broadened. The concept has now started recognizing the limitations and the needs of integration of different methods of pest control to ensure adequate remuneration to the producers and safety to the public health and environment. A complete reliance on the biological or natural process of pest control was not considered technically and economically feasible, and the need-based application of the chemical pesticides was incorporated in the concept. The purely ecological based concept was replaced with the optimum use of multiple tactics including the host resistance, cultural practices, biological control agents, botanicals, and environmentally safer chemicals.

IPM is a flexible approach, which combines different methods of pest control in a manner that provides maximum utility to the farmers as well as to the society. This flexibility is interpreted differently by different people. At extremes, there are two views on IPM: the technological and ecological (Waage, 1995). Both of these aim at reduction in the use of chemical pesticides, and without any concomitant decline in the agricultural productivity. Technological view is product-centered and emphasizes top down development and delivery of the solutions (Waage, 1995). Agrochemical industry is the main propagator of this view. This view is also partly supported by the national and the international agricultural research systems. This approach emphasizes intervention, based on pest threshold level. The old broad-spectrum pesticides are substituted by the new selective products, and the farmers are motivated to adopt the technological package. On the other hand, the ecological approach does not advocate the pest control interventions, especially use of chemical pesticides. It emphasizes farmers' participation in the pest management and relies on their knowledge and skills, besides helping them to increase their competence in the pest management.

Both the ecological and technological traditions are practiced at least partially by a majority of the farmers. Thus, in practice IPM exists on a continuum; it may be chemical-intensive or bio-intensive. It relies completely, neither on the chemical pesticides nor the natural control. But, it combines different pest management tactics that are compatible with the objectives of the productive agriculture, and ensure safety to the public health and ecology. The nature and extent of the intervention depends on the nature of the pest complex and its intensity.

2.2 Defining IPM

Since the formalization of the concept of IPM by Stern et al. in 1959, definitions of IPM have proliferated. The definition proposed by Stern et al. emphasized the profitability and sustainability aspects of crop production. They defined IPM as "Applied pest control which combines and integrates biological and chemical control. Chemical control is used as necessary and in a manner which is least disruptive to biological control." The FAO Panel of Experts on IPM (1967) also provided a similar definition, "IPM is a pest management system that, in the context of associated environment and the population dynamics of pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest population at levels below those causing economic injury."

Later, with the rising public awareness about the adverse effects of chemical pesticides on the ecology and public health, subsequent definitions included these concerns. The definition by Glass (1975) indicates this. He defined IPM as, "A strategy of pest management, which seeks to maximize natural control forces such as predators and parasites, and utilizes other tactics only as needed and with a minimum of environmental disturbances." The definition largely addresses the ecological concerns. It ignores economic aspects that concern the farmers the most, and are the driving force in their technology adoption decisions. The economic concerns were integrated by Tweedy (1979) by defining IPM as, "The use of multiple control measures which are compatible, economical, environmentally sound and culturally feasible for managing pest populations at an acceptable level".

The Office of Technology Assessment of the United States (1979) gave a comprehensive definition of IPM encompassing concerns of the production sustainability, public health and ecology. It defined IPM as "the optimization of pest control in an economically and ecologically sound manner, accomplished by the coordinated use of multiple tactics to assure stable crop production and to maintain the pest damage below the economic injury level while minimizing hazards to humans, animals, plants, and the environment."

Taking into consideration the rising concerns for the environment and human health safety, and farm profitability FAO revised its definition of IPM in 1992 as, "The presence of pests does not automatically require control measures, as damage may be insignificant. When plant protection measures are deemed necessary, a system of non-chemical pest methodologies should be considered before a decision is taken to use pesticides. Suitable pest control methods should be used in an integrated manner and pesticides should be used on an as-need basis only, and only as a last resort component of IPM strategy. In such a strategy, the effects of pesticides on human health, environment, sustainability of the agricultural system and economy should be carefully considered."

A similar definition, but with the explicit recognition to the importance of different control tactics given by the Global Facility for Plant Protection of FAO runs as "IPM is an approach to pest management, which emphasizes the development of right mix of control measures which are cost effective to the farmer and sustainable. The emphasis for the farmer is on profit, safety and stability. While IPM can include chemical control, it usually seeks to minimize chemical inputs, because of their cost, and the dangers they pose regarding the treadmill, residues in produce, environment and health. Primary emphasis is put on encouraging natural control processes, particularly the action of natural enemies, and other local and inexpensive approaches. Plant resistance, trap crops to lure pest away, modification in planting dates, intercropping, attractant plants and other methods all contribute to effective IPM in different systems."

The ultimate objective of IPM is to improve the social welfare in a balanced manner. This is explicitly brought out in the definition by Waibel and Zadoks (1996), "The real IPM is a crop protection system which is based on rational and unbiased information leading to a balance of non-chemical and chemical components, moving pesticide use levels away from their present political optimum to a social optimum defined in the context of welfare economics."

These definitions present a mix of the technological and ecological views, identify types of pest control practices and reflect concerns of the profitability, sustainability, food security, ecology and public health. Most of these have evolved from the theory and practice in the developed countries where the farmers are highly receptive to innovations, the consumers are conscious of health and food safety, and the flow of information from researchers to the users is smooth. These do not fully reflect the real situations prevailing in the developing countries where the majority of farmers is illiterate, the flow of information is rigid, and the food security dominates the food safety concerns. Thus, from a developing country perspective, 'human resource development' is critical for making IPM work under the field conditions. The Indonesian IPM program that is considered to be one of the most successful IPM programs in the world reflects these concerns, "IPM is an ecological approach where agriculture is viewed as a complex living system in which humans interact with land, water, plants and other organisms in an attempt to optimize human, natural and man-made resources. IPM is also a human resource development program. Farmers learn to work with nature and gain capacities necessary for productive, sustainable agriculture. Farmers become experts, and the central focus of the agricultural system. Farmers also become more active, independent, competent actors within agricultural development" (Indonesian Ministry of Agriculture Decree No. 390/Kpts/TP/600/5/1994).

Similar concerns are expressed in the operational definition followed by the Philippine National IPM Program, "IPM is an ecological approach with biological control as its foundation. It focuses on growing a healthy crop, conserving natural enemies, and observing fields regularly. IPM is also a program of human resource development that focuses on farmers as experts. Farmers' empowerment through improved decision making skills alongside the revitalization of farmers' organizations spur the process of fully assimilating IPM into existing community farming practices. IPM facilitates knowledge processes, continuous observation and feedback from the local environment, and enhances decision making capacity and capability. IPM is carried out by farmers, not for farmers" (The Philippine National IPM Program, Ksakalikasan, 1993).

The World Bank (1997) follows the definition given by the United States Department of Agriculture (USDA). The definition emphasizes the role of the farmers in IPM programs, "IPM is a knowledge-intensive and farmer-based management approach that encourages natural control of pest populations by anticipating pest problems and preventing pests from reaching economically damaging levels. Appropriate techniques are used, such as enhancing natural enemies, planting pest-resistant crops, adapting cultural management, and, as a last resort, using pesticides judiciously."

2.3 Goals of IPM

IPM seeks to achieve the following goals:

- Reduce pesticide risks to the producers, consumers and the environment
- Conserve beneficial insects and the natural enemies of insect pests
- Encourage use of biological methods of pest control
- Ensure farm profitability
- Empower farmers through education and training to improve their decision making

2.4 Principles of IPM

Effective implementation of IPM is based on the following principles:

- ◆ **Grow a healthy crop**: It includes choice of crop variety, seedbed management, plant nutrition, and irrigation and weed management.

- **Optimize natural enemies**: It emphasizes the importance of naturally occurring beneficials in the pest management and understanding their life cycles, habitats, food webs and the relationships with the insect pests.
- **Field monitoring**: It includes regular field monitoring for the symptoms and the changes in pest populations, and their relationships with the crop growth, weather and other crop management practices.
- **Farmers as experts:** Train farmers to empower them in agro-ecosystem analysis and crop management decisions based on their own observations made in the field from time to time.

2.5 Components of IPM

IPM includes a wide array of direct and indirect practices to limit the crop loss. Broadly, it requires three areas of competence: prevention, observation and intervention. Prevention aims at reducing the initial severity of the pest infestation. Observation aims to determine when and what action to take, while the intervention aims to reduce effects of the damaging pest populations below the economic injury level. Table 2.1 provides details of the components of each of these.

Table 2.1: Components of IPM

Prevention	Observation	Intervention
• Location • Crop rotation • Cropping pattern • Plant breeding • Crop husbandry and hygiene • Fertilization • Irrigation • Habitat management • Trap crops • Intercropping • Harvesting and storage	• Crop monitoring • Decision making • Area-wide management	• Cultural and physical control • Pheromones • Biological control • Chemical control

2.5.1 Preventive measures

Preventive measures are the indirect measures to limit the pest infestation. These include mainly the agronomic and management practices.

Location

Agro-climatic conditions, soils, topography, climate, etc., dictate the choice of crops and their varieties. Growing crops and their varieties at appropriate locations provides optimal conditions for the crop growth. A healthy crop is less prone to attack by the insect pests and diseases.

Crop rotation

Crop rotations are primarily followed to maintain the soil health and fertility as well as for utilizing family labor uniformly throughout the year. An unbroken sequence of any single crop may allow build up of the large pest populations and encourage the inter-season pest migration. Thus, crop rotation helps check inter-seasonal movement of the pests. However, it may not provide an effective control to every pest.

Cropping pattern

Crop diversity is important to avoid pest multiplication, as monocropping is amenable to pest pressure both in space and time. Some insect pests, in absence of alternative/preferred hosts, start eating up the monocultured crop.

Plant breeding

Choice of the crop variety is an important consideration in plant protection. Growing pest-resistant varieties provides effective protection against pests. The option is environmentally safe (reduces pesticide use and helps conserve natural enemies of the insect pests, and other beneficial insects) and economically sound (reduces cost of pest control, and transactions costs of information search and acquisition).

Crop husbandry and hygiene

Mechanical and physical crop protection methods prevent or minimize weed, disease and insect pest infestations. For instance, deep summer ploughing before seeding/sowing exposes the insect larvae to the sun and prevents pest build up, besides controlling the weeds.

Most insect pests occur only at certain stages of crop growth and remain active only for a few days/weeks. A slight variation in the planting dates can avoid pest attack. Maintenance of appropriate plant density can also reduce the pest multiplication. Dense planting increases humidity that encourages the spread of diseases.

Crop hygiene is also important in checking the pest build-up and their inter-seasonal migration. Destruction of the leftover crop residues minimizes the seasonal migration of pests. For instance, destruction of cotton stalks and fallen material that harbor the bollworm reduces carry over of the pest to the next crop/crop season.

Fertilization

Excessive use of nitrogenous fertilizers, particularly in the initial stages of crop growth, creates a favorable microclimate for the pest multiplication. While the organic manure helps crop achieve a steady and sturdy growth, and reduces the pest multiplication. Certain manures also have antibiotic effects.

Irrigation

Irrigation acts both ways as far as its role in the pest management is concerned; it can encourage as well as discourage the pest build-up. Flooding of some crops, like rice, helps controlling weeds. This, however, could be detrimental to the growth of some soil inhabiting natural enemies of the pests.

Habitat management

Conservation of natural habitats of the enemies of the insect pests (predators) is one of the most important tools of pest management. Planting of trees and hedges on the margins of the farmlands provides a cover and refuge to the natural enemies of the insect pests and predatory birds.

Inter/trap cropping

Trap crops act as alternative hosts to insect pests, and minimize infestation on the main crop. For example, maize as a border crop or an inter-crop in the cotton fields attracts bollworms and avoids damage to the main crop. Carefully selected intercrops, as cowpea in the cotton system, help multiplication of the natural enemies of the pests besides improving soil fertility.

Harvesting and storage
Appropriate timing and the method of harvesting and storage, check carry over of the weed seeds and the insect larvae.

2.5.2 Observation

Regular field observations for the pest emergence and growth help farmers take appropriate pest control actions at appropriate times.

Crop monitoring
Monitoring of crop for pest infestation is an important component of IPM. Regular inspection of the crop helps in assessing the plant growth, and take appropriate interventions to ensure a healthy crop growth. Various tools such as pheromone traps, diagnostic and forecasting systems are available to assist in the pest monitoring and to take judicious pest control decisions.

Decision support
Farmers need assistance in interpreting the pest data. Expert systems can be made available. These include: simple pegboards, special booklets, radio, television programs, etc.

Area-wide management
IPM is group-based approach and requires a community action to manage the pest in an economic manner. Certain pest management decisions need to be taken at the community level or at the central level by the governments. While the decisions regarding crop husbandry are generally taken by the farmers' groups, the decisions concerning quarantine regulations and legislation, training and advisory services, pest monitoring and forecasting systems are taken at the central level.

2.5.3 Intervention

Interventions are the direct measures of reducing pest populations to the acceptable limits. A number of direct methods such as mechanical, biological and chemical are used. The choice of the method depends on the level of pest infestation, the effectiveness of the method and the cost and benefit associated with it, and the availability of labor and other resources with the producers.

Cultural and physical control

A number of cultural and physical techniques reduce the pest infestation. These include hand picking of the insect pests and their larvae, removal of the diseased plants, manual/ mechanical weeding, etc. These techniques are labor-intensive and their application depends on the availability of the labor, wage rate, and their impact on crop economics.

Pheromones

Pheromones are generally species-specific and are used to monitor the pest infestation, and to initiate the pest control action accordingly. Pheromones also disrupt the mating by attracting and trapping the insect to an extent that the population can no longer sustain.

Biological control

Biological control relies on nature's own methods of regulating the pest populations. Natural enemies of the insect pests exist in the ecosystem. These include insects, predators and pathogens. Biological control uses these natural enemies in the following ways: natural enemies are introduced from their area of origin to the target area; natural enemies present in the ecosystem are conserved using cultural practices and habitat management to increase their activity, and artificial augmentation of the local natural enemies.

Indiscriminate and excessive use of chemical pesticides adversely affects populations of the natural enemies. Technologies for using these natural enemies have been developed and standardized for the commercial use. Some of the commercially available bio-pesticides are: Nuclear polyhedrosis virus (NPV), *Bacillus thureingeinsis* (Bt), *Trichogramma* and *Trichoderma*. Besides, the use of the pesticides of plant origin (neem) is also increasingly advocated. Neem products act as antifeedant and pest repellant, and provide effective control of a number of insect pests.

Chemical control

Chemical pesticides have been increasingly relied upon for pest management, mainly because of their availability in a wide range, the propaganda by the agrochemical industry, and above all their knockdown effect on the pests. In the IPM context, use of the pesticides is advocated as a last resort.

Integration of a number of preventive and intervention tactics makes IPM implementation a complex and knowledge-intensive process. Whether to practice IPM or not depend on the farmer’s understanding of the IPM process, its technical efficacy, economic viability and sustainability.

3 PLANT PROTECTION IN INDIA: STRATEGIES AND POLICIES

In the pre-green revolution era, Indian farmers had been using a number of non-chemical tactics to limit the crop loss due to insect pests, diseases, weeds and nematodes as a part of good crop husbandry. Cultural and biological controls were the dominant methods of pest control. Use of chemical pesticides for crop protection was practically unknown. Their use in India started with the import of DDT after World War II for the control of malaria. Although, tea and coffee estates had started using pesticides by the end of World War II, the use of pesticides in agriculture started with BHC in 1948 for the locust control. In 1949, small quantities of DDT and BHC were imported and distributed free of cost to the farmers. Their use started increasing with the launch of 'Grow More Food Campaign' by the Government of India during the First Five Year Plan (1951-56).

Until 1951, India relied mainly on the imported pesticides. Indigenous production started with the establishment of BHC manufacturing plant at Rishra near Kolkatta in 1952. Subsequently in 1954 a DDT manufacturing plant was started in Delhi. In 1952, India produced 200 tonnes of technical grade pesticides. By the end of the First Five Year Plan, the production had increased to more than 2800 tonnes, and the pesticide use in agriculture was 15 gm/ha. Thereafter, with the increasing realization of the importance of plant protection in increasing the agricultural production, the demand for chemical pesticides kept on increasing. By 1966 - the year of introduction of high yielding varieties of rice and wheat, the usage of pesticides had reached 94 gm/ha. Since then pesticide use has increased tremendously. At the end of the first decade of introduction new varieties, the pesticide use in agriculture has increased to 266 gm/ha. The new varieties were not high yielding in themselves; they required an intensive application of fertilizers and pesticides. Pesticide consumption kept on increasing till 1990-91, but started declining afterwards. At present, pesticide consumption is estimated about 250 gm/ha.

3.1 Crop Loss due to Pests

A number of insect pests, diseases, weeds, nematodes, and rodents constrain the realization of the potential agricultural production. Reliable estimates of the crop loss are scarce. Informed opinions and experimental evidences indicate considerable loss in the potential agricultural production (Table 3.1). About 50 percent of the potential output of cotton and 25 percent of rice is lost due to pests. Production loss due to pests in pulses and sugarcane is estimated at 30 and 20 percent, respectively. In case of coarse cereals, 25-35 percent of their potential production is lost due to pests. Loss in oilseeds too is also high. Loss in wheat is reported about 5 percent.

Table 3.1: Estimates of crop loss due to insect pests (%)

Crop	Pre-green revolution	Post-green revolution	
		1983	1993-94
Cotton	18	50	50
Rice	10	20	25
Wheat	na	10	5
Coarse cereals	na	25	25-35
Oilseeds	5	na	na
Brassicas	na	37-73	35
Groundnut	na	10	15
Pulses	5	10	30
Sugarcane	na	na	20
Storage	na	7	na

na= not available

Source: Pre-green revolution estimates are from Pradhan (1983). Post-green revolution estimates for 1983 are from Atwal (1986) and estimates for 1993-94 are from Dhaliwal and Arora (1996)

Available information indicates an increase in the pest-induced loss. Nevertheless, the figures presented in Table 3.1 indicate a three-fold increase in loss in the case of cotton, a two-fold increase in the case of rice and six-fold increase in pulses. Increase in the loss is attributed to the rising pest problem (Table 3.2). In traditional agriculture, there were only five important insect pests of cereals, which in recent years have increased to 44. Insect pests of pulses, fiber crops, vegetables and sugarcane have also multiplied. Besides, a number of insect pests have developed resistance to the insecticides intended to control them. *Helicoverpa*, white fly and diamond back moth are the examples. *Helicoverpa* has developed 164-300 fold resistance to cypermethrin, 79 fold to fenvalerate and 1.7 to 12.5 fold to carbaryl, monocrotophos, endosulfan, quinalphos and trizophos (Singh, 1997).

Indiscriminate use of pesticides and inappropriate crop husbandry practices are blamed for the rising pest problem. Rising tendencies towards monoculture, increasing use of the chemical fertilizers accompanied by the declining use of organic manure, continuous cropping, reduction in the crop rotations, etc. have contributed substantially to the rise in pest complex. Indiscriminate use of pesticides has adversely affected the populations of the natural enemies of the insect pests.

Table 3.2: Number of important insect pests in the traditional and the modern agriculture in India

Crop	Traditional agriculture	Modern agriculture
Cereals	5	44
Pulses	0	18
Oilseeds	7	17
Fibre crops	3	11
Sugarcane	0	6
Vegetables	1	16
Others	7	26

Source: Rao (1988)

3.2 Growth and Determinants of Pesticide Use

3.2.1 Trend in pesticide use

Total pesticide consumption in agriculture increased from 2.4 thousand tonnes in 1955-56 to 14.6 thousand tonnes in 1965-66. (Table 3.3).

Government initiatives to increase the agricultural production through the programs like 'Grow More Food' and 'Intensive Agriculture District Program' contributed to this. Thereafter, with the spread of green revolution the pesticide use kept on increasing and reached a peak of 75 thousand tonnes in 1990-91. However, it has been declining since 1990-91 and reached to 49.2 thousand tonnes in 1998-99.

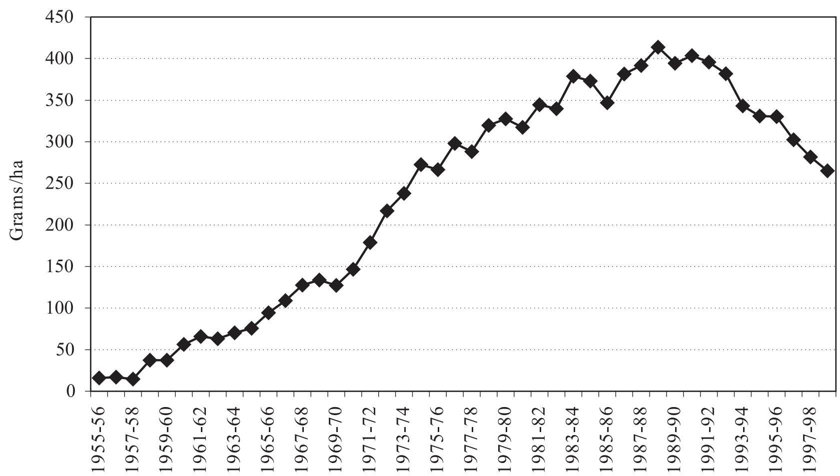
Table 3.3: Trend in pesticide use in agriculture

Year/Period	Consumption of pesticides	
	Total (000 tonnes)	Per ha (gm)
1955-56	2.4	16
1965-66	14.6	94
1975-76	45.6	266
1985-86	61.9	347
1990-91	75.0	404
1998-99	49.2	265
% annual growth		
1955-56 to 1964-65	23.5	22.4
1965-66 to 1974-75	12.8	12.0
1975-76 to 1984-85	4.0	3.5
1985-86 to 1998-99	-2.2	-2.6
1955-56 to 1998-99	7.2	6.6

Source: calculated using data from Directorate of Plant Protection and Quarantine, Ministry of Agriculture, GOI.

Per hectare pesticide use remained stagnant at around 16 gm during 1950s. It increased to 94 gm/ha in 1965-66 and further to 266 gm/ha in 1975-76. Afterwards, the rising trend in per hectare pesticide slackened; it grew at a rate of 3.5 percent a year between 1975-76 and 1984-85, compared to an annual growth of 12 percent during the first decade of the green revolution. Per hectare use remained stagnant at around 350 gm/ha between late 1970s and early 1980s. After reaching a peak of 414 gm/ha in 1989-90, it started declining. Between 1985-86 and 1998-99, pesticide use witnessed a negative growth (2.6 percent a year). In 1998-99, per hectare use was 266 gm. Figure 3.1 makes the trend more explicit.

Figure 3.1: Trend in per hecatre use of pesticides in agriculture



Extremely low level of pesticide consumption in the pre-green revolution era was due to their limited supply, and lack of awareness among the farmers about the pesticides as means of pest control. Introduction of new crop varieties gave a fillip to pesticide consumption. This was facilitated by expanding irrigated area, increasing use of chemical fertilizers, and rising tendencies of monoculture and continuous cropping. Moreover, the government policies of subsidized inputs and aggressive marketing campaigns by the pesticide companies also contributed to the observed growth in pesticide consumption, particularly during the first decade of green revolution.

By the end of first decade of green revolution, the goal of food self-sufficiency was at the threshold of fulfilment. And also, the ill effects of the pesticides on the ecology and human health, the problems of pest resistance, resurgence and secondary pest outbreak had started appearing. Besides, the rising prices of the pesticides, and the development of resistance in insect pests led to an increase in the cost of pest control and decline in marginal returns to the investment in the pesticides. The cropping pattern too had stabilized. The focus of the agricultural research had started shifting towards evolving the pest-resistant varieties. At the same time, the efforts were on to develop and standardize the biological pest management technologies, and educate the farmers in judicious use of pesticides. These efforts slowed down the growth in pesticide use.

3.2.2 Types of pesticide used

Pest management in India has largely focused on the insect control. This is reflected in the composition of pesticides used in agriculture (Table 3.4). During 1960s, insecticides accounted for bulk (86 %) of pesticides consumed in agriculture. Fungicides accounted for 12 percent. Use of herbicides was almost negligible. This pattern underwent a change over time. Share of insecticides kept on declining reaching to 64 percent in 1998-99. Use of herbicides increased considerably; from about 9 gm/ha in 1977-78 to 37 gm/ha in 1997-98. In terms of percentage, the share of herbicides increased from 3 percent to 14 percent during this period. Consumption of fungicides too increased, and most of it occurred between 1965-66 and 1977-78. Since then, it has remained stagnant at around 55 gm/ha. Their share too has not changed much.

Table 3.4:Changes in composition of pesticide use

	1965-66	1977-78	1990-91	1997-98
Consumption (gram/ha)				
Insecticides	81	270	186	176
Herbicides	-	9	31	37
Fungicides	11	57	59	53
Others	2	7	9	9
Percent share				
Insecticides	86	79	74	64
Herbicides	-	3	8	14
Fungicides	12	16	16	19
Others	2	2	2	3

Source: calculated using data from Directorate of Plant Protection and Quarantine, Ministry of Agriculture, GOI.

The main reason for the faster growth in herbicide consumption is the rising problem of weeds in the intensively cultivated regions. Weeds compete with the main crop for water and nutrients and limit the crop yield and its profitability. Secondly, the demand for labour in states like Punjab and Haryana has increased, leading to increase in the wage rates. This rendered manual weed control a costly option, compared to the labour-saving chemical control. Further, before the introduction of high yielding varieties, farmers had been collecting certain weeds for animal feeding. With high yielding varieties, availability of dry as well as green fodder increased, and the weeds as animal fodder became redundant.

3.2.3 Regional distribution, and intensity of pesticide use

Regional distribution of pesticides is highly skewed (Table 3.5). During triennium ending(TE) 1976-77, Andhra Pradesh alone accounted for a quarter of the total pesticides consumed in the country. Uttar Pradesh ranked

Table 3.5: Regional distribution of growth in pesticide use

State	TE 1976-77		TE 1989-90		TE 1997-98		% annual growth	
	Quantity (gm/ha)	Share (%)	Quantity (gm/ha)	Share (%)	Quantity (gm/ha)	Share (%)	1974-75 to 1989-90	1989-90 to 1997-98
Andhra Pradesh	865	25.2	787	14.2	674	15.9	-1.12	-8.68
Assam	84	0.6	151	0.8	76	0.5	7.91	-13.36
Bihar	209	5.3	214	3.2	111	2.1	1.88	-10.26
Gujarat	456	10.4	413	6.1	407	8.1	-2.68	-0.05
Haryana	278	3.3	788	6	828	8.9	8.93	-0.54
Himachal Pradesh	39	0.1	547	0.8	270	0.5	22.52	-0.53
Karnataka	185	4.5	353	6	274	6.2	5.88	-4.09
Kerala	299	2.1	352	1.5	317	1.8	1.77	1.68
Madhya Pradesh	182	8.7	155	4.9	61	2.7	-1.88	-17.22
Maharashtra	90	4.1	272	7.7	201	7.9	9.57	-4.38
Orissa	187	3.2	196	2.5	105	1.8	3.3	-19.17
Punjab	580	8.2	752	7.8	928	12.8	3.71	1.95
Rajasthan	73	2.8	179	4.2	150	5.6	6.39	0.24
Tamilnadu	609	9.8	1705	15.9	268	3.4	7.6	-19.62
Uttar Pradesh	292	15.4	324	11.4	296	13.8	3.55	-2.79
West Bengal	250	4.4	524	6.3	464	7.3	7.31	-1.2
India	259	100	400	100	305	100	3.2	-5.07

Source: calculated using data from Directorate of Plant Protection and Quarantine, Ministry of Agriculture, GOI.

next with a share of 15.4 percent and was followed by Gujarat (10.4 %), Tamil Nadu (9.8 %), Madhya Pradesh (8.7%) and Punjab (8.2 %). In terms of per hectare of gross cropped area, their use was the highest in Andhra Pradesh (865 gm), followed by Tamil Nadu (609 gm), Punjab (580 gm) and Gujarat (456 gm).

Pesticide use increased until 1990-91 in almost all the states, but at differential rates. During TE 1976-77, per hectare consumption of pesticides was the highest in Andhra Pradesh (865 gm) followed by Tamil Nadu (609 gm), Punjab (580 gm) and Gujarat (456 gm). During TE 1989-90, Tamil Nadu with per hectare consumption of 1705 gm ranked first, and was followed by Haryana, Andhra Pradesh, Punjab and Himachal Pradesh. The pattern changed during the 1990s. During TE 1997-98 highest consumption of pesticides was in Punajb (928 gm/ha), followed by Haryana, Andhra Pradesh and Gujarat. During 1990s, the per hectare pesticide consumption declined in most of the states except Punjab and Kerala. In Gujarat, Haryana, Himachal Pradesh and Rajasthan there were only marginal changes in the per hectare pesticide use. On the whole, the per hectare pesticide consumption declined at a rate of above 5 percent a year.

3.2.4 Determinants of pesticide use

A number of price and non-price factors, such as the cropping pattern, farm size, irrigation, prices of pesticides and other inputs, and the output prices influence pesticide use. Their effect on pesticide use is examined below.

Cropping pattern

Crops and their varieties vary in their inherent resistance to insect pests. And therefore, cropping pattern is expected to influence the pesticide use. In India, cotton is highly prone to insect pests and diseases; and 40-45 percent of the total pesticides consumed in agriculture goes towards controlling the cotton pests, though its share in the total cropped area has hardly ever exceeded 5 percent (Table 3.6). On an average, 3.8 kg of pesticides were applied on one hectare of cotton area in 1992-93.

Rice is the second largest consumer of pesticides. Its share in the total pesticide consumption is in congruence with its share in the total cropped area. Mean pesticide usage in 1992-93 was 0.31 kg/ha of rice area. Wheat, with an area share of 13 percent, accounted for only 6 percent of the total pesticide consumption. Pesticide use in wheat is limited mainly to the herbicides.

Fruits, vegetables and plantation crops consumed about 16 percent of the total pesticides used in agriculture, though their share in the total cropped area was 5.4 percent. The average pesticide use in the fruits and vegetables and the plantation crops was 1.1 and 1.5 kg/ha, respectively.

Table 3.6: Crop-wise estimates of pesticide consumption

Crop	Estimate I (1984-85)			Estimate II (1992-93)		
	Area share (%)	Share in pesticides (%)	Expenditure (Rs/ha)	Area share (%)	Share in pesticides (%)	Pesticide use (gm/ha)
Cotton	4.1	44.5	341	4.1	40	3754
Rice	23.3	22.8	31	22.4	18	306
Wheat	13.3	6.4	15	13.2	6	174
Arhar	1.8	2.8	49	-	-	-
Chickpea	3.8	0.2	2	-	-	-
Groundnut	4.2	2.5	18	-	-	-
Rapeseed-Mustard	2.0	0.2	0.3	-	-	-
Fruits & vegetables	3.2	7.3	70	3.4	10	1108
Plantation crops	-	-	-	2.0	6	1145

Source: Chand and Birthal (1997).

However, the entire cultivated area does not receive pesticide applications. In 1992, only 19 percent of the total cropped area in the country was treated with pesticides. But, there is considerable regional variation in the proportion of total cropped area treated with pesticides. Highest area treated with pesticides was in Punjab (64%), and followed by West Bengal (42%), Andhra Pradesh (36%), Tamil Nadu (33%) and Haryana (31%). In states, like Assam, Himachal Pradesh, Madhya Pradesh, Rajasthan and Uttar Pradesh less than 10 percent of the total cropped area was treated with pesticides. Thus, the per hectare pesticide consumption on treated area basis works out to be much higher than the one estimated using total cropped area as denominator. At all India level, pesticide use was 2.3 kg/ha of treated area as against 0.42 kg/ha estimated based on gross cropped area. It ranged between 0.8 and 2.0 kg/ha in Bihar, Karnataka, Maharashtra, Punjab, Rajasthan and West Bengal. In Andhra Pradesh, Gujarat, Haryana, Kerala and Tamil Nadu it ranged between 2 to 4 kg/ha. In Assam, Himachal Pradesh, Madhya Pradesh and Uttar Pradesh it was more than 4 kg/ha.

Table 3.7: Regional variation in area treated with pesticides, 1991-92

States	% of GCA treated with pesticides	Per ha pesticides use	
		On GCA basis	On treated area basis
Andhra Pradesh	36.47	938	2571
Assam	3.36	149	4440
Bihar	28.55	221	775
Gujarat	24.47	524	2141
Haryana	30.76	949	3086
Himachal Pradesh	3.99	266	6667
Karnataka	20.26	335	1654
Kerala	13.19	360	2727
Madhya Pradesh	2.09	196	9390
Maharashtra	23.86	331	1388
Orissa	13.43	499	3713
Punjab	64.44	830	1289
Rajasthan	9.48	179	1891
Tamilnadu	33.43	672	2009
Uttar Pradesh	6.33	346	5468
West Bengal	41.86	586	1400
India	18.57	424	2283

Source: Input Survey, Ministry of Agriculture, Govt. of India, 1992.

Crop-specific estimates of the pesticide use would also inflate substantially, depending on the area treated with pesticides. Table 3.8 shows that except for cotton where about two-third of its area was treated with pesticides, proportion of area of other crops treated with pesticides varied between 3 percent for chickpea to 33 percent for pigeonpea and jute. Proportion of area under sorghum, pearlmillet, maize and ragi treated with pesticides was extremely low. In case of wheat, only about 16 percent of the area was treated with pesticides.

Table 3.8: Crop-wise area treated with pesticides, 1991-92 (%)

Crops	Marginal	Small	Semi-medium	Medium	Large	Total
Paddy	26.47	23.13	24.86	26.24	23.45	25.41
Sorghum	7.38	10.22	9.51	9.89	7.65	9.36
Pearlmillet	4.60	5.22	6.02	5.80	3.33	5.09
Maize	2.36	3.54	4.32	5.15	4.22	3.91
Ragi	1.40	3.00	2.61	3.19	3.45	2.66
Wheat	4.13	11.04	15.56	24.52	28.92	15.75
Chickpea	1.35	2.79	2.79	4.31	2.50	3.01
Arhar	9.76	25.50	33.88	39.69	43.11	32.25
Sugarcane	4.01	21.27	41.31	24.26	22.35	21.32
Groundnut	16.62	24.54	28.81	32.36	25.28	27.44
Rapeseed-mustard	8.92	16.67	21.48	25.59	27.15	21.49
Cotton	66.33	69.32	67.04	67.78	65.43	67.38
Jute	34.29	35.98	32.96	19.15	9.09	32.61

Source: Input Survey, Ministry of Agriculture, Govt. of India, 1992.

Irrigation

Irrigation influences pesticide use via its effect on the crop growth. Irrigated areas/crops are expected to demand better plant protection, compared to rainfed areas/crops. In 1991-92, about one-third of the irrigated area was treated with pesticides. The corresponding figure for the unirrigated area was 11 percent (Table 3.9). Of the total area treated with pesticides 64 percent was irrigated.

Table 3.9: Area treated with pesticides by size group of land holdings and irrigation status, 1991-92

Holding	Area treated with pesticides (%)			% irrigated area of total treated area
	Irrigated	Unirrigated	Total	
Marginal	24.65	8.34	15.55	70.10
Small	27.38	11.50	17.85	61.07
Semi-medium	33.05	11.76	19.52	61.73
Medium	37.34	11.92	20.77	62.59
Large	41.33	7.48	17.58	70.17
Total	32.06	10.59	18.57	64.15

Source: Input Survey, Ministry of Agriculture, Govt. of India, 1992

Farm size

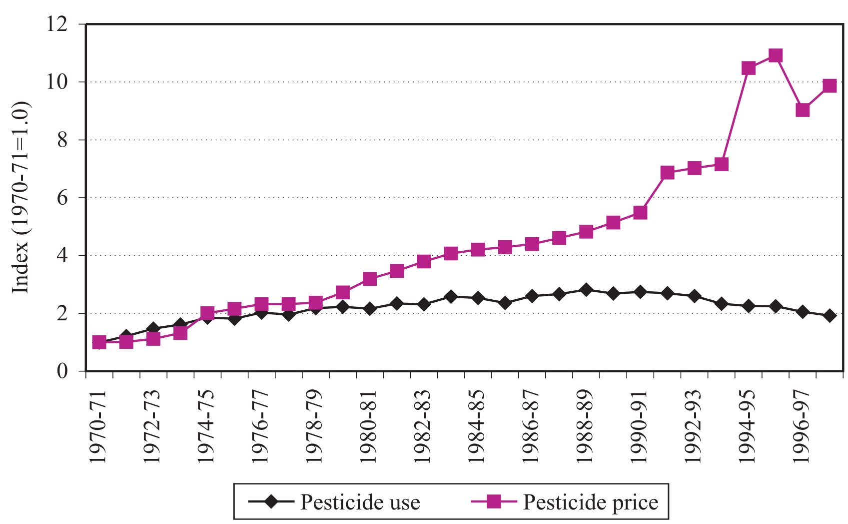
Pesticides are cash inputs, and their application rates are expected to increase with farm size. Table 3.9, that also presents the area treated with pesticides on different size groups of holdings, indicates a positive association between the proportion of area treated with pesticides and the size of land holding; though the association is weak. However, when irrigation factor is brought into the picture the association becomes stronger. On the marginal and small farms, about 25 percent of the irrigated area was treated with pesticides, on medium farms it was 35 percent and on large farms it was 41 percent.

Prices of inputs and outputs

Economic efficiency criterion suggests that farmers should choose that combination of the pest management techniques, which maximizes their utility function. In other words, the value of yield saved due to pest control should be greater than its cost. Farmers should increase the use of the pest management inputs till their marginal value of yield saved equals the marginal cost of control.

Pesticide price : Figure 3.2 depicts the trend in pesticide price vis-a-vis per hectare pesticide use. There are four distinct phases in this relationship. Till mid 1970s, increase in pesticide price was less than the increase in pesticide use. Thereafter, pesticide price increased and the growth in

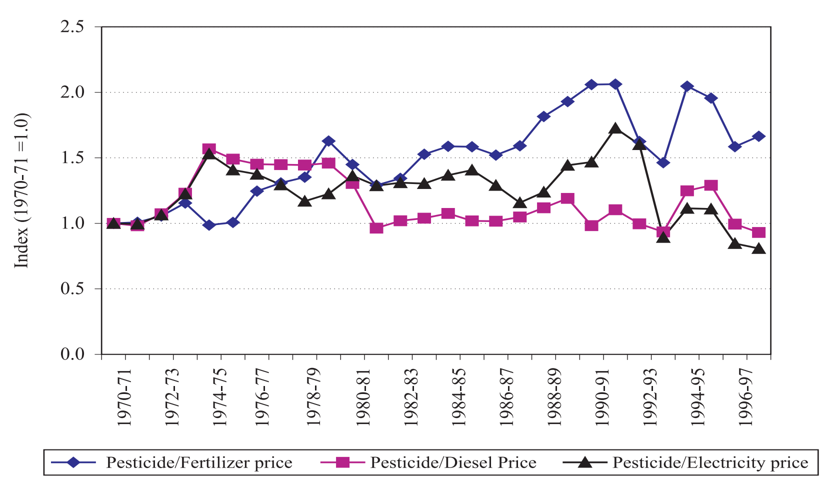
Figure 3.2 : Trend in pesticide use and pesticide price



pesticide use slackened. This was due to oil shock in 1974 that led to an increase in the prices of oil-based raw material used in pesticide formulation. The trend continued till 1980-81. During 1980s pesticide price increased at a faster rate, while pesticide use was almost stable. The rising trend in pesticide price became stronger during 1990s. This helped reduce pesticide use considerably. This suggests that farmers are responsive to the pesticide prices. Faster increase in the pesticide price during late 1980s and onward was partly due to gradual withdrawal of the subsidies on pesticides given by the central and state governments under different crop production programs. This phase also coincided with the change in the government policy of plant protection in favour of Integrated Pest Management.

Pesticide price in relation to prices of other inputs: Farmers allocate their limited financial resources to different inputs based on their prices, and contributions to the crop output. Figure 3.3 shows movement in the index of pesticide price in relation to price indices of other cash inputs (fertilizers, diesel and electricity). Throughout the pesticide price increased faster than the fertilizer price. The trend, however, was erratic. In relation to the diesel price, the pesticide price increased faster till mid 1970s. During late 1970s, the pesticide price moved together with the diesel price. The relative prices of pesticides fell sharply in early 1980s, and afterwards the

Figure 3.3: Relative price of pesticides compared with prices of other inputs

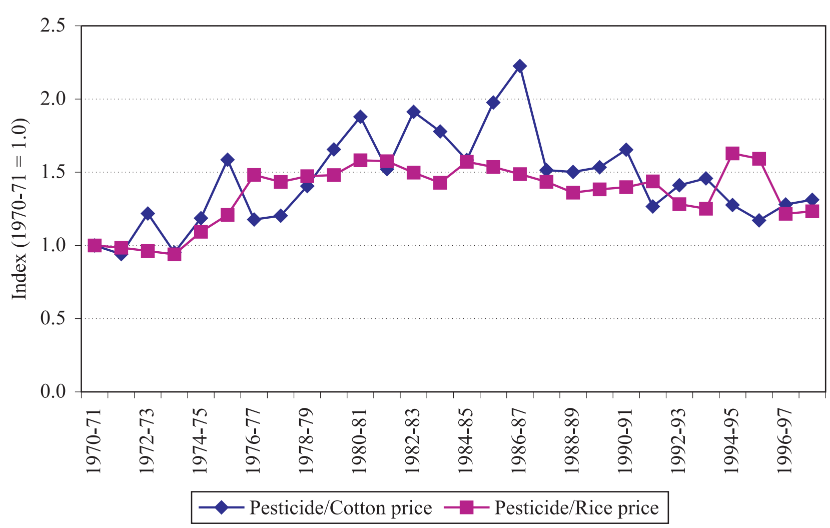


trend in the relative prices was almost stagnant. In early 1990s, the relative prices of pesticides increased but fell afterwards. Similar observations are made for the pesticide price in relation to the electricity price. The decline in the prices of pesticides in relation to other cash inputs used in crop production during 1990s was due to reduction in subsidy support to fertilizers, electricity and diesel under the economic reforms program.

Output prices : Faster growth in the output prices in relation to the input prices is expected to increase the input use. Figure 3.4 shows movement of the pesticide price in relation to the prices of cotton and rice - the two largest users of pesticides. The ratio of the pesticide price to the rice price increased gradually until late 1970s. It remained stable till mid 1980s. Thereafter, it showed a declining trend, but with gyrations. The trend in the pesticide price in relation to the raw cotton price was marred with fluctuations till late 1980s, but the general trend indicates faster growth in the pesticide price compared to the cotton price. In 1990s, however, the pesticide price has fallen or stabilized in relation to the raw cotton price.

Though, during 1990s prices of pesticides in relation to the output prices have fallen, their per hectare consumption has declined substantially. This is counterintuitive to the economic logic. This perhaps could be due to the

Figure 3.4: Pesticide price in relation to output prices



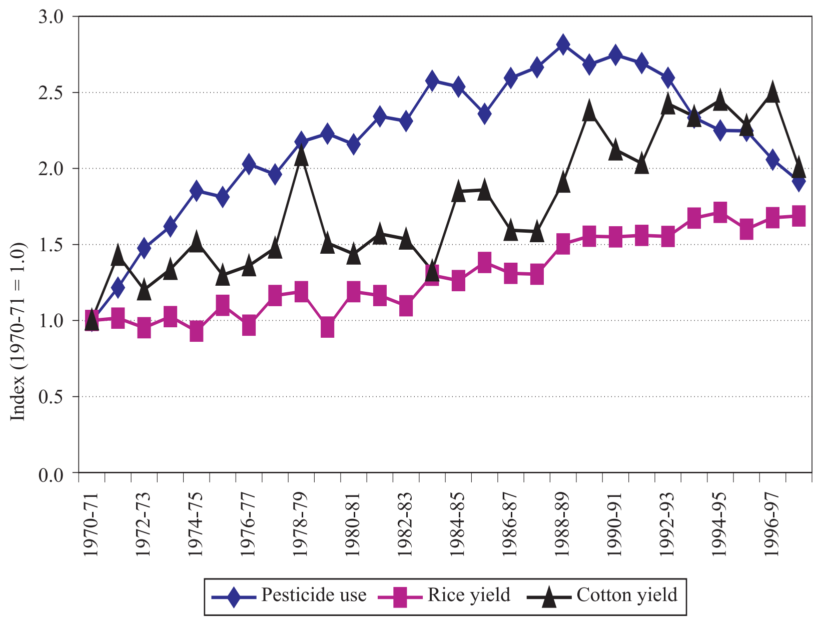
technological failure of pesticides to control insect pests, farmers' increasing awareness about the judicious use of pesticides, and application of non-chemical approaches.

3.3 Pesticides and Agricultural Productivity

Pesticides, alongwith the seeds and fertilizers, have contributed substantially to the growth of agricultural productivity. However, because of their potential hazards to public health and environment, their use in agriculture is being curtailed gradually. This strategy is viewed with apprehensions because of heavy losses due to pests, and slow adoption of the alternative technologies. Reduction in the pesticide use might lead to adverse effects on agricultural production and prices. Such apprehensions were quite strong during 1970s when the food security was the prime concern. The noted agricultural scientist Norman Borlaug (1972) indicated that a complete ban on pesticide use in agriculture might result in 50 percent reduction in crop production and 4-5 fold increase in food prices. However, with advancement in agricultural research these apprehensions are now disappearing gradually (Kenmore, 1996). Focus of plant breeding research has been shifting towards development of pest-resistant cultivars, and plant protection research has been concentrating on development of alternative technologies. Evidences from the developed as well as the developing countries indicate that it is possible to reduce pesticide use without much decline in the crop yields and increase in the output prices (Palladino, 1989; Pimental et al, 1993a; Kenmore, 1996).

As noticed earlier, there has been a continuous decline in pesticide use in India since 1990-91. Between 1990-91 and 1998-99, it declined by 35 percent. Whether this could affect agricultural productivity is examined for the cotton and rice - the two major consumers of pesticides. Figure 3.5 shows the relationship between pesticide use and the yields of cotton and rice at the national level. From 1970-71 till late 1980s, per hectare pesticide use increased, but the crop yields behaved erratically. During 1970s the cotton yield increased, and the paddy yield remained almost stagnant. During 1980s, cotton yield showed a declining trend until mid 1980s, but started increasing thereafter. Paddy yield showed an upward trend throughout 1980s. During 1990s, when the pesticide consumption started declining,

Figure 3.5: Relationship between pesticide use and yields of cotton and paddy in India



the cotton yield remained almost stagnant and the paddy yield increased steadily. It, however, may be noted that in the initial years of reduction in pesticide use, the cotton yield declined and the paddy yield remained almost stagnant. This shows that reducing pesticide use might lead to some decline in the crop yield in the short run, in the long run it does not seem to affect agricultural productivity significantly.

The regional insight into the relationship between pesticide use and crop yield is more revealing. Pesticide use reduced in almost all the states, but in varying magnitudes. Figures 3.6 to 3.16 present the trends in yields of cotton and rice in relation to the pesticide use for some selected states. In Andhra Pradesh, cotton yield declined during late 1970s despite increasing use of pesticides (Figure 3.6). During 1980s, it moved together with the pesticide use trend. It stabilized during 1990s, despite a steep fall in the pesticide use. But, the paddy yield maintained an upward trend in both rising and declining phases of pesticide use.

Figure 3.6 : Relationship between pesticide use and yields of cotton and paddy in Andhra Pradesh

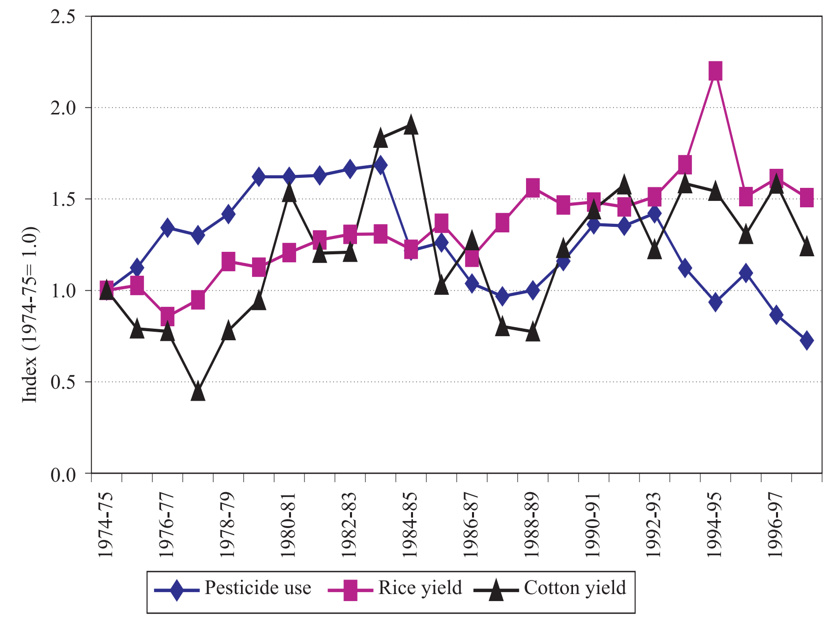


Figure 3.7 : Relationship between pesticide use and yields of cotton and paddy in Tamilnadu

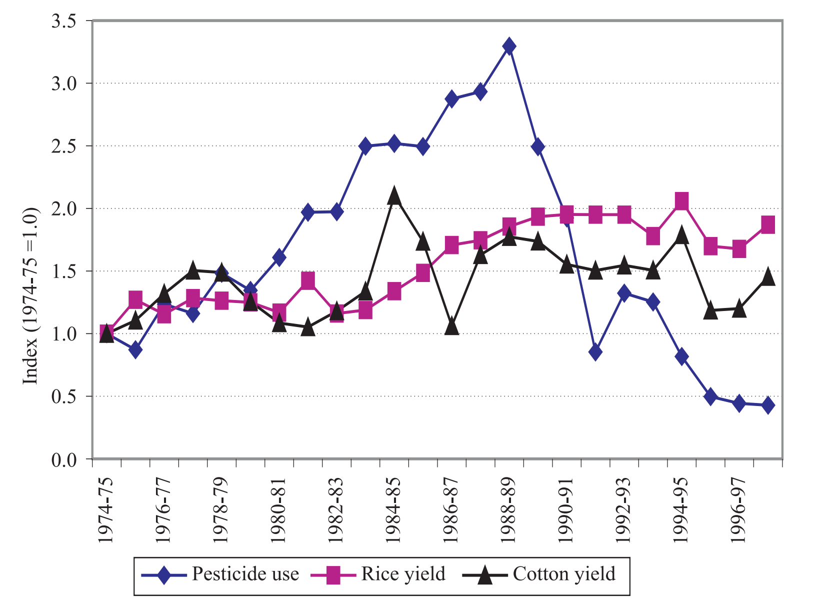
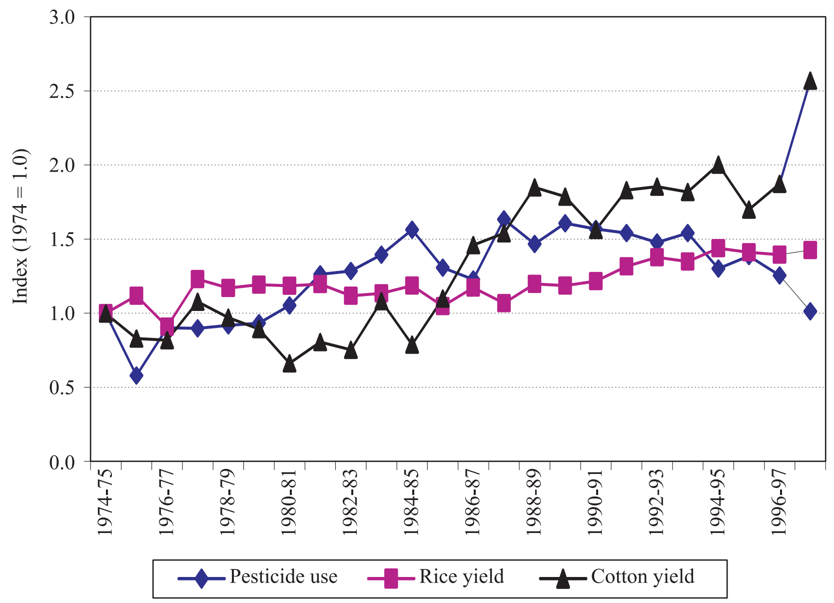


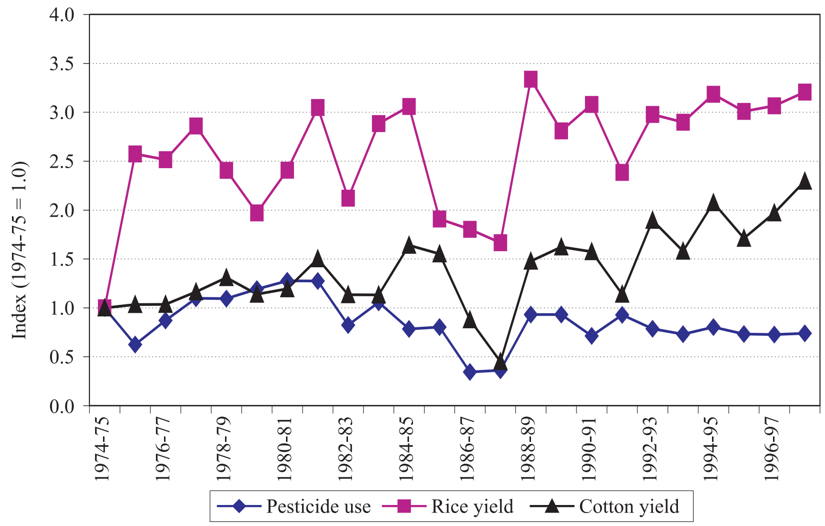
Figure 3.8 : Relationship between pesticide use and yields of cotton and paddy in Karnataka



Pesticide use in Tamil Nadu increased exponentially until 1989-90 and declined drastically afterwards (Figure 3.7). The reduction, however, did not affect the crop yield of either cotton or paddy. In the initial phase of reduction, yields remained almost stagnant at 1989-90 level. However, further reduction in the pesticide use could cause a marginal decline in the yield of these crops. In Karnataka, reduction in pesticide use did not affect the yield of both the crops (Figure 3.8). Pesticide use reduced drastically after 1992-93, yet the yield of both cotton and paddy remained upwardly mobile.

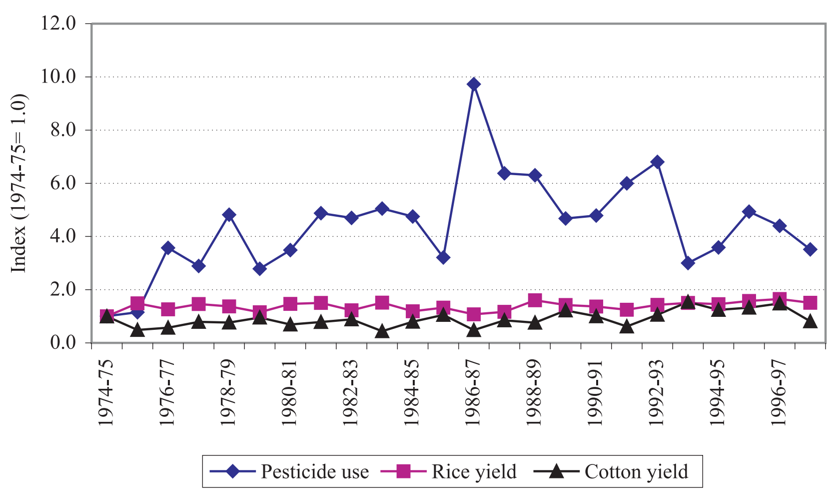
In Gujarat, the association between pesticide use and cotton yield was positive until 1991-92; the yield increased with the increase in the pesticide use and declined with the decline in the pesticide use (Figure 3.9). Since then, there has been a steady decline in the pesticide use, but the cotton yield kept on moving upward. In pre-1991-92 period, paddy yield showed a similar trend as the pesticide use. Afterwards when pesticide use started declining it almost remained stable.

Figure 3.9 : Relationship between pesticide use and yields of cotton and paddy in Gujarat



Maharashtra is one of the major cotton growing states in India. There appears to be no significant correlation between cotton yield and pesticide use (Figure 3.10). Per hectare pesticide use increased till 1986-87, and started

Figure 3.10: Relationship between pesticide use and yields of cotton and paddy in Maharashtra



declining thereafter. But cotton yield showed a slightly positive trend. So was in the case of paddy.

The relationship between pesticide use and paddy yield in Uttar Pradesh, Bihar, Orissa and West Bengal is shown through Figures 3.11 to 3.14 show.

Figure 3.11: Relationship between pesticide use and yields of cotton and paddy in Uttar Pradesh

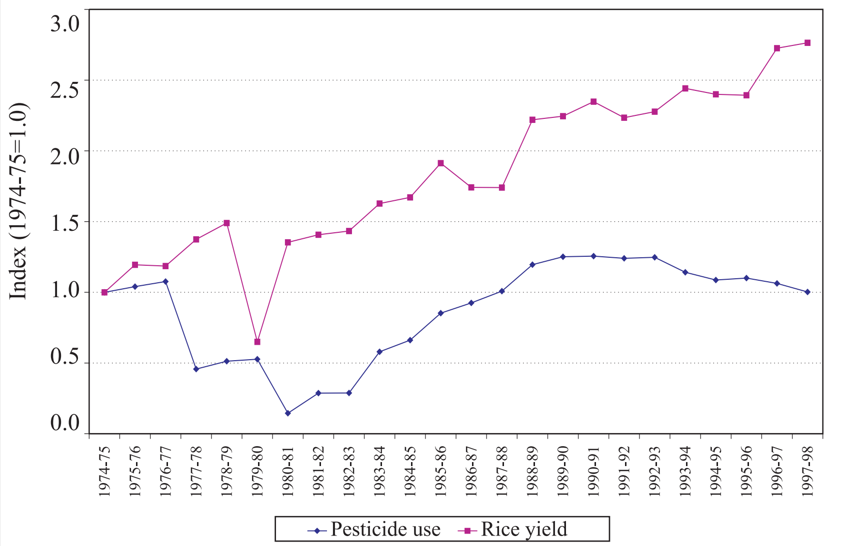


Figure 3.12 : Relationship between pesticide use and paddy yield in West Bengal

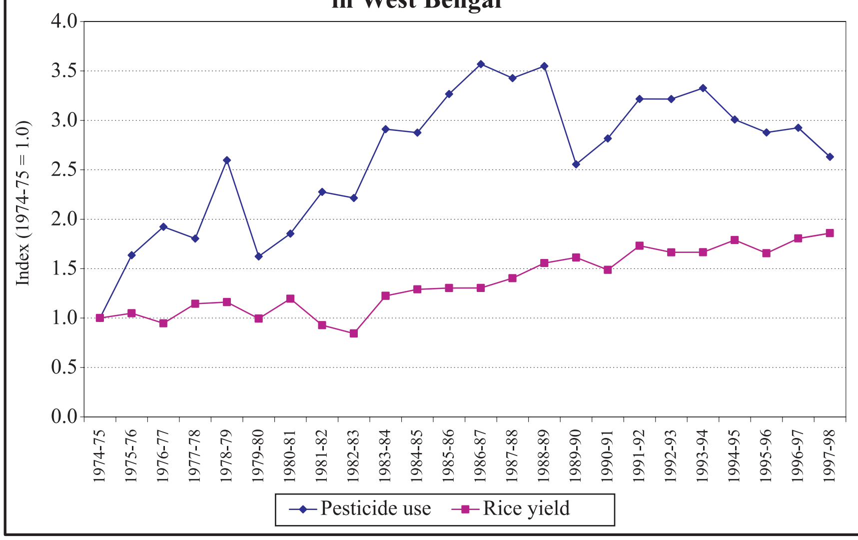


Figure 3.13: Relationship between pesticide use and yields of cotton and paddy in Bihar

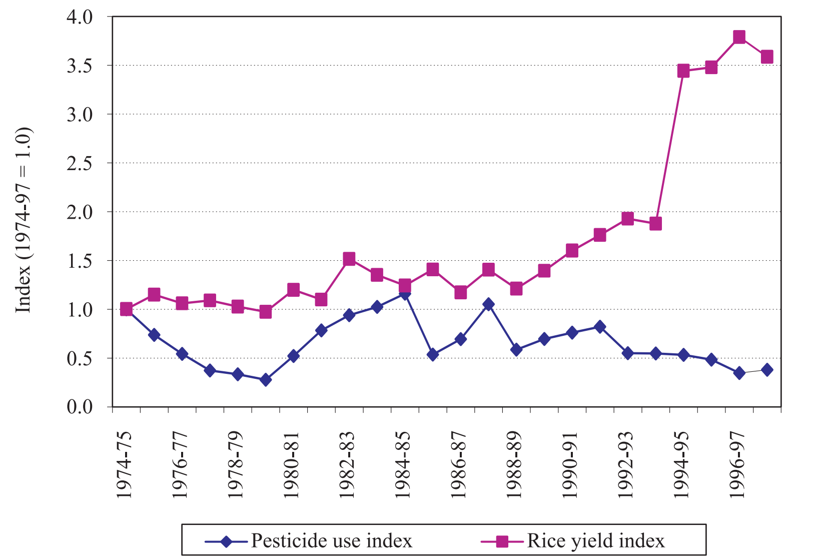
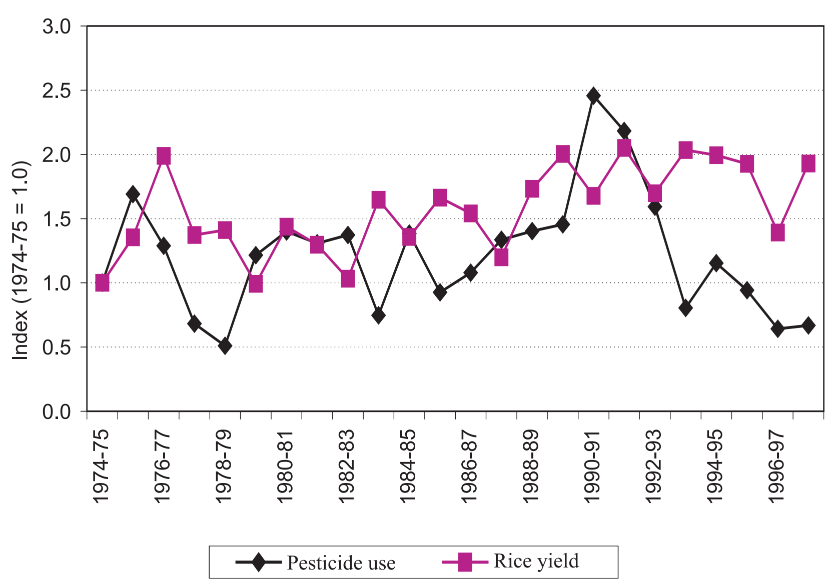


Figure 3.14 : Relationship between pesticide use and paddy yield in Orissa

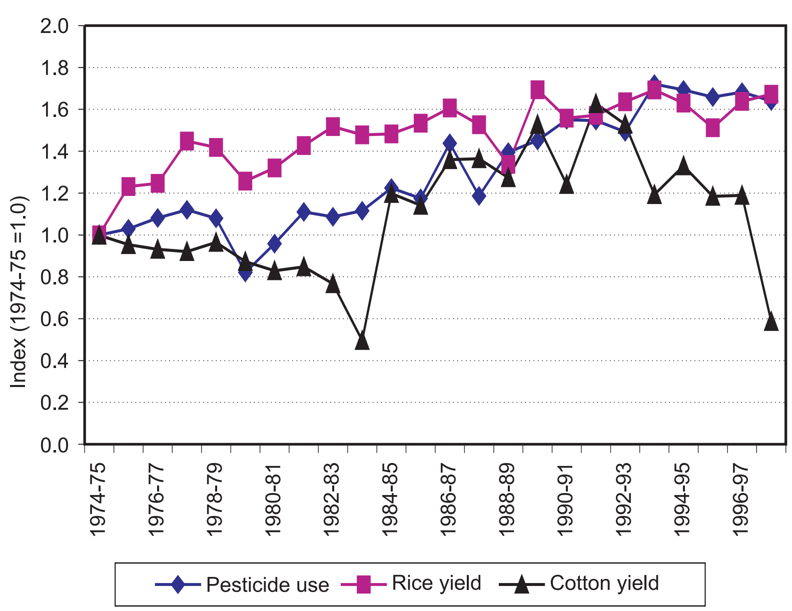


In Uttar Pradesh, paddy yield had a positive association with the pesticide use prior to beginning of the declining phase of pesticide use in 1990-91. Afterwards, there was a steady increase in the paddy yield. In West Bengal too, the yield trend remained positive in the declining phase of pesticides.

In Bihar, until 1991-92 paddy yield showed a similar trend as the pesticide use. Afterwards, the paddy yield increased faster, despite a negative trend in the pesticide use. In Orissa, the trend in pesticide use as well as paddy yield was erratic. Yet, the general trend indicates a positive association between per hectare pesticide use and the paddy yield until 1990-91. After 1990-91, pesticide use declined considerably, but without affecting the paddy yield.

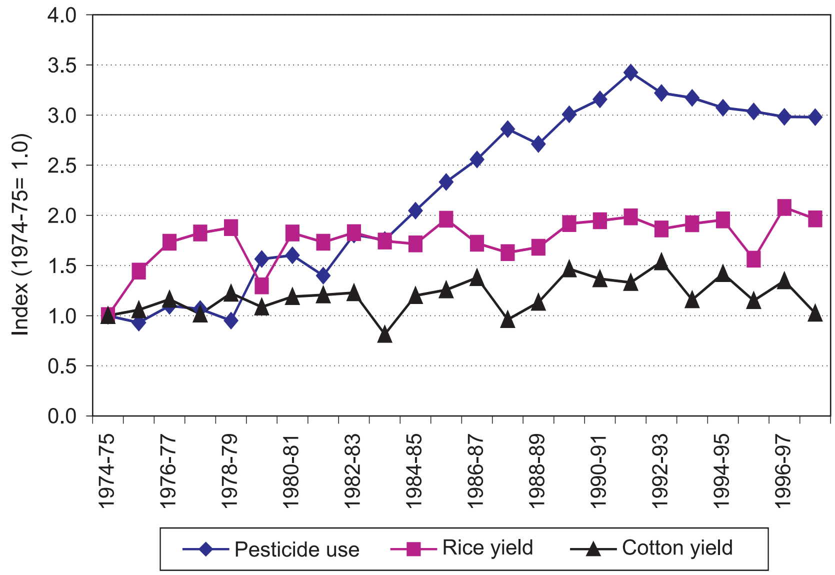
In Punjab and Haryana, the reduction in pesticide consumption has affected crop yield adversely. In Punjab, the negative trend in pesticide use set in after 1993-94. Though the reduction was marginal, it affected cotton yield adversely (Figure 3.15). Yield of paddy declined initially, but recovered subsequently. In Haryana, the negative trend in pesticide use set

Figure 3.15: Relationship between pesticide use and yields of cotton and paddy in Punjab



in 1991-92. Cotton yield experienced marginal decline, while the paddy yield remained almost stagnant (Figure 3.16).

Figure 3.16: Relationship between pesticide use and yields of cotton and paddy in Haryana



Based on the trend and intensity of the pesticide use, and their relationship with agricultural productivity, these states can be classified into four distinct categories. The first category includes the states with high per hectare pesticide use at the time of onset of declining trend, but it reduced drastically in the subsequent years and without affecting the agricultural productivity. This includes Andhra Pradesh and Tamil Nadu. The second category includes the states of Punjab and Haryana having high initial pesticide use, but even the marginal reduction in it could cause decline in the crop yield, particularly of cotton. The third category comprises of the low pesticide using states of Maharashtra and Orissa, where pesticide use could be reduced substantially, but without any adverse effects on the crop yield. The fourth category includes the low pesticide using states of Bihar, Gujarat, Karnataka, Uttar Pradesh and West Bengal where rate of reduction in pesticide consumption has been slow, but experienced continuous increase in the crop yield.

Broadly, these results imply that it is possible to reduce pesticide use without any concomitant decline in agricultural productivity, though initially crop yields might experience slight decline. In Punjab and Haryana, where the crop yield declined, pesticide use appears to be indiscriminate and excessive, which possibly has adversely affected the populations of natural enemies of insect pests and other beneficial insects and microorganisms. In other states, where the yields are either stable or increasing even with reduction in pesticide use, the populations of natural enemies seem to have recovered on reduction in pesticide consumption. The stable or positive trend in the crop yield could also be due to substitution of the chemical pesticides with the non-chemical approaches and increase in farmers' awareness about the judicious use of pesticides.

3.4 Programs and Policies for Promotion of IPM

Farmers in India had been practicing IPM since long. These practices were consistent with ecological principle of IPM. With the intensification of agriculture, ecological IPM gradually gave way to technological IPM with greater reliance on the chemical pesticides. Now, with the availability of new products of biotechnological research (bioagents, biopesticides and botanicals) the ecological IPM is again gaining importance.

India is a signatory to the United Nations Conference on Environment and Development 1972 wherein IPM was accepted as the preferred strategy of pest management under Agenda 21. The Agenda 21 states: 'Chemical control of agricultural pests has dominated the scene, but its overuse has the adverse effects on farm budgets, human health, and the environment, as well as on the international trade. New pest problems continue to arise. The integrated pest management, which combines biological control, host plant resistance, and appropriate farming practices is the best option for future, as it guarantees yields, reduces costs, is environmentally friendly and contributes to the sustainability of agriculture. Considering the global concerns, India adopted IPM as an official plant protection policy in 1985. Perhaps, India was the first country to do so. Since then, a number of research and policy initiatives have been taken to reduce the pesticide use in agriculture, and promote the concept of IPM. This section briefly reviews the progress of IPM and policy measures taken to promote it.

3.4.1 IPM research

Research on IPM in India dates back to mid 1930s when the efforts were made to collect, identify and rear parasitoids of sugarcane pests in Bihar at the Imperial (now Indian) Agricultural Research Institute (IARI). Intensive work on biological control was undertaken on shifting of the IARI to Delhi in 1936. These efforts got a boost when the Commonwealth Institute of Biological Control established a centre on biological control at Bangalore in 1957 to conduct exploratory surveys for identification of the natural enemies of insect pests of major crops. The Commonwealth Institute of Biological Control, however, withdrew its activities from India in 1987.

The first major initiative towards strengthening the biological control research was the establishment of an All India Coordinated Research Project (AICRP) on biological control by the Indian Council of Agricultural Research in 1977 at Bangalore. AICRP was upgraded as Project Directorate on Biological Control (PDBC) in1993. PDBC conducts basic and applied research on the biological control and test technologies evolved at its 16 centres spread throughout the country. PDBC has identified a number of biological control agents and standardized technologies for their commercial production.

Establishment of the National Centre for Integrated Pest Management (NCIPM) in 1988 was another major step towards strengthening IPM research and development efforts. The Centre has the mandate to develop and validate IPM modules by synthesizing researches conducted in the national agricultural research system. Besides, the NCIPM also undertakes on-farm testing and field demonstrations of IPM. Research on IPM is also conducted in the State Agricultural Universities. Many other public and the private sector institutions such as the Department of Biotechnology, the Department of Science and Technology, Non-Governmental Organizations, etc. too undertake research and development activities. Some of the biological products developed for commercial application are given in Table 3.10. Besides these, there are a number of other biological products that have been tested for their efficacy and commercialization.

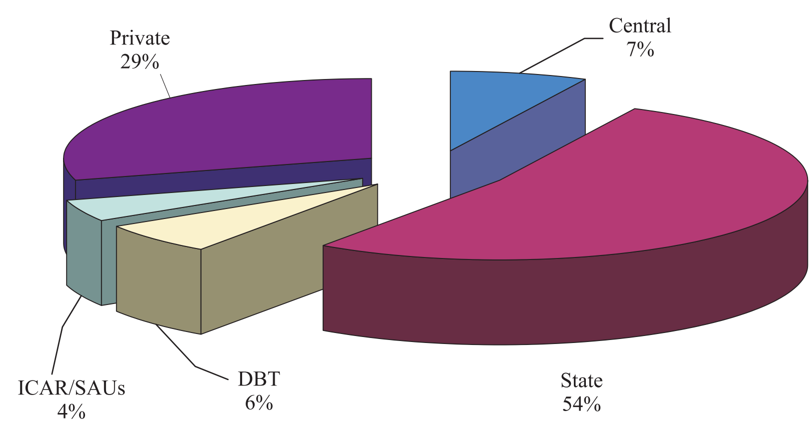
Table 3.10: Some commercially available biological pesticides in India

Biological product	Target Crops	Target insect pests
Parasitoids		
Trichogramma spp.	Rice	Stem borer,
	Cotton	Leaf folder
	Sugarcane	Boll worms
	Vegetables	Shoot borer
	Pulses	Fruit borer
	Maize	Helicoverpa
		Root borer
Predators		
Crysoperla carnea	Rice	WBPH, BPH
	Pulses	Helicoverpa, Borers
	Vegetables	Sucking pests
	Cotton	Boll worms
Bacterial		
Bacillus thuringiensis	Cotton	Boll worms
	Vegetables	Fruit borers, DBM
	Pulses	Heliothis
Viral Insecticides		
Nuclear Polyhedrosis	Cotton	Heliothis, Spodopetra
virus	Pulses	Heliothis, Spodopetra
	Vegetables	Heliothis, Spodopetra
	Groundnut	Helioverpa, Spodopetra
	Coconut	Rhinoceros beetle
Fungal anatagonists		
Trichoderma spp.	Oilseeds	Root rot
	Pulses	Wilt
Pheromones		Boll worms
		Cater pillar
		Borers
		Moths
Neem pesticides		

3.4.2 Infrastructure for production of biological pesticides

Biological pesticides are produced both by the public and private sector institutions. There are 356 registered laboratories producing biological agents. About 70 percent of these are in the domain of public sector, mostly owned by the state governments (Figure 3.17). The central government too has established Central Integrated Pest Management Centres (CIPMCs) - at least one in each state.

Figure 3.17. Public and private sector biocontrol laboratories in India, 1998-99



The regional distribution of biocontrol laboratories, however, is skewed (Table 3.11). Tamil Nadu accounts for one-third of the total laboratories, followed by Uttar Pradesh (7.9%), Andhra Pradesh (7.6%), Gujarat (5.6%) and Karnataka (4.8%). Except in Gujarat, Bihar, Madhya Pradesh, and Karnataka participation of the private sector in production of bio-pesticides is limited.

Considering the continental dimensions of the country, infrastructure for production of biopesticides is inadequate and thinly distributed. Most of the laboratories are small in size, and cater to the needs of the areas located around the laboratory. This is reflected in the area covered by a laboratory. On an average, about 521 thousand hectares of gross cropped area is covered by one laboratory. However, all crops are not the priority crops for implementation of IPM. Cotton and paddy are the main crops for

Table 3.11: Distribution of public and private sector laboratories and area coverage, 1998-99

States	Public	Private	Total	Gross cropped area/ laboratory (000ha)	Cotton+ paddy area/ laboratory (000ha)
Andhra Pradesh	8.0	6.7	7.6	494	163
Assam	2.0	1.0	1.7	665	415
Bihar	1.2	3.8	2.0	1562	711
Gujarat	2.0	14.3	5.6	566	110
Haryana	1.6	1.9	1.7	1023	258
Himachal Pradesh	1.6	0.0	1.1	249	22
Karnataka	3.2	8.6	4.8	765	112
Kerala	2.0	1.0	1.7	534	69
Madhya Pradesh	1.6	1.9	1.7	4180	987
Maharashtra	4.0	14.3	7.0	884	185
Orissa	4.0	1.0	3.1	898	411
Punjab	2.8	0.0	2.0	1114	430
Rajasthan	4.4	0.0	3.1	1928	73
Tamilnadu	32.7	36.2	33.7	60	22
Uttar Pradesh	9.6	3.8	7.9	944	202
West Bengal	6.0	1.0	4.5	559	369
Others	13.5	4.8	11.0	-	-
Total	100.0	100.0	100.0	521	147

implementation of IPM, and on average one biocontrol laboratory covers about 147 thousand hectares of area under these crops. There is also considerable regional variation in area coverage; it varies from 60 thousand hectares in Tamil Nadu to 4180 thousand hectares in Madhya Pradesh. Andhra Pradesh and Himachal Pradesh are the other states having a better intensity of biocontrol laboratories (<500 thousand hectares). In terms of cotton and paddy area, Himachal Pradesh, Kerala, Rajasthan and Tamil Nadu stand better (<100 thousand hectares). It may, however, be noted that except in Tamil Nadu, cotton and paddy occupy only a small fraction of gross cropped area in these states.

Market share of the biopesticides in total agrochemical market substantiates the observation that biological pesticides are used only on a small proportion of the area; biopesticides share only 1 percent of the value of agrochemical market (Table 3.12).

Table 3.12: Market share of bio-pesticides in total agrochemical market in India (%)

	India	World
Organo-phosphates	50	37
Synthetic pyrethroids	19	22
Organo-chlorines	16	6
Carbamates	4	23
Bio-pesticides	1	12
Others	10	0
Total	100	100

Source: Saxena (2001).

3.4.3 Dissemination of IPM

IPM, being an amalgam of a number of pest control tactics, is knowledge-intensive. Its effective implementation requires both extension workers and farmers to have sound understanding of the biology of pests and their natural enemies, and their relationships among themselves and with the surrounding environment. They also need to have sound knowledge of the technology characteristics, and of the socioeconomic and institutional requirements for putting it into practice. Lack of understanding of any of these would adversely affect adoption of IPM.

Both the national and the state governments have been supportive to IPM dissemination efforts. At the national level, the Directorate of Plant Protection, Quarantine and Storage under the Ministry of Agriculture is the apex organization. The main functions of the Directorate are: promotion of IPM, enforcement of plant protection and quarantine regulations, and training in plant protection. The Directorate functions with the support of its 87 sub-offices including 26 Central Integrated Pest Management Centres, 29 Plant Quarantine Stations, 2 Regional Pesticide Testing Laboratories, 29 Locust Control Stations and one National Plant Protection Training Institute.

The Directorate places considerable emphasis on the development of human resources for effective implementation of IPM. Training methodologies have been developed to train the extension workers and the farmers in IPM. A three-tier training program is in operation. The program includes (i) Season-Long Training of Master Trainers, (ii) Training of Agricultural Extension Officers and farmers by organizing Farmers Field Schools (FFS), and (iii) conducting on-farm demonstrations to train the farmers in IPM methodologies.

Under the Season-Long Training program, subject matter specialists are trained in IPM by the international experts in association with the experts drawn from the national agricultural research system and the state departments of agriculture. The training emphasizes agro-ecosystem analysis and participatory action research. The objective of FFS is to train extension workers and farmers in the latter' fields following 'learning by doing' approach. This is to empower them (i) in identification of natural enemies of insect pests and other beneficial insects, (ii) to familiarize them with the adverse effects of chemical pesticides on human health and environment, and (iii) to encourage them to adopt IPM packages. IPM demonstrations are conducted by the extension workers to train farmers in IPM.

During 1995-2000, more than 6200 FFS have been established (Table 3.13). At the national level, on an average an Agricultural Extension Officer (AEO) has been trained thrice in IPM as is indicated by the ratio of trained AEOs to total AEOs. However, there is considerable regional variation in it. It varies from one training/AEO in Madhya Pradesh to 15 trainings/AEO in Punjab. In Haryana, Maharashtra and Uttar Pradesh, average number of trainings/AEO are more than 5. In Assam, Karnataka, Rajasthan and West Bengal, the trainings received by an AEO varied between 3-5. These efforts, however, do not appear to have trickled down, as only 0.19 percent of the farmers in the country have been trained in IPM. This varies from 0.09 percent in Uttar Pradesh to 1.03 percent in Punjab.

Area protected with biological pesticides

IPM packages have been synthesized for 51 crops including cereals, pulses, oilseeds, coarse cereals, fruits, vegetables, plantation, and commercial crops. These packages comprise of the agronomic practices such as deep summer ploughing, use of pest resistant/tolerant varieties, crop rotation, etc.;

Table 3.13: Total number of Farmers' Field Schools organized, and extension workers and farmers trained in IPM during 1995-96 to 1999-2000

State	FFS	AEOs trained	Ratio of AEOs trained to total AEOs	Farmers trained	% farmers trained*
Andhra Pradesh	604	1881	2.7	18104	0.20
Assam	318	1556	4.4	9550	0.38
Bihar	308	1433	1.8	9267	0.07
Gujarat	293	1262	2.8	8810	0.25
Haryana	292	1224	5.1	8661	0.57
Himachal Pradesh	124	309	2.4	3360	0.40
Karnataka	404	1937	3.1	13490	0.23
Kerala	144	570	1.8	4740	0.11
Madhya Pradesh	424	1842	1.1	22706	0.33
Maharashtra	744	3712	5.4	23520	0.26
Orissa	224	1095	1.5	6740	0.17
Punjab	334	1904	15.0	11530	1.03
Rajasthan	292	1904	3.4	11530	0.22
Tamilnadu	245	1044	1.6	6400	0.18
Uttar Pradesh	644	2801	6.4	18896	0.09
West Bengal	216	1129	4.5	7070	0.11
Others	612	1166	5.1	2909	0.12
India	6222	26769	3.0	187283	0.19

*Number of farmers are assumed equivalent to number of land holdings.

Source: Based on information from Directorate of Plant Protection and Quarntine, Ministry of Agriculture, GOI.

mechanical pest control (collection and destruction of insect larvae and removal of infested plant parts); conservation and augmentation of natural enemies of pests; use of biopesticides and botanicals and need-based application of chemical pesticides. These packages are being validated in the farmers' fields.

Major crops protected with the biological control inputs in 1998-99 included cotton, paddy, chickpea, sugarcane, groundnut, pigeonpea, rapeseed-mustard, coconut and vegetables (Table 3.14). The area protected with biocontrol agents, however, is miniscule; only 0.75 percent of the total area under these crops is under bio-control (Table 3.15), while about one-third of the area under these crops receives application of chemical pesticides. Taking total protected area of these crops as a denominator shows only 2 percent area under IPM/biocontrol.

Table 3.14: Crops treated with biocontrol agents, 1998-99

State	Crops
Andhra Pradesh	Cotton, pigeonpea, chickpea, groundnut, paddy
Assam	Paddy and vegetables
Gujarat	Cotton, vegetables and groundnut
Karnataka	Cotton, sugarcane
Kerala	Coconut
Madhya Pradesh	Paddy, vegetables, cotton, maize, sugarcane, chickpea
Maharashtra	Cotton, sugarcane, pigeonpea, chickpea, vegetables, citrus, sunflower
Orissa	Paddy, sugarcane, coconut, groundnut, cotton, vegetables
Punjab	Paddy, cotton, sugarcane, chickpea
Rajasthan	Cotton, maize, mustard, sugarcane
Tamilnadu	Sugarcane, paddy, cotton, coconut, groundnut, pulses
West Bengal	Paddy, sugarcane, jute, chickpea, vegetables

Source: Directorate of Plant Protection and Quarntine, Ministry of Agriculture, GOI.

Further, area treated with biocontrol agents varies considerably across states (Table 3.15). Except in Assam and Tamil Nadu, area treated with the biological pesticides is negligible. In Assam, though area under plant protection is low, 15 percent of it is protected with biocontrol agents. In Tamil Nadu, it is estimated to be 9 percent.

Table 3.15: Area of the specified crops treated with biopesticides, 1998-99

States	Total area under specified crops (000ha)	Area of specified crops treated with pesticides (000ha)	Area of specified crops under biocontrol	% total of specified crops treated with pesticides	% total area of specified crops under biocontrol	Area ubder biocontrol as % of total treated area
Andhra Pradesh	7869	3478	16000	44.19	0.20	0.46
Assam	2627	77	13600	2.93	0.52	15.04
Gujarat	3724	1593	170	42.78	neg	0.01
Karnataka	2723	259	4648	9.52	0.17	1.76
Kerala	1080	na	2540	-	0.24	-
Madhya Pradesh	9712	649	2065	6.68	0.02	0.32
Maharashtra	6191	3365	77225	54.36	1.25	2.24
Orissa	5514	893	3501	16.20	0.06	0.39
Punjab	3197	2638	5213	82.52	0.16	0.20
Rajasthan	4609	1214	6730	26.33	0.15	0.55
Tamilnadu	4655	3116	300000	66.95	6.45	8.78
West Bengal	7666	3157	12355	41.18	0.16	0.39
India*	59567	20439	444047	34.31	0.75	2.13

*Total includes only the states for which information is available

Source: Directorate of Plant Protection and Quarntine, Ministry of Agriculture, GOI.

IPM is akin to a new technology. Farmers are often risk averse, and unless are convinced of its economic benefits and assured supply of biological inputs, they are unlikely to adopt it. However, the drastic reduction in pesticide use in recent years suggests that farmers are increasingly becoming aware of the social and environmental costs of chemical pesticides. IPM promotional efforts seem to have contributed to this, as one of the objectives of IPM is to educate farmers in judicious application of chemical pesticides.

3.4.4 Policies and incentives

Since the adoption of IPM as a cardinal principle of plant protection in 1985, both the central and the state governments have taken a number of steps to promote IPM. These include both economic and non-economic measures, such as ban on hazardous pesticides, phasing out of subsidies on pesticides and appliances, easing out registration norms for biopesticides, grants to state governments to establish biocontrol laboratories, mandatory allocation of funds to IPM promotion, and strengthening of research and extension. Some of these measures have been discussed in the previous paragraphs. Here our focus is on regulatory measures and financial support aspects of IPM programs.

Regulation of pesticides and biopesticides

Manufacturing, sale, use, transport, distribution and import of pesticides in India is governed by the Insecticides Act, 1968 of the Government of India. The Central Insecticides Board is the nodal agency to implement the Act. The Registration Committee of the Central Insecticide Board grants registration for pesticide manufacturing and export. State governments are responsible for issuing licenses for sale and formulation of pesticides. More or less the similar regulations govern production, import, sale and distribution of biological pest management technologies also. However, biocontrol agents need not to be registered under certain circumstances; farmers and cooperatives producing for own use are exempted from registration requirements. Three insecticides of plant origin that is, *Pyrethrum* from *Chrysanthemum*, neem based pesticides, and Nicotine sulphate from tobacco (export only); and one microbial pesticide, *Bacillus thuringiensis* , has been registered under the Insecticide Act. Microbial products such as Aureofungin, Sterptomycin sulphate, Kasugamycin and Validamycin are also registered for control of certain diseases. Besides, many pesticides based on microorganisms and plants are also registered on provisional basis.

Ban on hazardous pesticides

The Central Insecticide Board has banned a number of pesticides for use in agriculture, and put many others in the list of restricted use (Table 3.16). DDT and BHC, being cheaper and easily available were the widely used pesticides in agriculture before banning/restricting their use. The ban/restriction on their use could bring down pesticide consumption considerably.

Table 3.16. List of banned and restricted use pesticides in India, 1999

Banned pesticides	Restricted use pesticides
Di-bromo-chloro-propane	Aluminum phosphide
Endrin	Captafol
Penta-chloro-nitro-benzene	Carbaryl
Penta-chloro-phenol	Chloro-benezillate
Texaphene	DDT
Ethyl parathion	Ethylene
Chlordane	Di-bromide
Heptachlor	Lindane
Aldrin	Methyl parathion
Paraquat-dimethyl-sulphate	Methyl parathion
Nitrofen	Sodium-methane-arsonate
Tetradifen	
Calcium cyanide	
Ethyl-mercury-chloride	
Menozon	
Nicotine sulphate	
Phenyl-mercury acetate	
Sodium-methane arsonate	
BHC	

Source: Directorate of Plant Protection and Quarntine, Ministry of Agriculture, GOI.

Phasing out incentives to pesticide use

In an effort to achieve self-sufficiency in agricultural production, agricultural development policy in the 1960s and 1970s favoured increased use of chemical pesticides by maintaining taxes at low level, direct subsidies to farmers on pesticides and pesticide application equipment, and promotion of crop specific protection programs. These, however, are being gradually phased out. A quantum jump in prices of pesticides during nineties indicates this (see, figure 3.2).

Funding IPM

Making bioagents and biopesticides available to the farmers is one of the major policy concerns. To this end, both the central and the state governments have established laboratories for production of biocontrol agents. The Government of India is providing grants-in-aid worth Rs 50 lakhs to each state government to establish biological control laboratories. A national action plan on IPM has been finalized in consultation with the state departments of agriculture. Under this, it is mandatory for the state governments to expend 50 percent of their plant protection budget on IPM. The State Departments of Agriculture are also required to appoint a nodal officer for IPM. Some state governments also supply many biological pest management technologies at subsidized rates.

The paradigm shift in the pest management policy in favour of IPM could help reduce pesticide consumption drastically. A number of direct and indirect regulatory and policy measures were taken. Ban/restriction on hazardous chemicals for use in agriculture, phasing out of direct and indirect subsidies, increase in taxes and levies acted as disincentive to pesticide use. Concurrently, a number of steps were taken to promote IPM. Establishment of biocontrol laboratories, grants-in-aid for strengthening of biocontrol laboratories, easing registration norms for biopesticides, exemption of farmers and cooperatives from registration requirements for production of biopesticides for self use, subsidies on biopesticides, development of IPM packages, training of extension workers and farmers in pest management methodologies through establishment of FFS and IPM demonstrations, etc. were the major steps towards promotion of IPM.

Adoption of biological pest management technologies is poor, despite availability of a number of biological technologies. If the IPM were to become widespread, the biopesticide industry must have appropriate incentives to manufacture and promote the biological pesticides as alternatives to chemical pesticides. Similarly, the farmers too need incentives in terms of relevant knowledge of IPM technologies and practices, and prices of inputs and output.

4 METHODS AND DATA

The main objectives of IPM are to minimize the economic loss due to pests, and to protect environment and public health. The former generates direct economic benefits to the farmers and can be easily quantified. The valuation of the environmental and public health benefits is complex, and requires considerable scientific and field level information. This chapter provides a framework for quantification of direct economic benefits of IPM.

4.1 Evaluating of Pest Management Technologies at Experimental Level

4.1.1 Technical efficacy: Assessing yield loss

The most important indicator of the performance of a pest management technology under experimental conditions, is its ability to suppress the pest, and reduce the crop loss. Insecticide check and constraint experiments are the two widely used methods by the biological scientists to assess the crop damage due to insect pests (Rola and Pingali, 1993). In the insecticide check method, crop is protected by the best available technology, and the yield obtained is compared with the yield under natural infestation conditions. The difference is the loss due to pest. The yield or yield loss provides an assessment of the relative performance of different technological options; lower the loss, better is the technology. The approach, however, is criticized because of its limited applicability under farmers' conditions.

Constraint experiments are conducted to assess the yield loss due to pests under farmers' conditions. Levels of all other inputs in farmers' practices, except the pest management inputs, are raised to the level of the best protection trial. The mean yield with the best protection is compared with the mean yield obtained on farmers' fields to estimate the yield loss. Different technologies thus are evaluated for their effectiveness by comparing the yield or yield loss.

Simple yield comparison generally leads to underestimation of the yield loss, as this compares the yields with and without application of the technology. While, a considerable proportion of yield is lost, even after protecting the crop with the best available technology. Besides, the yield may vary from trial to trial at the same level of infestation, and pest control efforts. This suggests estimation of potential yield - the yield that could have been achieved in absence of pest infestation, and compare it with the actual yields under different pest management options to estimate the yield loss. In recent years, econometric approach has been used to estimate the potential yield (Waibel, 1986; Lichtenberg and Zilberman, 1986). It presupposes existence of a functional relationship between the yield loss and the pest infestation. Regression method is, then used to establish the relationship between the yield and the pest infestation level, and the potential yield is estimated by extending the regression line upto where it cuts the coordinate. The point of intersection corresponds to the potential yield.

Econometric approach can be used for single as well as several cultivation periods and has the advantage of incorporation of different technological options in the model.

The potential yield is obtained by regressing the actual yield (Y_i) on the level of pest infestation (I_i) in case of single pest control strategy, and the intercept term in the regression equation provides estimate of potential yield. The relationship between actual yield and level of pest infestation can be written as:

$$Y_i = f(I_i) \quad (1)$$

In case of multiple technological options, potential yield can be obtained by estimating equation 1 simultaneously with equation 2 below, which establishes relationship between the level of pest infestation and the different technological options (Ti). The level of pest management effort is also desirable while estimating the equation. This can be done by incorporating the cost of pest control (Ci).

$$I_i = f(T_i, C_i) \quad (2)$$

Equations 1 and 2 can be estimated as a set or system of equations. The intercept term in equation 1 provides the estimate of potential yield.

These relationships are best estimated using the trial level cross-section data. However in absence of trial data, the above relationships can be estimated using the time series averages of the trial data, and to neutralize the time effect on the level pest infestation, a time trend variable (t_i) can be added to the right hand side of equation 2.

Under experimental conditions, crop varieties are often changed year after year. As the varieties differ in their yield potential, variety specific dummies (D_v)can be incorporated in the right hand side of equation 1 to obtain the potential yield of a variety. Finally, we get the following equations.

$$Y_i = f, (I_i , D_v) \quad (3)$$

$$I_i = f (T_i , C_i , t_i) \quad (4)$$

These equations have been estimated using the SURE method to obtain the potential yield (Y_P). The actual yields (Y_T) with application of different pest management options are compared with the potential yield to estimate the yield loss. Equation 5 provides yield loss in percent.

$$Y_L = (Y_P - Y_T) / Y_P \; *100 \quad (5)$$

4.1.2 Economic efficacy: Cost and return analysis

Technical feasibility is a necessary, but not a sufficient condition for the use of a technology by the farmers. The choice of a technology is influenced by the expected costs and benefits from its adoption vis-à-vis competing alternatives. Thus, from an economic perspective, the technology will be accepted if it yields higher net returns, compared to the competing alternatives. In other words, the technology will be adopted, if its marginal returns are equal to the marginal cost. A cost and returns analysis is performed to examine the relative profitability of different pest control technologies. Changes in costs and benefits for each pest management option are calculated over the costs and benefits from no-protection. The change in net revenue due to application of technology is calculated as:

$$\Delta X_1 = X_1 - X_2$$

Where X_1 is per hectare net revenue from application of a technology and X_2 is per hectare net revenue from the unprotected field.

Marginal benefit-cost ratio (B/C) is estimated as:

$$B/C = \Delta X_1 - \Delta C_1$$

Where $\Delta C_1 = C_1 - C_2$ is the net cost change due to technology; C_2 is the per hectare cost on application of a technology, C_1 is the per hectare cost with no protection.

Net revenue changes and the benefit-cost ratios associated with different technological options are then compared to examine their relative profitability.

4.2 Measuring Adoption of IPM

Adoption is defined in many ways. Adoption of a technology that does not require integration with other technologies and/or farming practices can be measured by the proportion of the crop area applied with the technology. Its intensity of adoption can be measured by the quantity applied per unit of the cropped area. This is, however, not the case with IPM. IPM is a blend of a number of new and the conventional technologies, and agronomic practices. And, this renders measuring its adoption a complex exercise.

Studies have measured IPM adoption in an 'either-or' framework (Harper, 1990; McNamara, 1991; Thomas et al.,1990; Fernadez-Cornejo, 1994). These have treated IPM as a binary dependent variable while analyzing the impact of differences in the social, personal and economic characteristics of the adopters and the non-adopters on the adoption behaviour. Some studies have defined IPM over some range: non-adopters, low adopters, medium adopters and high adopters (Napit et al., 1988; Vandeman et al., 1994). Others have assumed the 'dominant technique' as an indicator of adoption of IPM package (Harper, 1990; McNamara, 1991). In recent years, ‘continuous scales’ have been developed to measure adoption of IPM. In these scales, various production practices are assigned weights based on their utility and compatibility with IPM package.

Each of the above approach has advantages and limitations. The ‘either-or approach’ is simple and useful when a single component of IPM is examined. This, however, ignores other IPM practices and their intensity. The ‘adoption range’ approach though provides some estimates of the adoption, it is useful when applied in case of a single technique. ‘Dominant technique’ as an indicator of adoption is being widely used. But, the crucial assumption here is that other IPM practices are the same across farms. ‘Continuous scales’ possess the advantage of combining different techniques considering their relative importance, but intensity of application of different practices is ignored. Moreover evolving weights for each practice is a complex exercise and requires considerable scientific inputs cutting across disciplinary boundaries.

Appropriateness of a particular measure of adoption depends on the nature and the utility of the components of IPM, and the potential changes needed in the existing farm practices required for implementation of the IPM package. In India, farmers have been using a number of agronomic and management practices since long as a part of good husbandry, which now are the components of IPM (Birthal, et al., 2000). The revitalized IPM concept incorporates use of technological inputs such as bioagents and biopesticides. Thus, we have treated IPM adoption in a dichotomous sense in terms of use of one or more of these new inputs.

The factors influencing adoption of IPM were analyzed using the probit model, with adoption as a dichotomous variable. It takes value of 1 if the farmer has used the biological pesticides, 0 otherwise.

4.3 Farm Level Effect of IPM: Budgeting Technique Approach

The first step in an economic appraisal of IPM is to assess the impact on the net revenue of the farmers. Such an analysis answers a simple question: how the costs and the returns are affected by adoption of IPM. This is done by comparing costs and returns of the adopters and the non-adopters.

The most commonly used technique to assess the impact of a new technology on net revenue is the budgeting analysis. There are two types of budgeting techniques, enterprise budgeting and partial budgeting. The difference between the enterprise and the partial budgeting is that the former considers all the costs and revenue changes for a single enterprise, while the partial budgeting considers only the cost and the revenue items that are expected to change significantly with the introduction of a new technology. Partial budgeting is often employed to make comparisons of the costs and the returns of the users and the non-users of a new technology on the assumption that the new technology does not affect other cropping practices. The partial budgeting, in the context of IPM provides information on the : (i) changes in costs, (ii) changes in returns, (iii) relationship of unit cost with the size of operation (iv) relationship between net revenues at varying level of pest infestation, and (v) effect of crop prices on feasibility of recommended technology.

IPM techniques are expected to cause changes in the cost of pest control or the yield or the both. Therefore, the partial budgeting technique has been used to assess the farm level effects of IPM by comparing the costs and revenue of the adopters and the non-adopters. The change in net revenue is calculated as:

$$\Delta X_1 = X_1 - X_2$$

Where, X_1 is per hectare net revenue on IPM farms, and X2 is per hectare net revenue on non-IPM farms. The difference can be tested for statistical validity by t-test.

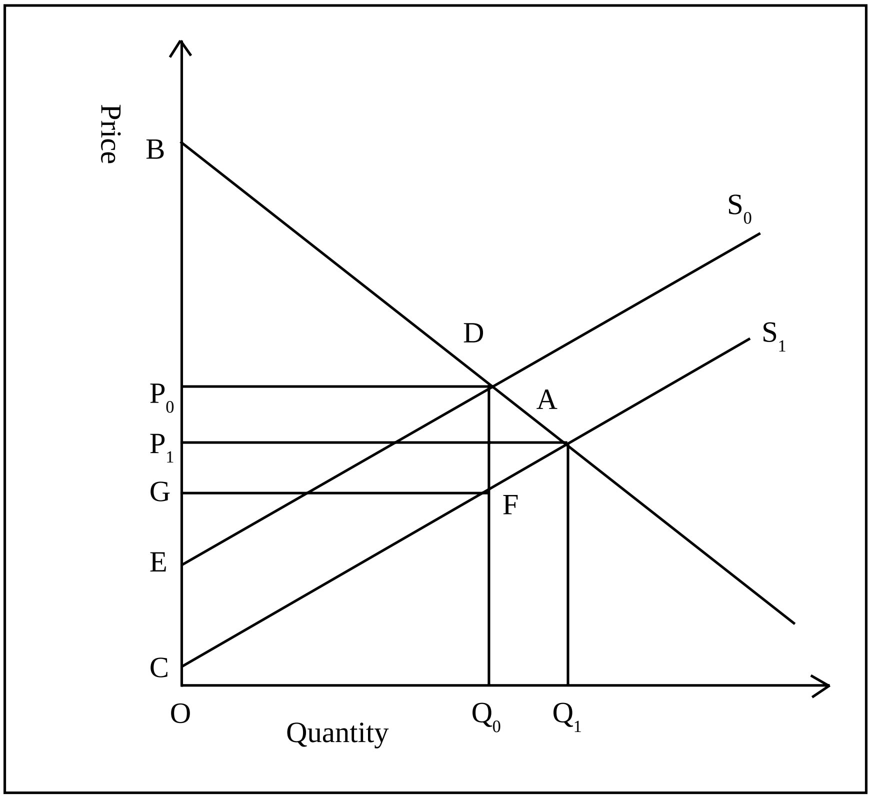
$$t = (\overline{X_1} - \overline{X_2}) / \sqrt{s^2 (1/n_1 + 1/n_2)}$$

Where s^2 is the pooled variance, and s_1^2 and s_2^2 are the sample variances.

$$s^2 = ((n_1 - 1)s_1^2 + (n_2 - 1)s_2^2)/(n_1 + n_2 - 2)$$

4.4 Aggregate Economic Impact of IPM: Economic Surplus Approach

Budgeting technique is transparent and its results are easily interpretable. However, the assumptions of the constant prices and no supply shift are quite restrictive, and do not conform to the real market behavior. Further, the net revenue may not accurately represent the net benefits to the producers and the consumers. Economic surplus approach[1] recognizes the changes in the cost of production, supply and prices resulting from the technological change and consequently the changes in producers and consumers welfare. A graphical representation of the distribution of gains from new technology is shown in Figure 4.1.



Consider a market with linear supply and demand curves that have positive intercepts. This is represented by the curves S_0 and D, and the associated price (P_0) and the quantity (Q_0). The consumer surplus in this case is P_0DB and the producer surplus is P_0DE. Now the reduction in cost due to adoption of the new technology causes outward shift in the supply curve from S_0 to S_1. The price comes down to P_1 as a result of the increase in the supply. The

[1] For details, see Alston, et al.(1995)

consumer surplus now is P_1AB, which is larger than P_0DB. The producer surplus is P_1AC. Whether it is larger or smaller than P_0DE is not readily apparent. Some manipulation reveals that the producers gain by shift in the supply curve to the extent of P_1AFG. However, the gains to the producer largely depend on the nature of the supply shift and the elasticity of demand.

It is assumed that IPM reduces the cost of production. The subsequent downward shift in the supply curve results in a new market equilibrium, in which the prices are lower and the quantities are larger. With this, consumers stand to gain. The benefits to the producers, however, depend on the elasticity of demand and the nature of supply shift (functional form of supply curve). An innovation that reduces the cost more for high cost producers than the lower cost producers results in a divergent supply shift, while an innovation that reduces the average cost equally for all the producers results in parallel supply shift (Linder and Jarret, 1978). The parallel supply shift generates positive benefits to the producers, while a divergent supply shift may result in the negative benefits to the producers (Beddow, 2000).

The literature provides little guidance on the choice of supply shift in case of IPM. Linder and Jarret (1978) indicate that the biological and chemical technologies *ceteris paribus* are likely to produce a divergent supply shift. IPM being a combination of chemical, biological and cultural methods of pest control, could cause a divergent shift in the supply. In other words, the producers might suffer a loss with the adoption of IPM. However, the differences in the cost of pest control are largely due to the differences in individuals' attitude towards pest risks. Nevertheless, pest is a common problem, and results in almost a similar loss pattern across the farms in a given location, if left uncontrolled. Thus, one can expect a parallel shift in the supply curve in case of IPM. A parallel supply shift is assumed for measuring the economic surplus in this study. For a parallel shift, change in consumer surplus (ΔCS) is calculated as:

$$\Delta CS = P_0 \, Q_0 \, Z \, (1+ 0.5Z\eta)$$

Where, $Z = K\varepsilon \,/(e + \eta)$, ε is the equilibrium price elasticity of supply, η is the equilibrium price elasticity of demand and K is the proportionate supply shift. The shift factor K is calculated as :

$$K = [Y/\varepsilon - C/(1+Y)]pA(1-\delta)$$

Where, Y is the proportionate yield change per hectare, C is the proportionate change in per hectare variable input costs, A is the adoption rate, p is the probability of research success and d is the annual rate of depreciation of the technology. In an ex post evaluation, p and d can be ignored.

The change in the producer surplus (ΔPS) is estimated as :

$$\Delta PS = (K\text{-}Z)P_0\, Q_0\, (1+ 0.5Z\eta)$$

The change in the total surplus is then summation of the changes in the consumer and the producer surpluses:

$$\Delta TS = \Delta CS + \Delta PS = P_0\, Q_0\, K\, (1+ 0.5Z\eta)$$

4.5 Estimation of Willingness to Participate in Collective Action

Pest has the characteristics of a detrimental common property resource, and therefore requires area-wide efforts to realize maximum benefits from the investment in pest control. This is rather more important in the case of IPM, which utilizes biological pesticides and the activities of which can be adversely affected by the use of chemical pesticides on the farms in the vicinity. There are a number of other agronomic and management activities, which are also important in pest management and require collective efforts.

Contingent valuation technique was used to elicit farmers' response on their willingness to participate in different pest management activities. Pest management activities vary in importance, and therefore farmers' willingness to participate is also expected to vary with the activity. A composite weighted index of the willingness to participate was constructed by assigning weights to the different activities according to their utility in the pest management. The weights were devised on a scale of 1 to 4 after consultations with experts including entomologists, agronomists and economists. The weighted index of willingness to participate was constructed as follows:

$$I_j = (w_i A_{ij}) / \sum w_i$$

Where I_j is the index of willingness of participation of j^{th} respondent. A_{ij} is the i^{th} activity in which the j^{th} respondent is willing to participate, and w_i is the weight of the i^{th} activity.

A number of socio-economic, psychological and the institutional factors influence the willingness to participate in the collective pest management. Ordered probit model was used to identify the relative importance of such factors in the emergence of collective action with the willingness index as the dependent variable.

4.6 The Data

Two types of data sets have been used in this study: data from experiments, and the survey data. Experimental data were used to examine the technical and economic efficacy of different pest management options, while the survey data were used to test the validity of experimental evidences under farmers' conditions.

4.6.1 Experimental data

Experimental data used to examine the technical and economic efficacy of different methods of pest control were compiled from the annual reports of the Project Directorate on Biological Control (PDBC), Bangalore. PDBC conducts multi-location trials to test the efficacy of different pest management options on a number of crops. After careful screening of the data, we selected three crops viz., cotton, paddy and chickpea for which the required information was consistently available for a period of 3-8 years.

The data is in the form of averages of inputs and outputs for different pest management options. Further, the data is not consistent over time, in terms of a particular input or combination of inputs. Inputs were often replaced every year. Therefore, we grouped different treatments into four categories viz. natural control, chemical control, biological control and IPM (integration of biological and chemical control). Natural control refers to 'no pest control'. Chemical control involves application of pesticides only, while biological control involves the use of one or more biological pesticides. Integrated pest management involves use of both the chemical and biological options.

4.6.2 Survey data

Empirical evidences based on the controlled experimentation, often are criticized for their non-replication under field conditions. And therefore, a number of technologies remain on the shelf, despite their proven technical and economic advantages. This is particularly true for IPM technologies. Thus, field surveys were undertaken in Tamil Nadu in 1998-99 to examine the technical and economic feasibility of IPM under farmers' conditions, and to understand the process of its adoption. Specifically, field investigations address the following issues:

- Are the farmers aware of IPM technologies ?
- What kinds of pest management technologies are being used by the farmers, and are these capable of substituting the chemical pesticides and to what extent?
- What is the economic impact of IPM technologies?
- What are the factors that influence the adoption of these technologies?
- Are the farmers willing to adopt IPM technologies?
- What are the conditions that promote the use of these technologies?

Selection of state

Two main criteria were followed in the selection of a state for the field surveys. First, trend in per hectare pesticide use and its level of application with 1990-91 as the base year. The states with high pesticide use in the base year, and a strong negative trend in pesticide use were identified. Tamil Nadu and Andhra Pradesh qualified this criterion. In the second stage, officials of the Departments of Agriculture and the State Agricultural Universities were consulted on the implementation of IPM program in these states. The status of biocontrol and biopesticide production infrastructure was also considered. Tamil Nadu stood out prominently at this stage (see Chapter 3 for details) and was selected for undertaking the field surveys.

Selection of districts

Cotton, paddy and vegetables account for the bulk of the pesticide consumption at the national level. This kind of information is lacking at the state level. A pattern similar to that at the national level is assumed to exist at the state/district level. For selection of a district, share of the district in the total area under the concerned crop in the state and the share of the concerned crop in the total cropped area were considered (Table 4.1). The districts were ranked in terms of the area share, and top one-third districts were considered. The share of the crop in the district was superimposed on area shares and the districts that had higher area share in the state as well as higher area under the crop were sorted out. Out of these, one district was randomly selected. These districts were Coimbtore for cotton, Thanjavur

Table 4.1: Share of the selected crops in total area under the crop and in the gross cropped area by district in Tamil Nadu, TE 1997-98.

District	% share in state total area under the crop				% share in district gross cropped area			
	Cotton	Paddy	Cabbage	Vege-tables	Cotton	Paddy	Cabbage	Vege-tables
Caddallore	1.27	5.11	0.00	3.93	0.64	24.21	0.00	1.49
Coimbatore	7.65	0.67	0.11	5.94	3.60	2.97	0.00	2.11
Dharmapuri	9.26	2.74	34.91	10.22	3.20	8.95	0.09	2.66
Dindigul	3.73	1.13	0.55	8.42	2.06	5.92	0.00	3.51
Erode	4.64	2.82	0.98	4.73	2.74	15.74	0.00	2.10
Kancheepuram	0.03	6.86	0.05	0.42	0.02	42.38	0.00	0.21
Kanniyakumari	0.00	1.48	0.00	5.16	0.00	26.64	0.00	7.43
Karur	0.38	0.71	0.00	0.88	0.51	9.12	0.00	0.90
Madurai	5.18	3.87	0.11	1.49	4.23	29.87	0.00	0.92
Nagapatinam	0.45	6.85	0.00	0.13	0.24	34.70	0.00	0.05
Namakkal	1.09	1.12	0.00	10.83	0.87	8.43	0.00	6.49
Perambalur	11.13	2.22	0.00	4.13	7.97	15.05	0.00	2.23
Pudukkottai	0.09	4.07	0.00	0.11	0.08	35.40	0.00	0.08
Ramanathpuram	1.35	5.95	0.00	0.04	0.99	41.26	0.00	0.02
Salem	8.44	2.10	1.36	17.04	3.88	9.12	0.00	5.90
Sivagangai	0.28	4.02	0.05	0.06	0.31	41.77	0.00	0.05
Thanjavur	0.41	7.90	0.00	0.33	0.21	38.44	0.00	0.13
The Niligris	0.00	0.08	55.87	4.12	0.01	7.18	4.00	28.54
Theni	3.97	0.85	5.10	2.74	5.26	10.59	0.05	2.74
Thirunelveli	4.32	3.59	0.00	1.67	3.69	29.02	0.00	1.07
Thiruvallur	0.00	5.11	0.00	0.43	0.00	36.51	0.00	0.25
Thiruvannamalai	0.91	6.58	0.49	0.78	0.40	27.19	0.00	0.26
Thiruvarur	0.42	7.08	0.00	0.06	0.25	39.76	0.00	0.03
Thoothukudi	7.84	0.81	0.00	2.23	7.62	7.55	0.00	1.66
Tiruchirapalli	5.47	2.98	0.00	5.27	4.01	20.67	0.00	2.91
Vellore	5.37	3.69	0.27	1.54	2.80	18.17	0.00	0.61
Villupuram	3.90	8.12	0.14	6.06	1.39	27.41	0.00	1.63
Virudhunagar	12.54	1.48	0.00	1.26	13.45	15.03	0.00	1.02
Total	100.00	100.00	100.00	100.00	2.39	22.56	0.02	1.80

Source: Crop and Season Report, Department of Agriculture, Govt. of Tamilnadu, 1999.

for paddy and Dharmapuri for vegetables. In Dharmapuri district, tomato was the main vegetable crop. It was included in the survey initially. The discussion with the extension workers indicated little use of biological pesticides in tomato, and therefore it was substituted with cabbage. Though, in percentage terms, cabbage occupies a small fraction of the total cropped area in the district, yet the district ranks second in terms of area under cabbage in the state.

Table 4.2 provides information on the use of plant protection inputs in Tamil Nadu by district. Since early 1990s, there has been a considerable reduction

Table 4.2: District-wise per hectare use of chemical pesticides and biopesticides in Tamilnadu, TE 1997-98.

District	Chemical pesticides gm/ha	Neem products ml/ha	Bt (gm/ha)	NPV (LE/ha)	*Tricho-derma virdi* (gm/ha)	*Tricho-gramma spp.* (cc/ha)	% change in per ha pesticides in 1997-98 over 1993-94
Coimbatore	216	23	0.25	0.22	0.60	3.86	63.4
Cuddalore	194	22	0.31	0.06	0.66	5.65	58.5
Dharmapuri	125	16	0.11	0.10	0.45	3.62	68.6
Dingigul	205	22	0.14	0.04	0.63	3.05	64.3
Erode	235	26	0.23	0.28	0.80	8.52	65.1
Kancheepuram	270	32	0.29	0.12	0.90	4.58	66.1
Kanyakumari	337	51	0.39	0.15	1.68	0.00	63.8
Karur	NA	52	0.00	0.00	2.47	0.00	NA
Madurai	363	36	0.41	0.39	1.51	10.42	60.9
Nagapattinam	259	25	0.15	0.11	0.77	3.65	65.4
Namakkal	NA	NA	0.09	0.37	0.00	0.00	NA
Perumbalur	NA	8	0.00	0.00	1.25	0.00	NA
Pudukkottai	311	41	0.23	0.10	0.86	4.43	63.2
Ramanathapuram	159	27	0.49	0.09	1.09	0.00	67.9
Salem	178	20	0.27	0.11	0.70	3.12	68.0
Sivaganga	215	33	0.30	0.26	1.34	7.32	71.8
Thanjavur	245	21	0.16	0.21	0.64	4.74	66.3
The Nilgiris	1681	139	1.50	0.59	0.00	0.00	53.4
Theni	NA	46	0.00	0.00	0.00	0.00	NA
Thirunelveli	260	33	0.22	0.33	1.33	2.18	63.5
Thiruvallur	NA	NA	0.00	0.00	0.00	0.00	NA
Thiruvannamalai	155	23	0.20	0.04	0.69	2.57	61.8
Thiruvarur	NA	25	0.00	0.00	0.78	0.00	NA
Tiruchirapalli	396	31	0.45	0.29	1.16	9.03	61.6
Toothukudi	254	37	0.36	0.15	1.30	0.00	61.3
Vellore	209	30	0.21	0.05	0.78	12.08	65.5
Villupuram	137	18	0.19	0.10	0.58	4.33	59.5
Virudhunagar	260	37	0.49	0.22	1.44	2.28	64.8
Total (State)	187	23	0.22	0.13	0.76	3.81	63.8

NA : Not Available
Source: Department of Agriculture, Govt. of Tamilnadu.

in pesticide use in all the districts of Tamil Nadu. Use of biological pesticides like NPV, *Trichogramma*, *Trichoderma*, Bt and neem products has increased.

Selection of blocks

For the selection of blocks, we relied mainly on expert advice of extension officers. The main criterion was the area under identified crop. From each district, two blocks having higher share in total cropped area were selected (Table 4.3). From Dharampuri district, only one block, Dengnikotai was selected because of the concentration of cabbage area in this block.

Table 4.3: Selection of blocks, villages and households

District	Block	No. of villages selected	No. of farmers selected	
			Adopters	Non-adopters
Coimbtore	Avinashi, Thondamathur	8	43	36
Thanjavur	Puddukottai Thiruvidaimathur	6	40	41
Dharampuri	Denganikotai	5	35	35

Selection of villages

From each of the identified block, 3-5 villages were selected randomly with due consideration to the area under the selected crop. In case of low or no area under the identified crop in the village, the process of random selection was repeated unless a village with sufficient area under the crop could be selected.

Selection of households

An assessment of the adoption of IPM in the identified crops was made through Rapid Rural Appraisal technique in the selected villages. The households were then classified into adopters and non-adopters. The criterion followed for the classification was the use of one or more of the biological pesticides. In the selected villages of Coimbtore, *Trichogramma* *chilonis* and NPV were the dominant biological pesticides used in cotton crop. Neem pesticides and neem oil were the main insect control inputs used in paddy in Thanjavur villages, while Bt and neem pesticides comprised the main biological inputs in cabbage production in Dharampuri villages. A sample of 35-40 farm households was drawn randomly in the probability proportion of distribution of adopters across the selected villages. Following the same procedure, almost an equal sample was drawn from the users of chemical pesticides.

5 ECONOMICS OF PEST MANAGEMENT UNDER EXPERIMENTAL CONDITIONS

Plant protection research in India has generated a number of non-chemical technologies. These are claimed to be consistent with the objectives of a sustainable and productive agriculture. Many of these have been recommended for commercial production and field application. The scientific claims are largely based on the technical performance of the technology (yield saved and environmental contributions). This, however, is not the sufficient condition for acceptance of a technology by the farmers. The technology should pass the other performance criteria: practicability, economic feasibility and sustainability. It is often observed that many technologies that are technically feasible under the experimental conditions fail to meet other criteria on the farmers' fields. This chapter examines the technical and economic efficacy of different pest management options, using time-series experimental data. The information was compiled from the annual reports of the Project Directorate on Biological Control, Bangalore for three crops that is, cotton, paddy and chickpea.

5.1 Evaluation of Pest Management Technologies in Cotton

Cotton is the priority crop for implementation of the biological pest management technologies, as about half of the potential cotton output is lost due to pests, despite the use of chemical pesticides. A number of insect pests such as, *Helicoverpa*, white fly, aphids, jassids, etc. infest cotton crop. *Helicoverpa* and white fly have developed manifold resistance to almost all the chemicals intended to control them. Non-chemical approaches are claimed to provide effective control of such insect pests. These approaches are evaluated for their technical and economic efficacy, using data from experiments[2] conducted at Gujarat Agricultural University, Anand; Punjab Agricultural University, Ludhiana; and Tamil Nadu Agricultural University, Coimbtore.

[2] For details of the experiments see annual reports of the Project Directorate on Biological Control.

In Gujarat, the experiments were conducted to examine the efficacy of chemical control, biological control and IPM, with natural control as a check. *Trichogramma chilonis* and *Crysoperla carnea* were the two biological pesticides used in biological control and IPM. Chemical pesticides were used as per the recommended spray schedules by the State Department of Agriculture. The trials were conducted on two cotton hybrids CH6 and CH8. Detailed information on the pest control inputs are provided in Annexure I.

Experimental trials in Tamil Nadu included: bio-intensive IPM proposed by PDBC, moderately chemical-intensive IPM developed by Tamil Nadu Agricultural University (TNAU), and chemical-intensive farmers' practices. Trials were conducted on two varieties, LRA5166 and MCU5. Bio-intensive IPM included application of *Trichogramma chilonis*, Nuclear polyhedrosis virus, *Crysoperla carnea*, neem oil and need based application of chemical pesticides. TNAU method included all the inputs as in bio-intensive IPM module, but with quantitative variations. Farmers' practices included chemical pesticides, NPV and neem oil. Details are given in Annexure II.

Pest management trials in Punjab included natural control, chemical control, biological control and IPM on four cotton varieties/hybrids, viz., LH1134, F846, F414 and F1054. *Trichogramma chilonis, Crysoperla carnea*, NPV, and Bt were the main inputs used in the biological control. IPM included *Trichogramma chilonis*, *Crysoperla carnea* and chemical pesticides (Annexure III).

5.1.1 Technical efficacy: Yield loss

Technical potential of the alternative pest management options is evaluated by comparing the yield loss due to insect pests. Yield loss is defined as the deviation of the actual yield from the potential yield. The potential yield has been estimated using econometric approach as discussed in the previous chapter. Level of pest infestation is an important determinant of potential yield (eq.3). This information was not available from any of the experimental location, and therefore the boll/bud damage in percent was taken as a proxy. Further, the level of infestation depends on the type of pest control method and the level of pest control effort. Dummies were constructed for different pest management methods. The cost of pest management has been included as an explanatory variable to capture the effect of control efforts on the level of pest infestation. A time trend variable has been included to capture the effect of the factors other than the pest control inputs on the pest infestation. Crop variety/hybrid dummies have been included in the yield equation to estimate the variety specific potential yield.

Estimates of the model[3] for Gujarat are presented in Table 5.1. The relationship between the pest infestation and all the pest management options is negative. Coefficients of IPM and biological control are highly significant and are also larger in magnitude, compared to the chemical control. These indicate better technical potential of the biological and IPM options. Relationship between the cost of protection and the level of infestation is

Table 5.1: SURE estimates of interrelationship between yield, pest infestation and Pest control methods in cotton in Gujarat

Explanatory variables	Dependent variable Yield (kg/ha)	% boll damage
Constant	1791.967(10.993) ***	29.704(10.297) ***
Boll damage (percent)	-33.083 (5.283) ***	-
Hybrid dummy, CH6 =0, CH8= 1	1547.458 (11.765) ***	-
Cost of protection (Rs/ha)	-	0.000178(1.662) *
Dummy for method:		
Natural =0		
Chemical =1	-	4.698 (1.748)*
Biological =1	-	-17.882(5.389)***
IPM =1	-	-22.581(5.800)***
Time trend	-	0.474 (1.088)
Log-likelihood	206.391	-85.567
No. of observations	29	

Figures in parentheses are t-values.

***, ** and * significant at 1, 5 and 10 percent level respectively.

[3] The data used in estimation of the model pertain to the period 1991-92-1997-98.

positive and significant at 10 percent, implying greater pest control efforts with the increasing pest infestation.

Relationship between the yield and the boll damage is negative and significant. Intercept term that provides estimate of the potential yield of CH6 is positive and significant. Coefficient of CH8 hybrid is positive and highly significant indicating its higher yield potential compared to CH6. Potential yield of CH6 and CH8 is estimated at 1792 kg/ha and 3339 kg/ha, respectively.

Estimates of the yield loss[4] corresponding to different technological options[5] are presented in Table 5.2. Biological and IPM options could avoid considerable yield loss. Yield loss on application of biological control

Table 5.2. Estimates of yield loss in cotton under different pest control options in Gujarat.

Pest control strategy	Actual yield (kg/ha)	Potential yield (kg/ha)	Yield loss (kg/ha)	%yield loss
Variety: CH6				
Chemical control	885	1792	907	50.61
Biological control –I	1241	1792	551	30.77
Biological control –II	1683	1792	109	6.08
IPM-I	1026	1792	766	42.75
IPM-II	1372	1792	420	23.44
Untreated	750	1792	1042	58.14
Variety : CH8				
Chemical control	2424	3339	915	27.43
Biological control –I	-	-	-	-
Biological control –II	2965	3339	374	11.21
IPM-I	-	-	-	-
IPM-II	2997	3339	342	10.25
Untreated	2100	3339	1239	37.13

Note: suffix I and II with biological and IPM methods respectively indicate without and with Crysoperla situations.

[4] Yield loss is the average loss for the years under consideration.

[5] Biological and IPM options have been categorized into two: with and without use of *Crysoperla carnea* because price of *Crysoperla carnea* is much higher, compared to *Trichogramma chilonis*, while its per hectare use is as high as that of *Trichogramma chilonis*. The suffix I refers to no use *Crysoperla* and II refers to use of *Crysoperla*.

without the use of *Crysoperla* was 31 percent, while with the use of *Crysoperla* it could be reduced to 6 percent. Application of IPM tactics, with and without *Crysoperla*, yielded loss of 23 and 43 percent, respectively. With the chemical control about half of the potential output was lost due to insect pests. Had the crop been left unprotected, about 58 percent of the output could have been lost.

In case of CH8, biological control and IPM with *Crysoperla* were even more effective. Yield loss was about 10-11 percent, compared to 27 percent with application of chemical control. Leaving the crop unprotected could have resulted in 37 percent loss in the crop output. Low yield loss of CH8 could perhaps be due to its higher insect resistance potential.

Regression estimates for Tamil Nadu[6] presented in Table 5.3 indicate superiority of the bio-intensive and the moderately chemical-intensive IPM (TNAU) over the farmers' practices. Insect pest problem in cotton, however, seems to have increased over time, as is implied by the positive and significant coefficient on time trend.

Table 5.3: SURE estimates of interrelationship between yield, pest infestation and pest control methods in cotton in Tamilnadu

Explanatory variables	Dependent variable Yield (kg/ha)	% boll damage
Constant	1930.889(14.928) ***	6.133(3.632) ***
Boll damage (percent)	-113.654 (7.646) ***	-
Variety dummy, LRA 5166=0, MCU5= 1	723.233 (6.001) ***	-
Cost of protection (Rs/ha)	-	0.0000726(0.934)
Dummy for method:	-	
Farmers' practices=0		
Bio-intensive IPM (PDBC)		-4.124 (1.836) *
IPM (TNAU)		-3.083 (2.728) ***
Time trend	-	0.701 (20.021) **
Log-likelihood	-109.275	-39.44
No. of observations	15	

***, ** and * indicate significance at 1, 5 and 10 percent level respectively.

[6] The data used for Tamil Nadu pertain to the period 1992-93 to 1996-97.

Yield has a negative and significant association with the pest infestation. Intercept term is positive and significant and its magnitude indicates potential yield of 1931 kg/ha for LRA5166. Coefficient on MCU5 is positive and significant indicating its higher yield potential over LRA5166. The potential yield of MCU5 is estimated 2654 kg/ha.

Estimates of cotton output lost under different technological scenarios presented in Table 5.4 indicate that the moderately chemical-intensive IPM (TNAU) without *Crysoperla* provided maximum protection to LRA5166. Yet, 21 percent of the potential output was lost. Bio-intensive IPM (PDBC) ranked second. This was followed by the chemical-intensive IPM (farmers' practices). Yield loss was the highest in case of biological control with *Crysoperla*. On MCU5, the bio-intensive IPM was found to be the best option with yield loss of about 25 percent, followed by the moderately chemical-intensive IPM (29%). Yield loss was maximum under the farmers' practices (44%).

Table 5.4: Estimates of yield loss in cotton under different pest control options in Tamilnadu.

Pest control strategy	Actual yield (kg/ha)	Potential yield (kg/ha)	Yield loss (kg/ha)	% yield loss
Variety: LRA5166				
Bio-intensive IPM	1319	1931	612	31.67
Moderately Chemical-intensive IPM	1523	1931	408	21.10
Biological control	810	1931	1121	58.01
Chemical-intensive IPM	1045	1931	886	45.86
Variety : MCU5				
Bio-intensive IPM	1977	2654	677	25.51
Moderately Chemical-intensive IPM	1879	2654	775	29.20
Biological control	-	-	-	-
Chemical-intensive IPM	1475	2654	1179	44.42

[7] The data used for Punjab pertain to the period 1990-91 to 1997-98.

The results[7] for Punjab are presented in Table 5.5. Relationship between the level of pest infestation and different technological options is negative. Chemical control, however, appears to have provided better protection against insect pests, compared to the biological control and IPM.

Table 5.5: SURE estimates of interrelationship between yield, pest infestation and pest control methods in cotton in Punjab.

Explanatory variables	Dependent variable Yield (kg/ha)	% bud damage
Constant	1978.651(17.923) ***	28.324(6.942) ***
Boll damage (percent)	-29.442 (16.569) ***	-
Variety dummy, LH1134=0	-	
F846 =1	-66.043 (0.512)	
F414 =1	-30.168(0.252)	
F1054=1	306.764 (2.112) **	
Cost of protection (Rs/ha)	-	-0.000384 (0.542)
Dummy for method:		
Chemical		-12.319(2.992) ***
Biological		-1.049(0.275)
IPM		-4.915(0.955)
Time trend		1.994 (1.423)
Log-likelihood	-350.405	-201.409
No. of observations	47	

***, ** and * indicate significance at 1, 5 and 10 percent level respectively

As expected, yield is a declining function of infestation, and the relationship is significant. Intercept term is positive and significant, and provides a potential yield of 1979 kg/ha for LH1134. Potential yield F846 and F414 is not significantly different from this. Potential yield of F1054 (2286 kg/ha) is significantly higher than LH1134.

Loss estimates shown in Table 5.6 indicate considerable loss in cotton output even with the application of different pest management strategies. Loss in potential yield of F846 was 43 percent with the chemical pest control, 58 percent with the biological control and 53 percent with IPM. It is, however, surprising that loss without protection was almost equal to that with the application of IPM. For F414, loss under natural control was 44 percent, and this could be reduced to 16 percent with application of chemical control.

Table 5.6:Estimates of yield loss in cotton under different pest control options in Punjab.

Pest control strategy	Actual yield (kg/ha)	Potential yield (kg/ha)	Yield loss (kg/ha)	% yield loss
Variety: F846				
Chemical	1099	1933	834	42.55
Biological control –I	805	1933	1128	57.91
Biological control –II	-			
IPM-I	897	1933	1036	53.07
IPM-II	897	1933	1036	53.07
Untreated	880	1933	1053	53.98
Variety : F414				
Chemical control	1633	1948	315	16.19
Biological control –I	-			
Biological control –II	1189	1948	759	38.98
IPM-I	1061	1948	887	45.55
IPM-II	-			
Untreated	1094	1948	854	43.84
Variety : LH 1134				
Chemical control	1770	1979	209	10.56
Biological control –I	1200	1979	779	39.36
Biological control –II				
IPM-I	1403	1979	576	29.11
IPM-II				
Untreated	650	1979	1329	67.16
Variety : F1054				
Chemical control	1514	2285	771	33.74
Biological control –I	1129	2285	1156	50.59
Biological control –II	1303	2285	982	42.98
IPM-I	1453	2285	832	36.41
IPM-II	1339	2285	946	41.40
Untreated	1122	2285	1163	50.90

Note: suffix I and II with biological and IPM methods respectively indicate without and with Crysoperla situations.

Biological control could reduce it to 39 percent, while the loss with application of IPM was slightly higher than loss under natural control.

About 51 percent of the potential output of F1054 was lost due to insect pests in absence of pest management. Chemical control could bring it down to 34 percent, and IPM without *Crysoperla* to 36 percent. Biological control and IPM with *Crysoperla* could reduce it to about 42 percent. Yield loss with application of biological control without *Crysoperla* was as good as with no-protection.

More than two-third of the potential yield of LH1134 could have been lost, had the crop been left unprotected. Protection with chemical pesticides brought it down substantially (11%). IPM and biological control without *Crysoperla* could reduce it to 29 and 39 percent, respectively.

These findings provide a mixed picture of the technical efficacy of the biological and IPM options. In Gujarat and Tamil Nadu, these provided better control to insect pests, compared to the chemical control, and could avoid considerable yield loss. On the other hand, in Punjab these were not as effective as the chemical control.

5.1.2 Economic efficacy: Cost and returns

Technologies with higher technical potential need not necessarily be economically feasible. Prices of pest management inputs and their intensity of application are critical in determining the economic feasibility. An economic analysis has been carried out to determine whether the biological control and IPM have the potential to substitute the chemical pesticides in a cost-effective manner.

Table 5.7 presents per hectare costs and benefits[8] of the application of different pest management options in cotton in Gujarat. Cost of biological control and IPM was higher than the cost of chemical control for both CH6 and CH8 cotton. The cost increased manifold with the integration of *Crysoperla* in biological control and IPM.

---

[8] The estimates of costs and returns represent the averages for the period under consideration and have been computed at TE 1997-98 average prices.

Table 5.7: Costs and returns in cotton production with different pest control options in Gujarat.

(Rs/ha)

Inputs	Chemical Control	Biological Control-I	Biological Control–II	IPM-I	IPM-II	Untreated
Variety: CH6						
Gross returns	13276	18608	25245	15390	20580	11253
Cost of protection						
Pesticides	2522	362	181	1761	1102	121
Biopesticides	-	2420	35200	2420	35640	-
Total	2522	2782	35381	4181	36742	121
Net returns	10754	15866	-10136	11209	-16162	11132
Added cost	2401	2661	35260	4060	36621	0
Added returns	2023	7355	13990	4137	9327	-
Net benefits	-18	4694	-21270	77	-27294	-
Benefit:cost	0.84	2.76	0.40	1.02	0.25	-
Variety : CH8						
Gross returns	36353	-	44475	-	44955	31493
Cost of protection						
Pesticides	2658	-	-	-	416	-
Biopesticides	-	-	9240	-	9240	-
Total	2658	-	9240	-	9656	0
Net returns	33695		35235		35299	31493
Added cost	2658	-	9240	-	9656	-
Added returns	4860	-	12982	-	13460	-
Net benefits	2202		3742		3804	
Benefit:cost	1.83	-	1.40	-	1.39	-

Gross returns from CH6 cotton under the natural infestation were Rs11253/ha. On accounting for expenditure of Rs121/ha[9] towards one application of chemical pesticides under the natural infestation conditions, net returns were reduced to Rs11132/ha. The net returns from application of chemical control and IPM-I were no different from this. Integration of *Crysoperla* in the biological control and in IPM resulted in negative net returns. Net benefits (added returns-added costs) were positive with application of biological control and IPM without *Crysoperla*.

[9] The cost of Rs 121/ha was on account of pre-sowing application of methyl-oxy-demotone, which was uniform across all the methods of pest control.

Despite higher cost of *Crysoperla*, application of biological control and IPM on CH8 was profitable, compared to the chemical control. Net benefits with application of biological control and IPM were estimated at Rs3742/ha and 3804/ha, respectively, while with the chemical control net benefits were Rs2202/ha. The positive net returns for CH8 under biological control and IPM with *Crysoperla* were due to its low dose/ha (Annexure I). This indicates a need for standardization of application doses.

Table 5.8 presents costs and returns associated with the different pest management technologies applied in cotton in Tamil Nadu. Cost of protection of variety LRA5166 with the biological and the moderately

Table 5.8: Cost and returns in cotton production under different pest control options in Tamilnadu

(Rs/ha)

Inputs	Bio-intensive IPM	Moderately Chemical-Intensive IPM	Biological Control IPM	Chemical-Intensive
Variety: LRA5166				
Gross returns	19355	22350	11883	15335
Cost of protection				
Pesticides	583	3610	-	3777
Biopesticides	28194	1350	24670	1200
Total	28777	4960	24670	4977
Net returns	-9422	17390	-12787	10358
Added cost	23800	-17	19693	0
Added returns	4020	7015	-3452	0
Net benefits	-19780	7032	-23145	0
Benefit:cost	0.17	-		
Variety : MCU5				
Gross returns	28995	27565	-	21368
Cost of protection				
Pesticides	1147	4541		5030
Biopesticides	30625	1350		900
Total	31772	5891		5930
Net returns	-2777	21676	-	15438
Added cost	25842	-39		0
Added returns	7627	6197		0
Net benefits	-18125	6236		0
Benefit:cost	0.28	-		0

chemical-intensive IPM was 5 to 6 times higher, compared to the moderately chemical-intensive and chemical-intensive IPM; the cost of protection was Rs5000/ha under the latter situations. Inclusion of *Crysoperla* inflated the cost of protection resulting into negative net returns. Net returns were positive with the moderately chemical-intensive and chemical-intensive IPM. Net benefits over chemical-intensive IPM were negative under all the situations except the moderately chemical-intensive IPM. In case of MCU5, the bio-intensive IPM yielded higher gross returns, compared to the moderately chemical-intensive IPM, yet the higher cost of protection due to use of *Crysoperla* rendered it unprofitable.

Economically, the chemical control emerged as the best option in Punjab irrespective of the varieties on which it had been applied. (Table 5.9). Cost of chemical control on F846 cotton was higher than that of biological control. But, it was less compared to IPM. Yet, the net returns from the chemical control were higher by 27 percent over biological control and 30 percent over IPM. Net returns from protection with any option were less than with no-protection. Net benefits were negative at the margin under the chemical control situation, and were highly negative under the biological control and IPM situations.

Cost of chemical control on F414 was less than the cost of biological control and IPM. Net returns from application of chemical control were almost twice as much as from the biological control and IPM. Even the returns from no-protection were higher than with the protection by the biological control and IPM. So were the net benefits from the application of these options.

Chemical control on LH1134 was cost-effective and yielded highest net returns, compared to the biological control and IPM. Net benefits were positive under all situations, but the highest net benefits were realized with the chemical control, and followed by IPM. In case of F1054, the cost of biological control was the least, and was followed by the chemical control in that order. Highest net returns were realized with application of chemical control, followed by IPM and biological control without *Crysoperla*. Net benefits were negative except under chemical control situation.

Table 5.9: Costs and returns in cotton production with different pest control options in Punjab.

(Rs/ha)

Inputs	Chemical Control	Biological Control-I	Biological Control–II	IPM-I	IPM-II	Untreated
Variety: F846						
Gross returns	15932	11673	-	13007	13007	12754
Cost of protection						
Pesticides	3217	-		243	1803	
Biopesticides	-	1653		3520	4015	
Total	3217	1653		3763	5818	
Net returns	12715	10020		9244	7189	12754
Added cost	3217	1653		3763	5818	
Added returns	3178	-1081		253	253	
Net benefits	-39	-1734		-3510	-5565	
Benefit:cost	0.99	-0.65		0.07	0.04	
Variety : F414						
Gross returns	23679	-	17241	15385		15863
Cost of protection						
Pesticides	2090			1304		
Biopesticides			4840	990		
Total	2090		4840	2294		
Net returns	25589		12401	13091		15863
Added cost	2090		4840	2294		
Added returns	7816		1378	-478		
Net benefits	5726		-3462	-6234		
Benefit:cost	3.74		0.28	-0.21		
Variety: LH1134						
Gross returns	25665	17400		20348		9424
Cost of protection						
Pesticides	1822	400		1184		35
Biopesticides		2090		1907		
Total	1822	2490		3091		35
Net returns	23843	14910		17257		9389
Added cost	1787	2055		3056		0
Added returns	16241	7976		10924		
Net benefits	14454	5921		7868		
Benefit:cost	9.09	3.88		3.57		
Variety :F1054						
Gross returns	21953	16367	18894	21061	19416	16273
Cost of protection						
Pesticides	4725	425	729	2492	2428	304
Biopesticides		2190	6660	2970	8580	
Total	4725	2615	7389	5462	11008	
Net returns	17228	13742	11505	15599	8408	15969
Added cost	4421	2311	7085	5158	10704	0
Added returns	5680	94	2621	4788	3143	
Net benefits	1439	-2217	-4464	-370	-7561	
Benefit: cost	1.29	0.04	0.37	0.93	0.29	

The analysis of technical and economic performance of biological control and IPM indicates variation in their performance across locations. This is perhaps due to the differences in agro-climatic conditions, which exert considerable influence on pest populations. Crop variety is also an important factor in pest management, as the varieties vary in their yield potential and resistance to pests. Technical potential of the biological and IPM options (in terms yield saved) was better than the chemical control in Gujarat and Tamil Nadu, while in Punjab these options were as good as no-protection. Economically too, their performance was better in Gujarat and to some extent in Tamil Nadu. The performance, however, depended on the biological inputs used. Use of high priced *Crysoperla* in the biological control escalated cost of cultivation and resulted in negative net benefits. This implies a need for standardization of application rates of the biological inputs and reduction in their production cost.

5.2 Evaluation of Pest Management Technologies in Paddy

Paddy is the most important food crop in India with a share of 23 percent in the gross cropped area. Its share in the total pesticide consumption is also 23 percent. Despite, about one-fourth of the crop output is lost due to pests. Insect pests such as, leaf folder, earhead bug, stem borer, gall midge, brown plant hopper, etc., restrict realization of the potential yield. New technologies/methods viz., biological control and IPM have been proposed to restrict crop damage below economic injury level. The performance of these technologies under experimental conditions is assessed for the states of Tamil Nadu and Punjab.

In Tamil Nadu, trials were conducted to assess the technical efficacy of biological control and IPM vis-à-vis the chemical control against stem borer and leaf folder on five varieties of paddy viz. ADT36, ASD18, CO45, IR20 and IR50. Biological inputs used were: *Trichogramma chilonis*, *Trichogramma japonicum*, *Bacillus thuringeinsis* and neem oil, and were mostly applied in combinations. IPM included chemical pesticides, *Trichogramma chilonis* and *Trichogramma japonicum*. Details of inputs used are given Annexure IV. The information pertains to period 1994-95 to 1997-98.

In Punjab, efficacy of biological control was tested against the stem borer and leaf folder on variety PR 106. *Trichogramma chilonis, Trichogramma japonicum* and *Bacillus thuringeinsis* were the biopesticides used, either singly or in combination. Input details are provided in Annexure V.

Table 5.10: SURE estimates of interrelationship between yield, pest infestation and pest control methods in paddy in Tamilnadu.

Explanatory variables	Dependent Variable			
	Yield (kg/ha)	Dead heart (%)	White earhead (%)	Leaf folder (%)
Constant	2880.239*** (6.327)	4.893*** (5.603)	18.872*** (8.111)	23.323*** (9.296)
Dead Heart (%)	-367.352*** (9.489)	-	-	-
White Ear Head (%)	-214.436*** (15.164)	-	-	-
Leaf Folder (%)	-163.579*** (11.680)	-	-	-
Variety dummy: ASD 18= 0				
ADT 36= 1	1411.487*** (3.468)			
CO 45 =1	2481.568*** (6.883)			
IR 20 =1	2533.503*** (6.289)			
IR 50 =1	2241.884*** (5.616)	-	-	-
Cost of protection (Rs/ha)	-	-0.00138*** (2.966)	-0.00388*** (3.213)	-0.00117 (0.869)
Dummy for method:				
Natural =0	-			
Chemical=1	-0.501 (0.522)	-0.162 (0.066)	-4.752* (1.709)	
Biological=1	-1.389 (1.037)	-0.704 (0.263)	-0.922 (0.307)	
IPM=1	1.024 (0.768)	0.363 (0.105)	-9.724** (2.515)	
Time trend	-	0.2156 (1.350)	-1.713*** (4.079)	-2.681*** (5.810)
Log-likelihood	-682.371	-177.671	-261.929	-257.448
No. of observations	78			

***, ** and * significant at 1, 5 and 10 percent level respectively

5.2.1 Technical efficacy: Yield loss

Results of the econometric model presented in Table 5.10 show that in Tamil Nadu different pest management options differed significantly in their capability to suppress the stem borer pests, either at the initial crop growth stage (dead heart) or at the head formation stage (white earhead). The incidence of stem borer at the head formation stage, however, seems to have lessened over the time. IPM provided maximum protection against the leaf folder. Chemical control was observed to be the next best alternative.

Relationship between paddy yield and the infestation is negative and significant. Intercept term in the yield equation is positive and significant, providing the potential yield of 2880 kg/ha for ASD18. Potential yields of other varieties are significantly higher than that of ASD18; 4292 kg/ha for ADT36, 5362 kg/ha for CO45, 5414 kg/ha for IR20 and 5122 kg/ha for IR50.

Estimates of the yield loss presented in Table 5.11 show a better yield saving potential of chemical control compared to the other pest management options in case of almost all varieties of paddy, except ASD18 for which biological control was found to provide better protection. Yet, the yield loss in case of ASD18 was quite high (about one-third of the potential output). Yield loss without protection could have resulted in a loss of 38 percent.

Application of the chemical and the biological methods on ADT36 variety could save 20 and 23 percent of the potential yield, respectively. Yield loss would have doubled in absence of any protection. In case of CO45, non-application of any protection measure also yielded similar loss estimate. However, the loss could be reduced to 16 and 25 percent, respectively on the application of chemical and biological methods. Application of IPM could bring it down to 10 percent.

Biological pest control on IR20 could reduce the yield loss by 2 percentage points over the natural infestation (32%). Chemical control was, however, more effective and could reduce the loss to 20 percent. For IR50, the yield loss was 22, 26 and 41 percent under chemical, biological and natural control, respectively.

Table 5.11: Estimates of yield loss in paddy under different pest control options in Tamilnadu

Method of control	Actual yield (kg/ha)	Potential yield (kg/ha)	Yield loss (kg/ha)	% yield loss
Variety:ADT36				
Chemical	3447	4292	845	19.67
Biological	3303	4292	989	23.04
IPM	-			
Untreated	2625	4292	1667	38.84
Variety:ASD18				
Chemical	1923	2880	957	33.23
Biological	2000	2880	880	30.57
IPM	-			
Untreated	1777	2880	1103	38.30
Variety:CO45				
Chemical	4527	5362	835	15.57
Biological	4007	5362	1355	25.27
IPM	4833	5362	529	9.87
Untreated	3345	5362	2016	37.61
Variety:IR20				
Chemical	4324	5414	1090	20.13
Biological	3759	5414	1655	30.57
IPM				
Untreated	3674	5414	1740	32.14
Variety:IR50				
Chemical	3978	5122	1144	22.34
Biological	3779	5122	1343	26.22
IPM				
Untreated	3038	5122	2084	40.69

Results from Punjab indicate that both the chemical and biological controls were effective in suppressing the stem borer in the initial (dead heart) as well as the later (white earhead) stages of the crop (Table 5.12). So was against the leaf folder. Non-significant coefficients of time variable in the stem borer infestation equations indicate little changes in the stem borer infestation over the time. Incidence of leaf folder, however, has increased.

Table 5.12: SURE estimates of interrelationship between yield, pest infestation and pest control methods in paddy in Punjab

Explanatory variables	Dependent Variable			
	Yield (kg/ha)	Dead heart (%)	White earhead (%)	Leaf folder (%)
Constant	6623.714	5.806	14.770	12.629
	(26.328) ***	(5.124) ***	(4.077) ***	(4.006) ***
Dead Heart (percent)	-310.806	-	-	-
	(7.291) ***			
White Ear Head (percent)	-117.883	-	-	-
	(9.294) ***			
Leaf Folder (percent)	-97.103	-	-	-
	(5.591) ***			
Cost of protection (Rs/ha)		0.000605	0.00146	0.00112
		(1.577)	(1.043)	(1.043)
Dummy for method:				
Natural =0				
Chemical=1		-3.304	-10.349	-10.993
		(2.600) ***	(3.993) ***	(3.103)***
Biological=1		-4.067	-9.439	-13.332
		(3.404) ***	(2.478) **	(3.325) ***
Time trend		0.1325	-0.0828	1.7433
		(0.460)	(0.092)	(2.168) **
Log-likelihood	-135.364	-28.092	-51.381	-44.923
No. of observations	17			

***, ** and * significant at 1, 5 and 10 percent level.

As expected, relationship of yield with the stem borer and the leaf folder infestation is negative and significant. Intercept term is positive and significant, providing a potential yield of 6624 kg/ha. Pest infestation reduces the crop yield significantly; a one percent increase in the stem borer infestation at the initial crop stage reduces the potential yield by 311 kg, while at the later stages the reduction in the potential yield is about 118 kg. Potential yield loss due to 1 percent increase in the incidence of the leaf folder is estimated to be 97 kg/ha.

Estimates of the yield loss given in Table 5.13 indicate better technical efficacy of chemical pest control over biological control. About 12 percent of the potential yield was lost under chemical control, while the corresponding figure for the biological control was 22 percent. Thirty percent of the potential yield could have been lost, had the crop not been protected against insect pests.

Table 5.13: Estimates of yield loss in paddy under different pest control options in Punjab

Pest control strategy	Actual yield (kg/ha)	Potential yield (kg/ha)	Yield loss (kg/ha)	% yield loss
Variety: PR106				
Chemical	5737	6624	887	13.38
Biological	5198	6624	1426	21.58
IPM	-	-	-	-
Untreated	4649	6624	1975	29.81

These findings indicate lower efficiency of biological control, compared to the chemical control in both Tamil Nadu and Punjab. However, in Tamil Nadu, difference between the two was marginal. Though, IPM trials were limited in numbers yet proved more effective, compared to the other two methods.

5.2.2 Economic efficacy: Cost and returns

In Tamil Nadu, cost of chemical pest control did not vary much for the different varieties (Table 5.14). It ranged between Rs 800/ha to Rs1000/ha. Biological control, however, was expensive; the cost of biological control was almost double the cost of chemical control, except in the case of variety ADT36. Cost of IPM was estimated at Rs 1200/ha. Chemical control also yielded higher net returns except in case of CO45 where the application of IPM proved most profitable. Net returns from the biological control on ASD18 and IR20 were even lower than that from the unprotected crop.

Table5.14: Cost and returns in paddy production under different pest control options in Tamilnadu

(Rs/ha)

Inputs	Chemical Control	Biological Control	IPM	Untreated
Variety: ADT36				
Gross returns	16926	16217		12889
Cost of protection				
Pesticides	919	-		-
Biopesticides	-	892		-
Total	919	892		-
Net returns	16009	15325		12889
Added cost	919	892		-
Added returns	4037	3328		-
Net benefits	3118	2436		-
Benefit:cost	4.39	3.73		-
Variety:ASD 18				
Gross returns	9442	9820		8725
Cost of protection				
Pesticides	835	-		
Biopesticides	-	1460		
Total	835	1460		
Net returns	8607	8360		8725
Added cost	835	1460		
Added returns	717	1095		
Net benefits	-118	-365		
Benefit:cost	0.86	0.75		
Variety:CO45				
Gross returns	22228	19674	23730	16424
Cost of protection				
Pesticides	980	-	557	
Biopesticides	-	1753	638	
Total	980	1753	1195	
Net returns	21248	17921	22535	16424
Added cost	980	1753	1195	
Added returns	5804	3250	7306	
Net benefits	4824	1497	6111	
Benefit:cost	5.92	1.85	6.11	
Variety:IR20				
Gross returns	21231	18457		18039
Cost of protection				
Pesticides	961	-		
Biopesticides	-	2252		
Total	961	2252		
Net returns	20270	16205		18039
Added cost	961	2252		
Added returns	5192	436		
Net benefits	4231	-1816		
Benefit:cost	5.40	0.19		
Variety:IR50				
Gross returns	19532	18555		14917
Cost of protection				
Pesticides	961	-		
Biopesticides	-	2163		
Total	961	2163		
Net returns	18571	16392		14917
Added cost	961	2163		
Added returns	4615	3638		
Net benefits	3654	1475		
Benefit:cost	4.80	1.68		

In Punjab, the cost of biological control was Rs 2032/ha (Table 5.15). This was 3.5 times more than the cost of chemical control. Gross returns from the chemical control were Rs 24097/ha, and from the biological control Rs 21830/ha. While the gross returns under the natural pest infestation conditions were to the tune of Rs19527/ha. The cost of chemical control was substantially lower than the biological control, and it also yielded higher net returns as well as the net benefits.

Evidences form both the locations indicate that biological control alone is not an attractive option in paddy, technically as well as economically. However, IPM seems to have an edge over the other pest management approaches.

Table 5.15: Cost and returns in paddy production under different pest control options in Punjab

(Rs/ha)

Inputs	Chemical control	Biological control	Untreated
Variety: PR 106			
Gross returns	24097	21830	19527
Cost of protection			
Pesticides	579	-	-
Biopesticides	-	2032	-
Total	579	2032	-
Net returns	23518	19798	19527
Added cost	579	2032	-
Added returns	4570	2303	-
Net benefits	3991	271	-
Benefit: cost	7.89	1.13	-

5.3 Evaluation of Pest Management Technologies in Chickpea

Chickpea is an important pulse crop in India and is grown mainly under rainfed conditions. Over the last few decades, chickpea area has almost been stagnating at around 6500 thousand hectares. Yield also has shown no sign of improvement. Insect pests (*Helicoverpa*) and the diseases (*Fusarium* wilt) cause considerable damage to chickpea output. Chemical measures have often failed to control these pests. Biological control and IPM are claimed to provide effective protection. These are examined using data from experiments conducted at Andhra Pradesh Agricultural University, Hyderabad, and Tamil Nadu Agricultural University, Coimbtore.

The pest management interventions included chemical control, biological control and IPM. Biological control made use of NPV and Bt, singly or in combination. IPM combined applications of NPV and chemical pesticides. The information used in the analysis pertains to the period 1992-93 to 1995-96. Details are provided in Annexure VI and VII.

5.3.1 Technical efficacy: Yield loss

Table 5.16 presents results of the association between chickpea yield, pest infestation and technological interventions for Andhra Pradesh. All the pest management options reduced the pest infestation significantly. The pest problem, however, appears to have increased over the time. However, this can be managed by investing more in pest control as is indicated by the negative and significant coefficient of cost of pest control.

Intercept term in the yield equation is positive and significant, providing potential yield of 2235 kg/ha. Estimates of yield loss shown in Table 5.17 indicate that 36 percent of chickpea output would have been lost, had the crop been left unprotected. IPM could bring it down to 6 percent, and the biological as well as chemical control to 25 percent.

In Tamil Nadu too, all the three pest management interventions were effective in suppressing the insect pests (Table 5.18). Pest problem appears to have increased over the time, and even the greater pest control efforts do not appear to have reduced it.

As expected, chickpea yield declined with the increase in the level of pest infestation. About 42 kg of chickpea was lost with one percent increase in the pest infestation level. Intercept term suggests chickpea production of 1468 kg/ha in absence of pest problem.

Table 5.16: SURE estimates of interrelationship between yield, pest infestation and pest control methods in chickpea in Andhra Pradesh

Explanatory variables	Dependent variable	
	Yield (kg/ha): Eq 1	% grain damage: Eq 2
Constant	2235.097 (12.286) ***	11.066 (5.530) ***
Grain damage (%)	-61.383 (3.277) ***	-
Cost of protection (Rs/ha)	-	-0.00144 (2.236) **
Dummy for method:		
Natural =0		
Chemical=1		-6.654 (3.238)***
Biological=1		-4.399 (2.153)**
IPM		-7.132 (2.744)***
Time trend		1.644 (3.201)***
Log-likelihood	-368.0.24	-368.024
No. of observations	36	

***, ** and * significant at 1, 5 and 10 percent level, respectively

Table 5.17: Estimates of yield loss in chickpea under different pest control options in Andhra Pradesh

Method of control	Actual yield (kg/ha)	Potential yield (kg/ha)	Yield loss (kg/ha)	% yield loss
Variety: Annegiri				
Chemical	1688	2235	547	24.47
Biological	1662	2235	573	25.64
IPM	2102	2235	133	5.95
Untreated	1430	2235	805	36.02

IPM emerges as the best technological option for controlling the insect pests of chickpea in Tamil Nadu; loss in potential yield was 9 percent with

Table 5.18: SURE estimates of interrelationship between yield, pest infestation and pest control methods in chickpea in Tamilnadu

Explanatory variables	Dependent variable	
	Yield	grain damage %
Constant	1467.514	8.760
	(24.111) ***	(4.718)***
Grain damage (percent)	-41.784	-
	(6.135) ***	
Cost of protection (Rs/ha)		-0.000206
		(0.194)
Dummy for method:		
Natural =0		
Chemical=1		-9.111
		(4.224) ***
Biological=1		-9.098
		(4.613) ***
IPM=1		-9.350
		(3.973) ***
Time trend		2.761
		(5.950) ***
Log-likelihood	-228.778	-81.247
No. of observations	34	

***, ** and * significant at 1, 5 and 10 percent level, respectively.

IPM (Table 5.19). Corresponding figure with the chemical control was 17 percent and with the biological control 21 percent. Under the natural infestation conditions, loss could have risen to 42 percent.

Table 5.19: Estimates of yield loss in chickpea under different pest control options in Tamilnadu

Method of control	Actual yield (kg/ha)	Potential yield (kg/ha)	Yield loss (kg/ha)	% yield loss
Variety: Not reported				
Chemical	1215	1468	253	17.18
Biological	1165	1468	303	20.61
IPM	1333	1468	135	9.17
Untreated	857	1468	611	41.62

The analysis suggests that application of biological pesticides alone is not effective against the insect pests of chickpea. Their use in combination with the chemical pesticides (IPM) would save considerable yield from being lost.

5.3.2 Economic efficacy: Cost and returns

Table 5.20 shows that in Andhra Pradesh chemical control was a cheaper option, the cost being Rs1242/ha. Control with the biological pesticides required about 50 percent higher expenses. IPM was the costliest option, the cost being Rs2201/ha. Yet, IPM was the most profitable. It yielded net returns worth Rs21987/ha. These were 21 percent higher over the chemical control and 27 percent over the biological control. Similarly, the net benefits from IPM were 3 times more than that from the chemical control, and 6 times more than that from the biological control.

In Tamil Nadu, there was little, if any, variation in the cost of different pest management options (Table 5.21). This was around Rs1100/ha. IPM yielded the highest net returns (Rs25327/ha), followed by the chemical control and

Table 5.20: Cost and returns in chickpea production under different pest control options in Andhra Pradesh

(Rs/ha)

Inputs	Chemical Control	Biological Control	IPM	Untreated
Variety: Annegiri				
Gross returns	19433	19130	24188	16459
Cost of protection				
Pesticides	1242		1373	
Biopesticides		1851	828	
Total	1242	1851	2201	
Net returns	18191	17279	21987	16459
Added cost	1242	1851	2201	
Added returns	2974	2671	7729	
Net benefits	1732	820	5528	
Benefit:cost	2.39	1.44	3.51	

Table 5.21: Cost and returns in chickpea production under different pest control options in Tamilnadu

(Rs/ha)

Inputs	Chemical Control	Biological Control	IPM	Untreated
Variety: Not reported				
Gross returns	24150	23151	26487	17024
Cost of protection				
Pesticides	1147	-	764	
Biopesticides	-	1069	396	
Total	1147	1069	1160	
Net returns	23003	22082	25327	17024
Added cost	1147	1069	1160	
Added returns	7126	6127	9463	
Net Benefits	5979	5058	8303	
Benefit:Cost	6.21	5.73	8.16	

the biological control. In terms of net benefits also, IPM was adjudged as the best.

The success of IPM in chickpea could be attributed to the physiological characteristics of the crop such as, short height, thin crop canopy, shorter leaves, etc. These characteristics make it difficult for the pest to hide and, thus, increase the efficiency of pest control. Further, the biopesticides such as, Bt are more effective in the winter season (during which chickpea is grown) because of greater amount of moisture in the air.

Analysis of experimental data indicates that the potential of biological inputs to substitute chemical pesticides varies widely across crops and locations. For cotton, the results provide a mixed picture. In Gujarat, the biological control and IPM proved better than the chemical control. In Tamil Nadu, their success was moderate. Selection of the biological pesticides and their application rates have played an important role in the success or failure of biological pest management. *Trichogramma chilonis* and NPV were the commonly applied biopesticides. Inclusion of *Crysoperla carnea* in IPM and biological control resulted in heavy economic losses because of its exorbitant prices. Nevertheless, the *Crysoperla* is considered to provide better control against *Helicoverpa*, compared to other biological products. In Punjab, neither IPM nor biological control could perform better than the chemical control. In many situations, application rates of biopesticides were so high that their cost alone wiped out the gross returns. Biological control in paddy was marginally inefficient, compared to the chemical control. So was its profitability. However, IPM proved better than other options. In chickpea also, IPM emerged as the best option. Performance of biological control was almost at par with the chemical control.

Economic benefits of IPM appear to be attractive enough to induce the farmers to adopt it. Whether similar benefits can be realized under the field conditions is a matter of an empirical investigation. Some important implications emerge from these findings. First, the experience of integrating *Crysoperla* in the biological control and IPM suggests the need to evolve cost-effective technologies and to standardize their application rates. Second, most of the biological pest management technologies being based on living organisms are sensitive to chemical pesticides, and their effectiveness will be greatly affected in an environment of frequent pesticide applications. This demands strategic research to evolve biological technologies that are compatible with the chemical pesticides. Biotechnology research would facilitate this. Finally, the economic analysis does not reflect the social and environmental costs and benefits of alternative pest management strategies. Accounting for the cost of negative externalities of chemical pesticides would increase the cost of chemical control. On the other hand, the biological control and IPM, being benign to ecology and human health, generate positive externalities, which at present are discounted heavily by the farmers. A complete accounting of costs and benefits of chemical control vis-à-vis biological control and IPM would improve the benefit-cost ratio of the latter.

6 ADOPTION OF IPM TECHNOLOGIES

IPM technologies are widely acknowledged for their benign effects on the environment, public health and farm profitability. Bioagents and biopesticides are the important constituents of IPM. Information on their adoption is scarce. Anecdotal evidences indicate that, at present, the market for these products is limited in India. Biopesticides share only one percent of the agrochemical market (Saxena 2001). This is because, a number of supply-side and demand-side factors constrain their commercialization and use. The purpose of this chapter is to understand the process of adoption of IPM technologies by the farmers. To achieve this objective cross-section farm level data were derived through personal surveys in Coimbtore, Tanjavur and Dharampuri districts of Tamil Nadu. The survey focused on three crops: cotton (Coimbtore), paddy (Thanjavur) and cabbage (Dharampuri).

6.1 Level of Adoption

IPM encompasses a number of technologies and practices. The complexity of the package and the varying importance of its constituents render precise measurement of adoption of IPM difficult. Nevertheless, farmers cannot be expected to adopt the entire package at once, but only a few components depending on their knowledge and attitude towards these, and their availability.

Most of the agronomic practices, advocated as a part of IPM, are followed by a majority of the farmers as routine crop husbandry practices. And therefore, we have measured adoption of IPM following 'the dominant technique' approach. Use of biological pest management inputs- bioagents and biopesticides, has been considered as the criterion for adoption of IPM. Classification of users and non-users in a village provides village level estimates of adoption of IPM (Table 6.1). Biological pest management inputs used in the selected villages included *Trichogramma chilonis*, NPV and Neem products on cotton, neem products on paddy, and Bt and neem products on cabbage.

In the selected villages of Coimbtore district, chemical control was the preferred strategy and was practiced by 53 percent of the farmers on two-third of the total cotton area. Thirty eight percent of the farmers used biological inputs covering about 27 percent of the area. Rest of the farmers used neither chemical pesticides nor biological pesticides.

In Thanjavur district, 37 percent paddy farmers protected the crop with neem products (neem pesticides and oil), 49 percent depended on chemicals for pest control, and 14 percent did not use any plant protection input. Area covered under the corresponding pest management strategies also followed a similar distribution.

A majority of the cabbage farmers in Dharampuri district used chemical pesticides. Application of the biological pest management inputs was limited to 24 percent of the cabbage area by 20 percent of the farmers.

6.2 Characteristics of Adopters and Non-adopters

The choice of a technology is largely dictated by its profitability in comparison to other technological options. Besides, a number of

Table 6.1: Adoption of IPM technologies in identified crops in the sample villages

IPM Adoption	Cotton (Coimbrore)	Paddy (Thanjavur)	Cabbage (Dharampuri)
No. of farmers growing the crop	678	1118	522
% using bioagents/ biopesticides	38.4	36.6	19.5
% using chemical pesticides alone	53.0	49.5	80.5
% using none	8.6	13.9	0.0
Area under crop (ha)	275	849	356
% protected with IPM	26.8	37.5	24.2
% protected with chemical pesticides	65.8	49.5	75.8
% unprotected	7.4	13.0	0.0

socioeconomic, institutional and environmental factors also influence the choice of technology. The literature shows that early adopters of the new innovations are generally younger, have attained higher level of education, and possess larger land holdings (Feder, 1985; Thomas et al., 1990; Harper et al., 1990; Polson and Spencer, 1991; Nkonya et al., 1997; Lapar and Pandey, 1999).

Table 6.2 compares the characteristics of adopters and non-adopters of IPM technologies. As expected, the adopters were relatively younger than the non-adopters; the difference, however, was not statistically significant. The educational level of the adopters was also significantly higher than that of the non-adopters.

Table 6.2: Mean (standard deviation) of the variables distinguising adopters from non-adopters

	Cotton		Paddy		Cabbage	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
Personal characteristics						
Age (years)	44.5	47.2	41.6	45.4*	38.0	38.2
	(8.3)	(9.4)	(8.9)	(9.0)	(5.4)	(5.3)
Years of schooling	8.3	4.8 ***	9.7	6.1***	10.1	7.0***
	(3.6)	(3.7)	(3.0)	(3.9)	(2.1)	(4.3)
Farm characteristics						
Size of land holding(acres)	4.9	3.3 ***	9.7	5.7 *	4.9	4.4
	(2.6)	(1.4)	(13.6)	(4.9)	(4.6)	(2.5)
No. of fragments	1.5	1.7	1.5	2.0*	2.1	2.0
	(0.6)	(0.7)	(1.0)	(1.2)	(1.0)	(1.2)
No. of adult workers/acre	0.6	0.5	0.3	0.4	0.8	0.7
	(0.7)	(0.4)	(0.8)	(0.4)	(0.3)	(0.4)
Area under crop (%)	31.9	31.5	77.0	67.8***	18.8	18.2
	(16.6)	(18.7)	(16.3)	(17.8)	(6.0)	(0.1)
Awareness of pesticide externalities (score)						
Technological failure	2.1	1.4 ***	1.1	1.1	1.5	1.2
	(0.9)	(1.0)	(1.1)	(1.4)	(0.8)	(0.9)
Ecological ill effects	2.4	1.6***	2.2	1.2***	1.9	0.9***
	(0.8)	(0.8)	(0.8)	(1.0)	(1.1)	(1.7)
Health impairments	1.9	1.4 ***	2.4	1.8*	3.6	2.4***
	(1.1)	(0.7)	(1.9)	(1.3)	(1.3)	(1.3)
Pesticide residues in food	3.2	2.6	2.6	1.5***	3.4	2.0***
	(1.7)	(2.0)	(1.0)	(1.4)	(2.3)	(2.4)

Figures in parentheses are standard deviations. ***, ** and * indicate significance at 1, 5 and 10 percent level, respectively.

Size of land holding of the adopters was also higher in the cotton and paddy zones. In the cabbage zone, there was no significant difference in the size of land holding of the adopters and non-adopters. Fragmentation of holdings is considered to be an important hindrance in technology adoption; the adopters had less number of land fragments, compared to the non-adopters.

IPM is considered to be a labour-intensive method; its components such as, collection of insect larvae, release of *Trichogramma*, etc., require more of labour, compared to the spraying of pesticides. This might discourage adoption of such technologies and practices. Except in the paddy zone, family labour availability per unit of operated area was slightly higher in the adopter households. The availability of labour is thus expected to influence farmers' acreage allocation decisions. In absolute terms, adopters allocated higher acreage to the identified crops than the non-adopters. However, as proportion of total cropped area it did not differ much between the adopters and non-adopters.

Negative externalities of the chemical pesticides to crops, ecology and public health are also important considerations in the promotion of IPM technologies. Farmers' knowledge of such externalities can be a critical factor in technology choice. Negative externalities of the chemical pesticides include technological failure (resistance to insecticides, pest resurgence and secondary pest outbreak), damage to beneficial organisms (beneficial insects, predators and soil microorganisms), human health impairments as result of direct exposure to pesticides (effects on eyes, skins, nervous system, and gastro-intenstinal system), and entry of pesticides in the food chain (residues in food grains, livestock products and animal feed and fodder). A composite awareness score was computed for each externality class by adding up the awareness (yes/no) response of the decision-makers. Frequencies of farmers' response to individual externality are provided in Annexure VIII. Both the adopters and non-adopters in all the zones had a fairly good knowledge of the negative externalities of the chemical pesticides to crops, ecology and human health. The mean awareness score of the adopters, however, was higher than that of the non-adopters. In the paddy zone, awareness among the non-adopters on crop-specific externalities (technological failure) of the chemical pesticides was as good as among the adopters. These results are on the expected lines, as the adopters have experienced negative externalities of the chemical pesticides as well as the positive externalities of the biopesticides.

6.3. The Process of Pest Management

6.3.1 Identification of the insect pests, and the criteria for their control

Pest control intervention begins with appearance of the insect pest, and its success depends whether the farmers have appropriately recognized the pest. Farmers were shown the pictures of some common insect pests of the identified crops, and were asked to recognize these. Table 6.3 presents frequency distribution of the farmers recognizing different insect pests.

Table 6.3: Farmers' pest recognition ability (% farmers reporting)

Pest recognition	Cotton		Paddy		Cabbage	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
Cotton insect pests						
Helicoverpa	97.7	66.7	-	-	-	-
Spotted bollworm	62.8	55.6	-	-	-	-
Pink bollworm	55.8	52.8	-	-	-	-
White fly	88.4	75.0	-	-	-	-
Aphid	81.4	69.4	-	-	-	-
Jassid	81.4	63.9	-	-	-	-
Paddy insect pests						
Army worm	-	-	7.5	14.6	-	-
Brown plant hopper	-	-	77.5	61.0	-	-
Case worm	-	-	15.0	14.6	-	-
Ear head bug	-	-	55.0	53.7	-	-
Leaf folder	-	-	57.5	58.5	-	-
Stem borer	-	-	60.0	48.8	-	-
Thrips	-	-	5.0	0.0	-	-
Cabbage insect pest						
Diamond back moth	-	-	-	-	100.0	100.0
Leaf caterpillar	-	-	-	-	42.9	34.3
White fly	-	-	-	-	60.0	57.1
Aphid	-	-	-	-	77.1	80.0
Root fly	-	-	-	-	60.0	57.1

The cotton pests, *Helicoverpa*, spotted bollworm, pink bollworm, white fly, aphid and jassid were the commonly known pests to both the adopters and non-adopters. Adopters, however, had a better pest recognition ability.

Farmers rarely followed a uniform criterion to initiate the pest control action. The criteria followed by them were: pest density, damage visibility, appearance of moth, and calendar spraying (Table 6.4). The first two of these are closer to the action threshold criterion, which is based on the pest infestation level.

Table 6.4: Decision criteria of the farmers for action against pest (%)

Decision criteria	Cotton		Paddy		Cabbage	
	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters
Appearance of moth	37.2	30.6	15.0	22.0	51.4	60.0
Damage visibility	7.0	22.2	72.5	61.0	34.3	20.0
Pest density	55.8	25.0	12.5	9.8	14.3	11.4
Calendar spraying	0.0	22.2	0.0	7.3	0.0	8.6

In the cotton zone, 30 percent non-adopters started action against pest with the appearance of moth, and 22 percent followed calendar spraying. Pest density and damage visibility criteria were followed by 25 and 30 percent of the adopters and non-adopters, respectively. In contrast, the adopters were more scientific in executing pest management interventions; 56 percent followed pest density, and 7 percent damage visibility as the criterion. Others initiated action on the appearance of the moth.

Damage visibility was the main criterion for action against insect pests in the paddy zone. This was followed by 73 percent adopters and 61 percent non-adopters. Moth appearance ranked next, and was followed by the pest density. Seven percent non-adopters followed calendar spraying.

In the cabbage zone, 60 percent non-adopters and 50 percent adopters started intervention on the appearance of the moth. Rest of the adopters based their intervention decisions on the damage visibility and the pest density; thirty one percent non-adopters followed each of these criteria.

These observations suggest that farmers possess an adequate understanding of the insect pests. They follow diverse criteria for initiating actions against these. A majority of them rarely relies on the traditional calendar spraying schedule. Reliance on the criteria other than pest density indicates their aversion towards the pest risks.

6.3.2 Pest management practices

Farmers took both preventive and curative measures to limit the crop loss due to insect pests. These are classified into chemical, biological and cultural measures. Frequency distribution of the adopters and non-adopters following different practices is given in Table 6.5.

Table 6.5: Pest control practices of adopter and non-adopter farmers (%)

Pest control practices	Cotton		Paddy		Cabbage	
	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters
Chemical						
Insecticides	93.0	100.0	5.0	100.0	97.1	100.0
Weedicides	25.6	33.3	0.0	0.0	0.0	0.0
Fungicides	23.3	25.0	0.0	0.0	68.6	60.0
Biological						
Tricho-cards	90.7	0.0	0.0	0.0	0.0	0.0
NPV	65.1	0.0	0.0	0.0	0.0	0.0
Bt	0.0	0.0	0.0	0.0	97.1	0.0
Neem products	41.9	0.0	100.0	0.0	28.6	0.0
Pheromone traps	86.0	41.7	0.0	0.0	0.0	0.0
Cultural						
Dry period ploughing	95.3	94.4	62.5	56.1	100.0	100.0
Adjust sowing dates	65.1	66.7	30.0	41.5	71.4	71.4
Proper plant spacing	97.7	94.4	32.5	34.1	17.1	28.6
Seed replacement	86.0	86.1	55.0	53.7	100.0	100.0
Trap/border cropping	44.2	36.1	0.0	0.0	28.6	34.3
Hand picking of larvae	74.4	94.4	0.0	0.0	0.0	0.0
Manual weeding	88.4	94.4	47.5	26.8	62.9	71.4
Crop rotation	74.4	69.4	25.0	31.7	0.0	8.6

Chemical pesticides

Insecticides were indispensable in the cotton and cabbage production, irrespective of whether farmers used the biological technologies or not (Table 6.5). About 93 percent cotton IPM farmers and 97 percent cabbage IPM farmers applied insecticides. In addition, they also applied fungicides and herbicides. A similar pattern was observed for the non-adopters. Adopters in the paddy zone rarely used chemical pesticides.

Biological pesticides

Trichogramma chilonis, NPV, and neem products were the common biological products used in the cotton production system. *Trichogramma* was applied by 91 percent, NPV by 65 percent and neem products by 42 percent of the farmers. Pheromone traps were also installed to monitor and control the insect pests both by the adopters and non-adopters. Use of Bt was widespread in cabbage. Neem based pesticides and neem oil were also used. In the paddy zone, farmers used neem products only.

Cultural practices

A majority of the farmers, consciously or unconsciously, follows a number of agronomic practices that reduce the pest build up. These include: dry period ploughing, synchronized sowing, proper plant spacing, seed replacement and crop rotation. Most of these practices are routine farm management practices. Other direct cultural interventions like hand picking of insect larvae, manual weeding and trap cropping are also followed to reduce the pest infestation.

Ploughing

Deep summer ploughing exposes the soil inhabiting insect larvae and the disease organisms to the sun, and thus helps reduce pest multiplication. Ploughing was a common practice in the cotton and cabbage zones. In paddy zone, this was followed by about 60 percent of the farmers (adopters as well as non-adopters).

Adjustment in sowing dates

Most of the crops are susceptible to insect pest attack only at certain crop growth stages, and for a limited period. Slight adjustment in the sowing dates can help avoid the pest infestation. About two-third of both the adopters and non-adopters of the biological pest management technologies in the cotton and 70 percent in the cabbage systems reported to modify the planting schedule to avoid pest attack. In the paddy zone, only a few farmers reported modification in the sowing dates.

Plant spacing

Dense planting increases humidity, which provides a favorable microclimate for pest multiplication. A majority of the cotton farmers reported to maintain proper plant spacing. While the paddy and cabbage farmers rarely maintained proper plant spacing.

Seed replacement

Use of the home produced seed, year after year, is not desirable from the point of pest management, because it loses its pest-resistance potential. Replacement of the seed or variety helps crop withstand the pest attack. Eighty six percent of both the adopters and non-adopters of cotton IPM, and all the cabbage farmers reported replacement of seed frequently. While in the paddy zone, about half of the adopters as well as non-adopters followed this practice.

Trap/border cropping

Trap/border crops serve as alternate hosts for the insect pests. Crops like maize and cowpea also help multiplication of the natural enemies of insect pests. Growing trap/border crops was not a common practice in any of the zones. In the cotton zone, 36 percent non-adopters and 44 percent adopters grew trap/border crops such as, maize, cowpea, greengram and castor. Rapeseed-mustard was grown as a trap crop in cabbage by 29 percent adopters, and 34 percent non-adopters. The practice of growing trap or border crops was absent in the case of paddy cultivation.

Hand picking of insect larvae

Picking of insect larvae and destroying them is the one of most effective ways to check pest multiplication. The method, however, is labor-intensive and may not be economical, all the times and at all the places. Nevertheless, the practice was widely followed in the cotton region. The practice was absent in the paddy and cabbage zones

Weeding

Weeds, besides competing with the main crop for nutrients and water, provide shelter to the insect pests. Periodic removal of weeds is, thus, essential for healthy crop growth. Manual weed control was a common practice in the cotton and cabbage zones. Forty eight percent IPM adopters and 27 percent non-adopters in the paddy zone reported practicing manual weeding.

Crop rotation

An unbroken sequence of a single crop, encourages seasonal migration of pests. Seventy four percent IPM adopters and 69 percent non-adopters in the cotton zone reported not to follow the single crop sequence, though the cotton can be grown as cotton-cotton sequence in the region. The field was either kept fallow or was sown with some other crop. Paddy-paddy rotation was common in Tanjavur district. Only 25 percent users of the biological pesticides and 32 percent non-users reported paddy alternated with other crops or kept the land fallow. Similarly, cabbage-cabbage rotation was a common crop sequence in Dharampuri district.

It is evident from the above that farmers use a number of pest management practices. Many agronomic practices that now are a part of the IPM package have been integral part of the good crop husbandry since times immemorial. Their application across farms might be at variance with the recommended practices due to resource constraints and individual's perception towards the effectiveness of the practice.

6.4 Sources of Information

Farmers obtained the information on biological technologies from multiple sources. The public extension system, however, was the main information provider (Table 6.6). In the cotton zone, research institutes, fellow farmers and mass media (television, radio and magazines) were the other sources of information. In the paddy zone, research institutes and agricultural input dealers were next to the public extension system. In the cabbage zone also, the public extension system retained its dominant position, and the agricultural input dealers emerged as the second most important source of information. Mass media and fellow farmers were the next in the order.

It is important to note that the input dealers had played an important role as technology information providers in the past, particularly on the seeds, fertilizers and pesticides. In case of biological technologies also, they have emerged as the second best source of information, particularly in the paddy and cabbage zones. This is largely for inputs such as, Bt and neem products that have a longer shelf life and can be stored without refrigeration, but not *Trichogramma* and NPV (used in cotton) that have a short shelf life.

Table 6.6: Sources of information on biological pesticides (%adopters)

Sources	Cotton			Paddy		Cabbage	
	Tricho cards	NPV	Neem	Phero-mones	Neem	Bt	Neem
Public extension	71.8	75.0	88.9	70.3	55.5	52.9	90.0
Research institute	20.5	21.4	16.7	0.0	32.5	5.9	0.0
Fellow farmers	17.9	17.9	22.2	21.6	27.5	11.8	30.0
Private input dealers	7.7	39.3	44.4	5.4	32.5	35.3	70.0
Television	15.4	10.7	33.3	10.8	12.5	11.8	10.0
Radio	12.8	25.0	11.1	10.8	15.0	14.7	20.0
Magazine/Newspaper	10.3	14.3	22.2	13.5	7.5	8.8	20.0
Total users	39	28	18	37	40	34	10

6.5 Sources of Supply

IPM farmers procured biological pest control inputs from many sources. Cotton farmers procured *Trichogramma* and NPV largely from the public extension system (Table 6.7). Private input dealers were the other main suppliers of these. Neem products were largely procured from the input dealers. In the paddy zone also, supply of neem products came largely from private sources. In the cabbage zone, the private input dealers were the main suppliers of Bt, while the public extension system was the main source for the neem products.

6.6 Farmers' Perceptions Regarding Biological Technologies

Technology characteristics play an important role in farmers' decision on its adoption or rejection. Until recently, economists had ignored the

Table 6.7: Sources of procurement of bioagents/biopesticides by adopters (% reporting)

Sources	Cotton			Paddy		Cabbage	
	Tricho cards	NPV	Neem	Phero-mones	Neem	Bt	Neem
Public extension	69.2	60.7	27.8	100.0	70.0	11.8	80.0
Research institute	2.6	3.6	0.0	0.0	0.0	0.0	0.0
Private input dealers	30.8	35.7	77.8	0.0	65.0	88.2	20.0
Manufacturers	5.1	7.1	0.0	0.0	0.0	0.0	0.0
Total users	39	28	18	37	40	34	10

technology characteristics while analyzing the adoption decisions (Adesina and Zinnah, 1993; Adesina and Baidu-Forson, 1995; Lapar and Pandey, 1999; Shiyani et al.,2000). However, the sociologists and anthropologists have viewed these as important factors in the adoption decisions (Kivlin and Fliegel, 1966; Nowak, 1992). The subsequent discussion in this chapter focuses on the role of farmers' perceptions and the socioeconomic factors in the adoption of biological pest management technologies. The analysis is done for both the adopters and non-adopters. The non-adopters for this purpose are only those, who were aware of biological technologies being used by their fellow farmers.

Adopters' perceptions were analyzed in terms of the effectiveness of the biological technologies, and the problems encountered in their application. In the cotton zone, 64 percent of the users of *Trichogramma* reported that it was effective only against the target insect pest, *Helicoverpa* (Table 6.8). Its slow action against the target pest was indicated by 38 percent of the users. Besides, its short shelf and uncertain quality of the product were other problems. Non-availability, in the required amount and at the right time, was the main supply side problem. Only 13 percent farmers indicated no problem in the use of *Trichogramma*.

NPV was another major bioagent used in the cotton IPM. Like *Trichogramma*, its host-specificity was its main drawback. Its slow action against target pest, and quality uncertainty were other important technology related problems. Major economic problems associated with the use of NPV were: lack of availability at right time, and higher cost of application.

Neem pesticides provide protection against a number of insect pests, but they are slow in action. This was reported by a majority of the users in all the crop zones. Further, the users were quite conscious of the quality of the product. Lack of supplies, when needed and in right quantity, and high cost of application were the major economic problems faced by the users.

Bt was the main biological product applied to control cabbage insect pests. About 35 percent users indicated its slow action against the insect pests as the main technological problem. Twenty four percent users also indicated the host-specificity of Bt as a problem. Its high cost of application and lack of adequate and timely supplies were the main economic problems.

Table 6.8: Problems in use of biological technologies (% adopters reporting)

Sources	Cotton			Paddy		Cabbage	
	Tricho cards	NPV	Neem	Phero-mones	Neem	Bt	Neem
Distribution of adopters							
Unaware	0.0	5.0	0.0	5.0	0.0	2.9	0.0
Aware but not using	9.3	29.9	58.1	9.0	0.0	0.0	71.4
Users	90.7	65.1	41.9	86.0	100.0	100.0	28.6
Problems of users							
Host-specificity	64.1	60.7	11.1	45.9	12.5	23.5	0.0
Slow effect	38.5	42.9	77.8	16.2	72.5	35.3	100.0
Short shelf life	20.5	0.0	0.0	0.0	5.0	5.9	10.0
Quality uncertainty	33.3	39.3	50.0	10.8	55.0	8.8	20.0
Inadequate supply	46.2	75.0	27.8	48.6	67.5	61.8	30.0
Unsynchronized supply	51.3	75.0	44.4	48.6	62.5	61.8	40.0
Costly	17.9	42.9	77.8	16.2	12.5	73.5	30.0
Low crop yield	15.4	21.4	27.8	0.0	12.5	11.8	20.0
Labour intensive	15.4	10.7	11.1	0.0	15.0	8.8	20.0
Pesticide use in the vicinity	59.0	67.9	72.2	0.0	52.5	41.2	30.0
Lack of timely expert advice	15.4	21.4	33.3	0.0	52.5	52.9	50.0
No problem	12.8	14.3	5.6	37.8	0.0	0.0	0.0

Note: Distribution of problems relates to the users only.

Despite all these problems, only a small proportion of the adopters indicated their negative effect on the crop yield. This suggests that the use of biological technologies in IPM is as effective as conventional chemical pest control. In the process farmers, however, faced a number of social and informational problems also (Table 6.8). Most of the biological inputs (excluding botanicals) are produced using microorganisms, and their activities are adversely affected by the use of chemical pesticides in the neighborhood. Besides, the chemical pesticides, being fast in action, cause insect pests move to the neighboring fields that use slow-action biological products. A majority of the farmers indicated this as the major social problem in the use of biological pesticides. Lack of timely expert advice was also an important problem.

From the non-adopters we solicited information regarding their awareness about the biological technologies being used by the other farmers in village, and also their perceptions on the desirable attributes of the technologies, and the conditions for their adoption. In the cotton zone, 69 percent non-adopters were aware of *Trichogramma*, 61 percent of NPV and 89 percent of neem products (Table 6.9). In the paddy zone, 90 percent were aware of neem products. Awareness was also high in the cabbage region; 71 percent non-adopters were aware of Bt and 89 percent of neem products.

These farmers were willing to adopt the biological technologies, given certain technology characteristics. An overwhelming majority of the farmers, irrespective of regional considerations, expect the new technology to be as effective as the chemical pesticides (Table 6.9). The technology should also be broad-spectrum, that is it should control a range of insect pests. Those aware of the shelf life and quality of technology, also indicated these as important considerations in their adoption decisions. This was particularly the case with *Trichogramma* adoption. Similarly, those aware of sensitivity of the biological technology to the chemical pesticides wish to see chemical-resistance characteristics in these technologies.

Apart from the technology characteristics, the farmers expect an assured and timely supply of these technologies. Low cost of the technology is also important consideration. A few farmers also indicated that they might adopt the technology, if it were labour-saving. Most of the new technologies,

Table 6.9: Farmers' subjective considerations for adoption of biological pesticides (% non-adopters)

Subjective consideration	Cotton			Paddy		Cabbage	
	Tricho cards	NPV	Neem	Phero-mones	Neem	Bt	Neem
Distribution of adopters							
Unaware	30.6	38.9	11.1	27.8	10.0	28.6	11.4
Aware	69.4	61.1	88.9	72.2	90.0	71.4	88.6
Considerations for adoption							
Broad-spectrum	84.0	81.8	34.4	65.4	47.2	92.0	80.6
Knock down effect	84.0	86.4	56.3	80.8	33.3	88.0	71.0
Chemical resistant	36.0	31.8	0.0	0.0	0.0	0.0	0.0
Assured supply	96.0	81.8	34.4	65.4	47.2	96.0	77.4
Availability when needed	96.0	81.8	15.6	50.0	47.2	60.0	48.4
Cost-effective	68.0	68.2	53.1	53.8	41.7	64.0	51.6
Labour saving	20.0	18.2	0.0	0.0	19.4	20.0	38.7
Wider adoption	68.0	72.7	25.0	30.8	30.6	56.0	45.2
Information on method of use	32.0	31.8	0.0	23.1	33.3	44.0	35.5
Information on target pests	80.0	72.7	43.8	26.9	30.6	36.0	29.0

Note: Distribution of considerations relates only to the farmers who aware of biological pesticides.

being based on biological materials/living organisms, are slow in action and sensitive to the chemical pesticides, and therefore community adoption was desired by 25 to 72 percent of the prospective users. The perception were stronger for the *Trichogramma* and NPV.

Being aware of a technology is not a sufficient condition for its adoption. Farmers should know about its method of application, timing of application, and the target pest. A majority of the cotton farmers indicated need for more information on the target pests and the timing of application of these technologies particularly on *Trichogramma* and NPV before they could decide to use these. Information needs of the cabbage and paddy farmers were not as strong as that of the cotton farmers.

6.7 Determinants of Adoption

6.7.1 Selection of variables

Probit model has been used to identify factors influencing adoption of biological technologies[10]. The dependent variable is dichotomous, and takes a value of 1 if a farmer has used any of the biological product, 0 otherwise. A number of demographic, social, economic and environmental factors were hypothesized to influence the adoption decisions. Age of the decision-maker is an important factor, as it reflects the composite effect of the farming experience, attitude towards the new technology and the planning horizon. While the older farmers have a longer experience, younger ones are expected to have a longer planning horizon and a favorable attitude towards the new technology. Thus, age could have both a positive and negative effect on the adoption decisions. The net effect, however, is indeterminate a priori. Education is considered to improve access to the information, and thus is assumed to have a favorable effect on the farmers' adoption decisions.

Size of land holding reflects a farmer's capacity to invest in the new technology as well as his risk-taking ability. Simultaneously, fragmentation of land holdings might act as a disincentive to adoption; the farmers having less fragments are expected to invest more in new technologies because of economies of scale (labor-saving, efficient farm management, etc.). Its relevance is more in case of pest management, as the common property resource characteristic of the pest necessitates collective efforts by the

[10] The proportion of the adopters and non-adopters of IPM technologies is almost the same in our sample, as we purposively drew almost an equal number of the both. The village level adoption rates indicate low proportion of adopters. Thus the sample is biased towards adopters, This is likely to result into biased estimates. To correct this, we have weighted the sample with true proportion of the adopters and non-adopters in the selected villages. The general procedure is as follows: Suppose, the sample contains 50 percent adopters and 50 percent non-adopters, while their true proportions in the population are 0.25 and 0.75 respectively. Then adopters are over-represented by a factor of 0.50/0.25=2, while the non-adopters are underrepresented by a factor of 0.50/0.75=0.67. To have a right mix of the adopters and non-adopters, it is necessary to scale down the number of adopters by a factor of 0.25/0.50=0.50, and scale up the number of non-adopters by a factor of 0.75/0.50=1.50. Scaling factors can be used for each of the variable. This however can be handled by a single weighting variable.

farmers or the ownership of a contiguous large tract of the land by an individual. Thus, a priori a negative association is assumed to exist between the adoption of biological pesticides and the number of land fragments.

To realize full potential of the biotechnologies their applications need to be synchronized. That means an adequate and timely availability of labour that perhaps cannot be ensured other than the family labour. It is hypothesized that the farmers with more family labour per unit of land tend to bring in more area under the bio-intensive IPM. Another important factor in the adoption of biological pesticides is the area under the target crop. This could influence the adoption both ways. A larger proportion of the area under crop indicates a tendency towards monocropping resulting into higher pest infestation and thereby adoption of the better technologies. On the other hand, diversified cropping pattern, being a part of ecological IPM, is expected to reduce the pest infestation, and thereby the income risks. Thus, the farmers following a diversified cropping pattern are expected to use less of the improved technologies.

Costs and benefits associated with the biological pesticides (in terms of lower cost, yield saving etc.) are important economic considerations in the adoption decisions of the farmers. While the adopters have reaped such benefits, the non-adopters might not be fully aware of these, and therefore it is not possible to capture the role of such factors in the adoption process. However, both the adopters and the non-adopters were aware of the benefits and the costs of the existing technology (chemical pesticides). We have taken an indirect route wherein farmers' awareness of the negative externalities of the chemical pesticides is considered to act as a catalyst in the adoption of biological pesticides.

6.7.2 Model results

The results of the probit model are presented in Table 6.10. Age of the decision-maker does not appear as a significant factor in adoption process, while the education emerges as an important determinant of the adoption. The estimates of marginal probability indicate that with one percent increase in the level of education, adoption of biological pesticides increases by 6 percent in the case of cotton, 4.8 percent in the case of paddy and 3.8 percent in the case of cabbage.

The decisions to adopt biological pest management are positively and significantly influenced by the households' resource endowments in the cotton and paddy production systems. Fragmentation of land holding, as expected, has a discouraging effect on the adoption. The marginal effects

Table 6.10:Factors influencing adoption of biological technologies

Factors	Cotton		Paddy		Cabbage	
	Co-efficient	Marginal effect	Co-efficient	Marginal effect	Co-efficient	Marginal effect
Personal characteristics						
Age (years)	-0.0113	-0.0045	-0.0077	-0.0027	-0.0229	-0.0049
	(0.606)		(0.283)		(0.55)	
Years of schooling	0.1493 **	0.0595	0.1344	0.0479	0.1809**	0.0384
	(2.306)		(2.171)**		(2.186)	
Farm characteristics						
Size of land holding (acres)	0.9118 ***	0.3654	0.3766 ***	0.1342	0.0174	0.0037
	(2.744)		(3.445)		(0.231)	
No. of fragments	-1.3474**	-0.5372	-2.2080***	-0.7878	-0.6982***	-0.1483
	(2.399)		(4.301)		(2.718)	
No. of adult workers/acre	1.2354**	0.5001	1.0935**	0.3900	0.4998	0.1062
	(2.133)		(2.243)		(0.681)	
Area under crop (%)	-0.0059	-0.0023	-0.0050	-0.0018	0.0031	0.0007
	(0.427)		(0.706)		(0.139)	
Awareness of pesticide	-0.0984	-0.0392	0.1067	0.0381	-0.4135	-0.0878
externalities (score)	(0.394)		(0.605)		(1.079)	
Technological failure						
Ecological ill effects	0.5541	0.2209	0.5623*	0.2006	0.7975 ***	0.1694
	(1.114)		(1.881)		(2.819)	
Health impairments	0.2002	0.0798	0.0663	0.0236	0.1338	0.0284
	(0.838)		(0.526)		(0.648)	
Pesticide residues in	0.2602*	0.1037	-0.1125	-0.0401	0.0014	0.0003
food	(1.766)		(0.504)		(0.010	
Constant	-4.7688 **		-1.2924		-1.5171	
	(2.219)		(0.871)		(0.860)	
Log-likelihood function	-22.4088		-24.5897		-24.6934	
Restricted log-likelihood	-50.5918		-55.3482		-48.5359	
Chi-squared	56.3660		61.5196		47.6851	

Figures in parentheses are t- values

***, ** and * significant at 1, 5 and 10 percent level respectively.

too indicate a greater role of these factors in the technology adoption decisions. Area under the crop as proportion of the total cropped area is not a significant determinant of adoption. Biological pesticides being new technologies, are likely to be adopted first by the innovative farmers who generally have larger landholdings and better access to information.

Likelihood of adoption of the biological pest management increases with the increase in the farmers' awareness of the economic and environmental costs of chemical pesticides. However, most of the proxies for these are not significant. The mean values of these parameters are also not significantly different between the adopter and non-adopters. This indicates that the farmers, in general, are aware of the negative externalities of chemical pesticides, but due to newness of the biological pesticides, the economic factors override environmental concerns in their adoption decisions.

The model results indicate that a majority of the farmers is aware of the biological pest management technologies as well as the drawbacks of the existing chemical pest control technologies. However, asymmetric information on the tools and the methods of application of biological technologies and the benefit-cost ratios bring in elements of risk and uncertainty in farmers' adoption decisions. Provision of adequate information and timely availability of biological inputs might accelerate adoption of biological pesticides. Community pest management would act as a catalyst in the process.

7 ECONOMIC IMPACT OF IPM

Analysis of the experimental data, presented in chapter 5, provides a mixed picture of the technical and economic efficacy of IPM. At certain locations, it is technically efficient but economically inefficient; at others it is technically as well as economically efficient. *Ceteris paribus*, the regional variation in the performance of IPM is due to the differences in the types of biological pesticides used, their application rates and prices. Yet, the general indication is that IPM has the potential to substitute the chemical pesticides. Does IPM perform equally good under field conditions? Further, we have noticed in the previous chapter that the farmers are aware of IPM technologies, but are confronted with a number of problems/constraints in their adoption. The major concerns are the profitability and the viability of the technology. This chapter examines the economic feasibility of IPM, and its impact.

7.1 Farm Level Effects

7.1.1 Pesticide use

One of the major objectives of IPM is to reduce the use of chemical pesticides, and thereby their negative externalities to the public health and environment. The extent to which IPM could reduce the use of chemical pesticides is given in Table 7.1. In cotton, *Trichogramma*, NPV, neem seed kernel extract and neem pesticides were the main biological products integrated into IPM. Their application rate was 16.6 cc, 361 LE, 150 gm and 430 gm per ha, respectively. Some non-IPM farmers had also installed the pheromone traps. The use of pesticides could be reduced considerably; the mean usage of technical grade pesticides on IPM farms was 446 gm/ha - three times less than on the non-IPM farms.

Neem products were the main products used in paddy IPM. The farmers applied 1023 gm/ha neem pesticides, and 666 gm/ha neem oil. Use of the chemical pesticides was negligible. On non-IPM farms, pesticide use was

Table 7.1: Means and standard deviations of inputs (per ha) used by adopters and non-adopters of IPM

	Unit	Cotton		Paddy		Cabbage	
		Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
1. Human labour							
Male	Person days	35.0 (16.9)	39.6 (15.8)	79.4 (25.1)	81.0 (26.2)	92.0 (22.1)	98.3** (19.1)
Female	Person days	63.0 (20.7)	54.5** (19.1)	50.5 (23.4)	47.3 (20.6)	129.2 (39.9)	120.6 (41.8)
2. Seed	Kg	9.8 (2.8)	9.4 (3.6)	75.6 (9.7)	74.5 (11.1)	379.0 (397.0)	279.0** (30.0)
3. Plant nutrients							
Urea	Kg	75.3 (69.3)	85.8 (53.0)	136.6 (84.3)	148.6 (92.2)	135.7 (95.4)	169.4** (115.6)
DAP	Kg	54.9 (72.2)	64.4 (78.2)	96.6 (61.8)	94.0 (54.9)	164.3 (121.7)	170.0 (116.6)
17:17:17 complex	Kg	119.4 (72.5)	137.5 (61.1)	13.8 (52.5)	20.9 (52.9)	134.4 (116.9)	101.6** (89.8)
Zinc shulphate	Gm	990.0 (425.0)	130.0*** (92.0)	3.4 (6.5)	4.7 (5.4)		
MOP		-	-	66.4 (83.3)	84.2 (83.5)	31.8 (61.7)	44.7 (91.5)
SSP		-	-	8.1 (72.1)	25.7* (44.1)		
Mineral mixture	Kg	19.1 (23.7)	19.3 (17.0)				
Azospirillum	Gm	400.0 (404.0)	69.0*** (200.0)	289.0 (310.0)	58.0*** (235.0)	389.0 (528.0)	357.0 (780.0)
Phosphobacteria	Gm	165.0 (231.0)	16.0*** (88.0)	137.0 (356.0)	0.0 (0.0)	11.0 (104.0)	270.0*** (620.0)
Farm yard manure	Tonne	5.5 (3.7)	5.3 (3.3)	6.8 (3.9)	5.7 (4.9)	11.2 (4.0)	10.8 (5.1)
Bio-gas slurry	Qtl	1.6 (4.3)	1.2 (1.5)				
Neem cake	Kg	103.0 (108.5)	110 (156.4)	63.0 (56.7)	22.3*** (33.2)	65.7 (122.4)	70.8 (115.8)
4. Pest control inputs							
Insecticides	Gm	362.0 (224.0)	1354.0*** (767.0)	1.0 (12.0)	710.0*** (499.0)	1400 (1200)	3100*** (1200)
Weedicides	Gm	17.0 (44.0)	82.0** (163.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Fungicides	Gm	67.0 (145.0)	74.0 (219.0)	0.0 (0.0)	0.0 (0.0)	1100 (1200)	1400* (1100)
Trichogramma	Cc	16.6 (9.9)	-				
HeliothisNPV	LE	361.0 (302.0)	-				
NSKE	Gm	150.0 (830.0)	-				
Neem pesticides	Gm	430.0 (600.0)	1023.0 (1366.0)				
Neem oil	Gm		-	666.0 (1946.0)		1400 (3400)	
Pheromone traps	No.	8.2 (6.5)	3.7*** (6.1)	-	-	-	-
Bt	Kg	-	-	-	-	2.6 (1.5)	-
5. Draught power							
Bullocks	Pair days	5.6 (5.0)	6.5 (5.8)	0.5 (1.8)	0.4 (3.0)	3.4 (4.1)	2.8 (3.7)
Tractor	Hours	3.3 (4.9)	2.8 (4.1)	3.4 (1.3)	3.4 (1.8)	7.4 (2.9)	7.9 (2.6)

Figures in parentheses are standard deviations

***, ** and * significant at 1, 5 and 10 percent level , respectively.

estimated 710 gm/ha. Fungicides and weedicides were not used on IPM as well as non-IPM farms.

Bt and neem oil were the main biological pesticides applied on the cabbage. Average use of these inputs was 2.6 kg/ha, and 1.4 kg/ha, respectively. Use of chemical pesticides was 2.5 kg/ha on IPM farms, while the non-IPM farmers used almost twice of this. Thus, the adoption IPM could bring down pesticide use by about 50 percent.

Role of the other pest management techniques should, however, not be discounted (Birthal et al., 2000). Table 7.1 also shows that the adopters applied less of the chemical fertilizers particularly the nitrogenous ones. Less use of the inorganic nitrogen in the initial stage of crop growth is often recommended as a part of IPM package. Nitrogen release from the inorganic sources is faster, promoting a luxurious crop canopy conducive to the pest multiplication.

7.1.2 Crop yield

To see whether IPM is technically efficient, yield rates[11] on IPM and non-IPM farms were compared (Table 7.2). Mean yield of cotton on IPM farms was 14.2 q/ha, which was marginally (3.5 percent) higher than on the non-IPM farms. Paddy yield on IPM farms (47.6 q/ha) was significantly higher than on the non-IPM farms (46.1q/ha). So was in the case of cabbage. This substantiates the experimental claims of a better yield saving potential of IPM technology.

Higher yield on IPM farms could also be due to the differences in inputs used other than the pest control inputs. Table 7.1 shows less use of inorganic fertilizers and higher use of organic fertilizers and farmyard manure on

---

[11] Generally farmers grow a number of varieties, which can under or overestimate the average yield if there are significant differences in yield rates across varieties and area under these. In case of cotton we encountered three varieties/hybrids (LRA5166, MCU5 and RCH), which had significant differences in their yields. The proportion of area under these varied between IPM and non-IPM farms. In such situations, distribution of area under different varieties/hybrids can be equalized across groups while estimating the average yield of a crop within the group. In case of paddy and cabbage systems too farmers grew many varieties/hybrids, but the mean yield of these did not differ significantly.

Table 7.2: Differences in crop yield (qtl/ha) between IPM and non-IPM farms

Crop	Adopters	Non-adopters	% difference over Non-adopters
Cotton	14.2 (2.9)	13.8 (2.7)	3.5
Paddy	47.6 (3.3)	46.1 (2.2)	3.3***
Cabbage	444.8 (25.9)	466.0(28.0)	4.8***

Figures in parentheses are standard deviations

***, ** and * significant at 1, 5 and 10 percent level respectively

IPM farms. There was, little if any, difference in the use of other inputs between the IPM and non-IPM farms. These observations give further credence to the observation that IPM has the potential to reduce use of chemical pesticides without any adverse effect on crop yield and demanding any additional resources.

7.1.3 Costs and returns

Having established the technical potential of IPM, we further examine its short run effects on farm profitability.

Cost of cultivation

Estimates of the variable cost, with and without IPM are given in Table 7.3. Total cost includes the cost of human labor and draught services, seed of the main as well as inter/trap crop, organic and inorganic fertilizers, irrigation, chemical pesticides and biological pesticides.

Average cost of cultivation of cotton on IPM farms was marginally less (3.6 %) than on the non-IPM farms. On both the IPM and non-IPM farms, plant nutrients were main items of expenditure (40 percent). On IPM farms, cost of plant nutrients was lower by 3.8 percent. Human labor was the next most important item of expenditure on both IPM (38.6 %) and non-IPM (38.3 %). The difference between the two is insignificant. The expenditure on draught services and seed also was not different. Plant protection inputs

Table 7.3: Differences in cost of cultivation (Rs/ha) on IPM and non-IPM farms

	Cotton		Paddy		Cabbage	
	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters
Human labour	4664	4801	6156	6274	11068	11040
	(1441)	(1727)	(1395)	(1577)	(2582)	(2572)
Seed	741	803	741	745	2582	2626
	(432)	(522)	(141)	(112)	(669)	(748)
Plant nutrients	4832	5018	3234	3002	5155	5055
	(2122)	(2228)	(1020)	(1080)	(1642)	(1723)
Plant protection	1168	1261	339	548	3841	3876
inputs	(537)	(713)	(421)	(338)	(1905)	(1334)
Draught power	672	648	554	546	1391	1410
	(406)	(370)	(188)	(300)	(524)	(535)
Irrigation	0.0	0.0	458	477	0.0	0.0
			(561)	(556)		
Others	13.5	9.6	0.0	0.0	11	15
	(28.8)	(17.0)			(19)	(34)
Total	12090	12540	11480	11592	24049	24022
	(3452)	(4351)	(2017)	(2059)	(4482)	(4864)

Note: Others include cost of inter/trap/border crop seeds

Figures in parentheses are standard deviations

***, ** and * significant at 1, 5 and 10 percent level respectively

accounted for 10.1 percent of the total cost on non-IPM farms and 9.7 percent on IPM farms. The cost of plant protection inputs was 7.4 percent lower on IPM farms.

Cost of paddy cultivation was almost equal on IPM and non-IPM farms. Human labour accounted for 54 percent of the total cost on both the categories of farms. Plant nutrients accounted for 28 percent and 26 percent of the total cost on IPM and non-IPM farms, respectively. Share of plant protection inputs was 3.0 percent on the IPM farms and 4.7 percent on the non-IPM farms. Plant protection cost with biological pesticides was 38 percent less than without the use of biological pesticides. Expenditures on human labour, draught services, seed and irrigation were also not much different between the IPM and non-IPM farms.

Cost of cabbage cultivation with and without IPM was not much different. Human labour accounted for 46 percent of the total cost, and followed by plant nutrients (21%), plant protection inputs (16 %) and seed (11%). There was, little if any, difference in the per hectare costs of these inputs between the IPM and non-IPM farms.

Cost of plant protection

IPM is labour-intensive. Operations such as, manual collection of insect larvae and their destruction, manual weed control, tagging of *Trichogramma* cards, etc. demand more labour, compared to pesticide spraying. The cost of pest control, presented in the previous section, on the assumption of equal labour requirement, does not reflect the full cost of plant protection. Table 7.4 provides a complete accounting of the cost of plant protection including the cost of inputs and their application. The application cost also includes the expenses towards human labour in manual insect control, manual weeding and removal of diseased plants.

Total cost of protection of cotton with IPM was Rs2846/ha, which is about 6.7 percent less than without IPM. As such, the cost of pest control comprised 23.5 and 24.3 percent of the total cost on IPM and non-IPM farms, respectively. Of the total cost of pest management, insect control accounted for 63.8 percent on IPM farms and 68.0 percent on non-IPM farms (Figures 7.1 and 7.2). Splitting the total cost of plant protection showed 43.7 percent expenses towards the application of insecticides and the manual insect control on the non-IPM farms, and 36.8 percent on the IPM farms. The application cost on the IPM farms was 26.2 percent less, compared to non-IPM farms. This was perhaps due to the less number of applications of IPM inputs.

Weed control was the next important activity on the cotton farms, accounting for 32.0 and 27.3 percent of the cost of pest control on IPM and non-IPM farms, respectively (Figures 7.1 and 7.2). Most of this was on account of manual weeding. Expenses towards manual weed control were, however, higher on IPM farms. Disease control shared 4.2 percent of the total cost of plant protection on IPM farms and 4.7 percent on non-IPM farms. Two-third of this on IPM farms and 50 percent on non-IPM farms was on account of the removal of diseased plants. Total cost of disease control was less on IPM farms by about 15 percent.

Table 7.4: Cost of pest control on IPM and non-IPM farms (Rs/ha)

	Cotton		Paddy		Cabbage	
	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters
Insect control						
Cash inputs	1146	1169	339	548***	3548	3521
	(538)	(644)	(421)	(342)	(1963)	(1245)
Labour	669	906***	165	294***	1343	1454
	(307)	(540)	(132)	(270)	(623)	(566)
Total	1815	2075	503	842***	4891	4974
	(669)	(1053)	(531)	(524)	(2448)	(1546)
Weed control						
Cash inputs	17	63***	0.0	0.0	0.0	0.0
	(46)	(107)	(0.0)	(0.0)	(0.0)	(0.0)
Labour	894	770	153	98	1621	1381
	(523)	(570)	(366)	(381)	(1343)	(1344)
Total	910	833	153	98	1621	1381
	(522)	(590)	(366)	(381)	(1343)	(1344)
Disease control						
Cash inputs	18	39	0.0	0.0	316	385
	(39)	(105)	(0.0)	(0.0)	(311)	(275)
Labour	102	104	0.0	0.0	265	318
	(122)	(126)	(0.0)	(0.0)	(324)	(241)
Total	120	143	0.0	0.0	581	703
	(142)	(210)	(0.0)	(0.0)	(306)	(496)
Total pest control	2846	3051	656	940	7093	7058
	(941)	(1407)	(605)	(805)	(2000)	(2149)

Note: 1. Cost of cash inputs also includes inter/trap/border crop seed

2. Labour costs also includes expenses towards manual collection of insect larvae, manula weeding and uprooting of diseased plants

Figures in parentheses are standard deviations

***, ** and * significant at 1, 5 and 10 percent level respectively

Cost of plant protection in the case of paddy was Rs656/ha with IPM, and Rs940/ha without IPM, and the difference is statistically significant. Ninety percent of the pest control expenses on non-IPM farms, and 77 percent on IPM farms were on account of insect control (Figures 7.3 and 7.4). On both the IPM and non-IPM farms, application costs accounted for one-third of the insect control cost. The cost of weed control was on account of manual weeding alone.

Figure 7.1. Structure of pest control cost on IPM cotton farms

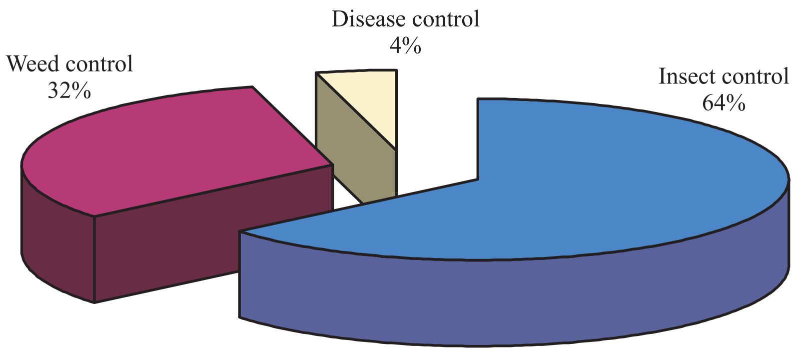
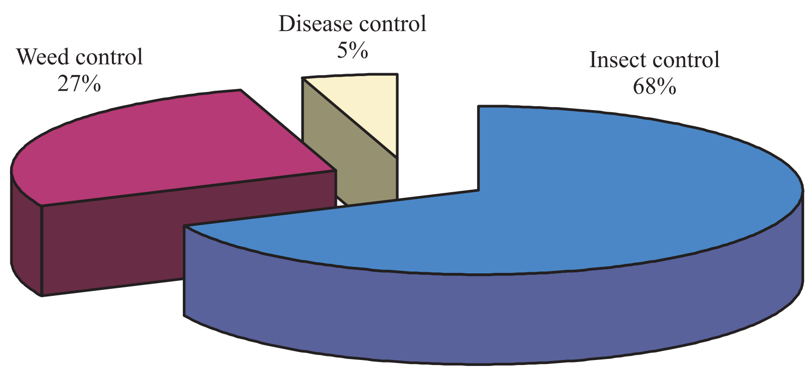


Figure 7.2: Structure of pest control cost on non-IPM cotton farms



In the case of cabbage production there was, little, if any difference in the cost of plant protection with and without IPM. So was its share in the total cost. Average cost of plant protection was Rs7092/ha on IPM farms, and Rs7058 on non-IPM farms. Of this, insect control shared 70 percent both on IPM and non-IPM farms (Figures 7.5 and 7.6). Insecticide application costs accounted for 27.5 percent on the IPM farms and 29.2 on non-IPM farms.

Figure 7.3: Structure of pest control cost on paddy IPM farms

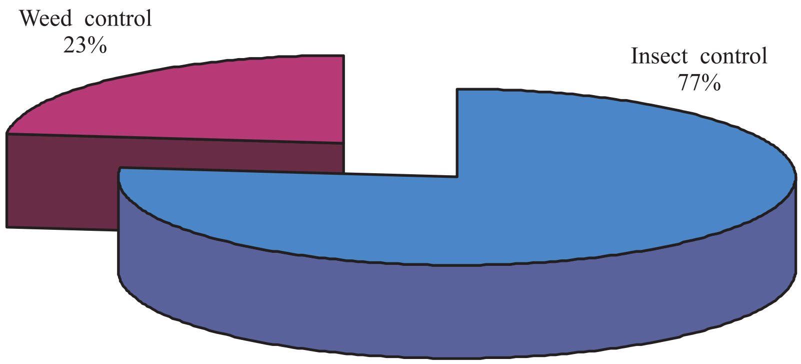
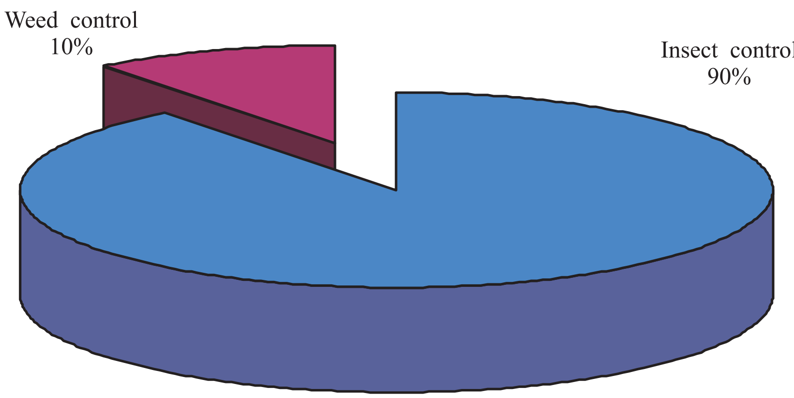


Figure 7.4: Structure of pest control cost on paddy non-IPM farms



Manual weeding was the next important pest control activity with a share of 22.8 percent in the total cost of pest management on IPM farms, and 19.6 percent on non-IPM farms. Disease control accounted for 8.2 percent of the total plant protection cost on IPM farms and 10.0 percent on non-IPM farms. About 45 percent of this was on account of application of the fungicides and removal of the diseased plants.

Figure 7.5: Structure of pest control cost on cabbage IPM farms

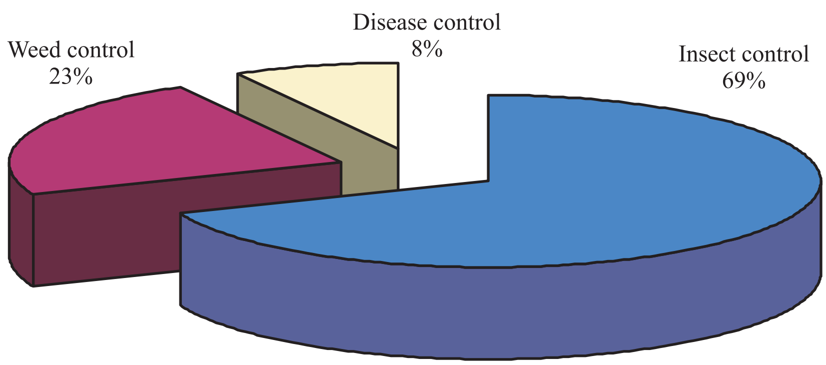
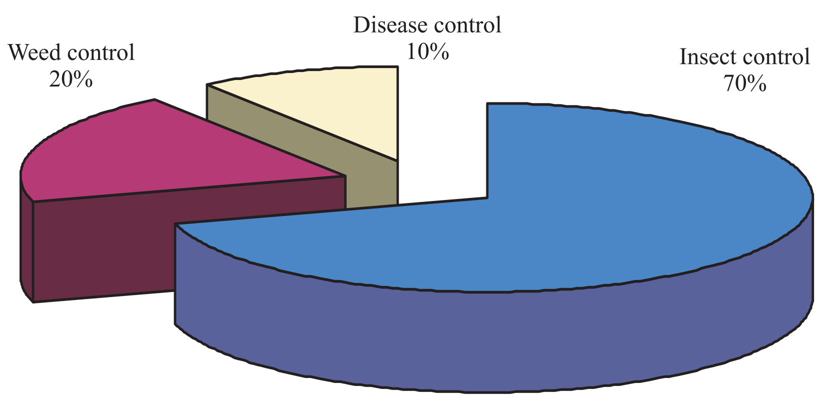


Figure 7.6: Structure of pest control cost on cabbage non-IPM farms



Cost of production

Cost per unit of output was calculated to find out the cost-effectiveness of IPM technology. Estimates of the cost of production presented in Table 7.5 show a cost of Rs850 to produce one quintal of cotton on IPM farms. This is 6.8 percent less, compared to that on non-IPM farms. Cost of paddy production was Rs241/q on IPM farms, less by 4 percent than on non-

Table 7.5: Unit cost of production with and without IPM (Rs/qtl)

	Insect control	Pest control	Others	Total
Cotton				
IPM	127.6	200.0	649.2	849.6
	(46.8)	(29.4)	(226.7)	(275.7)
Non-IPM	150.9	221.8	690.2	912.0
	(71.9)	(88.2)	(238.0)	(302.0)
% change over non-IPM	-15.5*	-9.8*	-5.9	-6.8
Paddy				
IPM	10.6	13.8	227.5	241.3
	(11.5)	(12.7)	(34.6)	(40.5)
Non-IPM	18.3	20.4	231.2	251.6
	(10.2)	(15.5)	(39.1)	(40.3)
% change over non-IPM	-42.1***	-32.3***	-1.6	-4.1
Cabbage				
IPM	10.5	15.2	36.4	51.6
	(5.3)	(4.4)	(6.2)	(8.8)
Non-IPM	11.2	15.9	38.1	54.0
	(3.4)	(4.6)	(6.9)	(10.0)
% change over non-IPM	-6.2	-4.1	-4.6*	-4.4

Figures in parentheses are standard deviations

***, ** and * significant at 1, 5 and 10 percent level respectively

IPM farms. Cost of cabbage production with IPM was also less by 4.4 percent.

Less cost of production on IPM farms was mainly on account of the low cost of plant protection. In the case of cotton, plant protection cost with IPM was less by 10 percent, compared to without IPM. In the case of paddy, reduction was about 32 percent.

The main implication emerging from the analysis of the cost structure is that, IPM does not demand additional resources and also does not cause any significant change in the cost structure. Further, the reduction in the cost due to IPM does not reduce crop yields. In the initial stages of IPM implementation, one should not expect substantial yield or cost advantage because of a number of operating constraints, like inadequate supply of biological inputs, lack of information on tools and methods of IPM, slow kill efficiency of biological inputs in an environment dominated by chemical pesticides, market imperfections, etc. Its wide scale adoption is expected to effect further improvements in its efficacy.

Gross and net returns

With positive effect on the crop yield, and reduction in the cost of protection IPM is expected to yield higher net returns, compared to the conventional chemical control. The returns from the application of IPM could be even more if there were a premium price for IPM produced crops[12] . This, however, was not observed here. Table 7.6 gives estimates of the gross and net returns with and without IPM.

Application of IPM in cotton generated gross returns worth Rs30201/ha, which is higher by Rs1081/ha than without IPM. On accounting for the cost differences, the net returns increased to Rs1531/ha. In other words, IPM farmers could realize 9.2 percent additional revenue over their non-IPM counterparts. The difference is statistically significant at 10 percent level.

Table 7.6: Gross and net returns with and without IPM (Rs/ha)

Returns	Gross returns	Variable cost	Net returns
Cotton			
IPM	30201 (6583)	12090 (3452)	18111 (6629)
Non-IPM	29120 (5660)	12540 (4351)	16580 (6035)
% change over non-IPM	3.7	-3.6	9.2
Paddy			
IPM	24141 (1892)	11480 (2017)	12661 (2629)
Non-IPM	23256 (1438)	11592 (2059)	11664 (2222)
% change over non-IPM	3.8	-1.0	8.5
Cabbage			
IPM	42611 (3305)	24049 (4482)	18562 (4812)
Non-IPM	40575 (4139)	24022 (4864)	16553 (5602)
% change over non-IPM	5.0***	0.1	12.1**

***, ** and * significant at 1, 5 and 10 percent level respectively
Figures in parantheses are standard deviations.

[12] In developed countries IPM produced crops are generally free from pesticide residues and command a premium price.

Gross value of the paddy produced with application of IPM was Rs24141/ ha. This was higher by Rs885/ha than without IPM. Further, the addition of the cost saved due to IPM, increased this difference to Rs997/ha. On the whole, the application of IPM increased the net revenue by 8.5 percent, which is significantly different from the one realized without IPM.

Application of IPM in cabbage also generated higher returns. Value of the cabbage output with IPM was estimated worth Rs 42611/ha, compared to Rs 40575/ha without IPM. The net returns over variable cost were Rs18562/ ha with IPM, and Rs16553 without IPM. Thus, the adoption of IPM yielded net benefits worth Rs2009/ha, which are significantly higher than without IPM.

These results establish that IPM has the economic potential to substitute the chemical pesticides without demanding any additional resources and affecting the crop yield. This advantage is largely due to the better pest control efficacy of IPM. A full accounting of the costs and the benefits of IPM in terms of its positive externalities to the environment and public health would further improve its benefit-cost ratio.

7.2 Aggregate Economic Effects

Farm level economic benefits of IPM can be scaled-up to the regional level by multiplying the per ha net benefits from IPM and the area on which it is applied This ,however, does not properly characterize the benefits as this considers only the supply-side aspects. Demand related factors are also equally important while assessing the impact. The economic surplus approach considers both the supply and demand factors influenced by the technological change, and distributes the gains from the technology adoption between the consumers and the producers.

Target domains for scaling up the effects of IPM technologies were delineated considering the homogeneity in agro-climatic conditions. For cotton, the target domain comprises six districts of Tamil Nadu viz. Coimbtore, Dindigul, Erode, Madurai, Puddukottai and Trichy. These districts together have about 74 thousand ha of area under cotton. The target domain for the paddy IPM includes districts of Thanjavur, Thiruvarur and Nagipatinum, with a paddy area of 494 thousand ha. The districts of

Dharmapuri, Salem and Namakkal with an area of 0.8 thousand ha under cabbage comprise the target domain for cabbage IPM. Values of the parameters[13] used in the estimation of economic surplus are given in Table 7.7.

Table 7.7: Values of parameters used in estimation of economic surplus

Parameter	Cotton	Paddy	Cabbage
Area under crop (000ha)	73.8	493.7	0.81
Proportion of area under IPM	0.268	0.375	0.242
Proportionate change in unit cost	-0.0684	-0.0409	-0.0442
Elasticity of supply	0.43	0.32	0.21
Elasticity of demand	-0.59	-0.28	-0.78

Note: Estimates of demand elasticity of cotton have been taken from Gulati and Kelley (1999) and of rice and cabbage from Kumar (1998). Estimates of supply elasticity of cotton have been taken from ICRISAT-ICAR (1999), of paddy from Gulati and Kelley (1999) and of cabbage from Saleth (1999).

Application of IPM in cotton could generate economic surplus worth Rs8695 thousands, of which the producers shared 42 percent (Table 7.8). In the case of paddy it could generate surplus worth Rs89913 thousands, which was shared equally between the producers and the consumers. The economic surplus from application of IPM in cabbage was estimated Rs653 thousand, and most of it accrued to the producers (79%).

Table 7.8: Effect of IPM on producer and consumer surplus (Rs000)

Surplus	Cotton	Paddy	Cabbage
Total surplus	8695	89913	653
Producer	5029	41959	515
surplus	(57.8)	(46.7)	(78.9)
Consumer	3666	47954	138
surplus	(42.2)	(53.3)	(21.1)

[13] No estimates of demand and supply elasticity of cabbage were available. Elasticity of demand for vegetables is assumed to be the elasticity of cabbage, and elasticity of supply has been assumed that of green chilies.

7.3. Sensitivity of IPM Effects to The Changes in The Input Prices

7.3.1 Prices of biological pesticides

Economic feasibility analysis until now was based on the actual prices of the biological pesticides borne by the farmers. Prices, however, vary depending on the source of procurement. The prices of the inputs procured from the public sector supply system are generally lower than their market prices. Thus, the cost estimates presented in the previous section were underestimates. This section examines the sensitivity of IPM effects to the changes in the prices of biological pest management inputs.

Table 7.9 presents the shares of the public and the private sectors in the supplies of biological pesticides, and the prices thereof. In the cotton production system, bulk of the *Trichogramma*, NPV and pheromone traps were supplied by the public extension system. In the paddy system, farmers procured the entire supply of neem oil, and two-third of the neem based pesticides from the public extension agencies. Cabbage farmers acquired 88 percent of the Bt supply from the private input dealers, and 90 percent of the neem oil supply from the public extension system.

Table 7.9: Supply of biological pesticides and their prices

Biopesticide	Unit	Market price	Govt. price	Average price	Share of public sector in total supply (%)
Cotton					
Trichogramma	Rs/cc	17	7	10	75
NPV	Rs/100LE	159	130	142	58
Neem pesticides	Rs/litre	280	200	268	17
Paddy					
Neem pesticides	Rs/litre	280	200	234	63
Neem oil	Rs/litre	205	148	148	100
Cabbage					
Bt	Rs/kg	797	610	775	12
Neem oil	Rs/litre	205	148	153	91

Prices of the inputs procured from the public extension system and from the market differed considerably. Market price of *Trichogramma* was 2.4 times higher than the one charged by the public extension system. NPV procured from the market was costlier by 22 percent. Neem oil and neem pesticides were costlier by 36-38 percent. These differences will influence the unit cost of production, and thereby the economic effects of IPM. The sensitivity of the farm level and aggregate effects of IPM is, therefore, examined under the subsidized and market price situations.

7.3.2 Farm level effects

At market prices, the cost of cultivation of cotton increases by 11.1 percent over the existing cost (Table 7.10). This makes IPM slightly costlier than the chemical pest control. The cost of production increases from Rs850/q to Rs872/q. The net return advantage over the chemical control declines from 9.2 percent to 7.7 percent. At the subsidized input prices, the cost of cultivation reduces by 4.4 percent over the existing average prices. The cost advantage over chemical control increases from 6.7 percent to 10.8 percent, and the net return advantage increases to 10.0 percent from 9.2 percent. The cost of production declines to Rs841/q. This is less by Rs31/q than at the market prices.

Raising prices of the neem products to the level of market prices would increase the cost of paddy IPM by Rs38/ha. Yet, it is cheaper by 26 percent, compared to the chemical control. The profitability of IPM over the chemical control declines from Rs997/ha to Rs959/ha. At market prices, there is marginal increase in the cost of production. While at the subsidized prices, cost of IPM is reduced by Rs26/ha. The cost of production also declines. Per hectare cost of IPM at subsidized prices is less by Rs72, compared to the market prices.

Application of biological pesticides (Bt and neem products) in cabbage, at market prices, adds Rs129/ha to the existing cost of IPM. Existing cost disadvantage over chemical control increases from Rs34/ha to Rs163/ha, and net returns decline by Rs156/ha. Unit cost of production increases by Rs0.3/q. At the subsidized prices, the cost of pest control and the total variable cost on IPM farms decline by 6.1 and 1.8 percent, respectively. This renders IPM application cost-effective, compared to the chemical control (Rs399/ha). Unit cost of production declines to Rs50.7/q.

Table 7.10: Farm level impact of changes in prices, and supply arrangements of biopesticides

Impact	Existing average price situation		Market price situation		Subsidized price situation	
Cotton	IPM	Non-IPM	IPM	Non-IPM	IPM	Non-IPM
Cost of pest control (Rs/ha)	2846	3050	3163 (11.1)	3111 (2.0)	2722 (-4.40)	3050 (0.0)
Total cost (Rs/ha)	12090	12540	12407 (2.6)	12601 (0.5)	11966 (-1.0)	12540 (0.0)
Net returns (Rs/ha)	18111	16580	17794 (-1.8)	16519 (-0.4)	18235 (0.70	16580 (0.0)
Unit cost (Rs/qtl)	849.6	912.0	871.9 (2.6)	916.4 (0.5)	840.9 (-1.0)	912.0 (0.0)
Paddy						
Cost of pest control (Rs/ha)	657	940	695 (5.8)	940 (0.0)	623 (-5.2)	940 (0.0)
Total cost (Rs/ha)	11480	11592	11518 (0.3)	11592 (0.0)	11446 (-0.3)	11592 (0.0)
Net returns (Rs/ha)	12661	11664	12623 (-0.3)	11664 (0.0)	12695 (0.3)	11664 (0.0)
Unit cost (Rs/qtl)	241.3	251.6	242.1 (0.3)	251.6 (0.0)	240.6 (-0.3)	251.6 (0.0)
Cabbage						
Cost of pest control (Rs/ha)	7092	7058	7221 (1.8)	7058 (0.0)	6661 (-6.1)	7058 (0.0)
Total cost (Rs/ha)	24049	24022	24178 (0.5)	24022 (0.0)	23623 (-1.8)	24022 (0.0)
Net returns (Rs/ha)	18562	16553	18433 (-0.3)	16553 (0.0)	18988 (2.3)	16553 (0.0)
Unit cost (Rs/qtl)	51.6	54.0	51.9 (0.5)	54.0 (0.0)	50.7 (-1.8)	54.0 (0.0)

Figures in parentheses indicate % change over existing price scenario

7.3.3 Aggregate economic effects

Effects of the changes in prices of the biological pesticides on consumer and producer surplus are presented in Table 7.11. At the market prices, the total surplus declines by 29 percent, while at the subsidized prices it increases by 15 percent. The difference in the surplus at the subsidized and the market prices is 63 percent.

In the case of paddy, at the market prices, the existing surplus declines by 8 percent, while at the subsidized prices it increases by 7 percent. The

Table 7.11: Market level impact of changes in prices and supply arrangements of biological pesticides

Surplus	Cotton	Paddy	Cabbage
Existing supplies and prices			
Total surplus	8695	89913	653
Producer surplus	5029	41959	515
Consumer surplus	3666	47954	138
Entire supply at market prices			
Total surplus	6174	82871	580
	(-28.4)	(-7.8)	(-11.2)
Producer surplus	3571	38673	457
Consumer surplus	2603	44198	123
Entire supply at subsidized prices			
Total surplus	10033	96078	907
	(15.4)	(6.9)	(38.9)
Producer surplus	5803	44835	715
Consumer surplus	4230	51240	192

Figures in parentheses are percent change over existing surplus.

difference in the total surplus with and without subsidized prices is 15 percent.

With the entire supply of biological pesticides coming at the market prices, the cabbage surplus is reduced by 17 percent. Provision of subsidies on the biological pesticides adds 39 percent to the existing surplus. This is 56 percent higher than the market prices.

These finding indicate that at the existing prices of bisopesticides, IPM is marginally profitable. That means input prices will be one of the key determinants of the adoption of IPM. An increase in the prices of biological pesticides would erode farm profitability, and would act a disincentive to their adoption. However, considering its social and environmental benefits, it is appropriate to encourage farmers to adopt IPM as a cardinal principle of plant protection, as well to the industry to invest in the production and promotion of the biological pesticides through price and non-price incentives.

8 COLLECTIVE ACTION IN PEST MANAGEMENT

Pest has the characteristics of a detrimental common property resource (Regev et al., 1976). It does not recognize the spatial and the temporal boundaries (Ravnborg et al., 2000), and its repercussions are felt area wide. That means effective pest control requires collective efforts. Yet most of the times, pest control efforts are individualistic, resulting into low pest control efficiency and higher cost of control.

Collective pest management assumes greater significance in the context of IPM. IPM technologies are derivatives of living organisms. These are host specific and slow in action, and their pest control efficacy is adversely affected on the use of chemical pesticides in the vicinity. Collective approach to pest management internalizes the externalities of chemical pesticides as well improves the efficacy of pest management. It also generates economies of scale by lowering the transaction cost of information search and acquisition, and the operational cost of control (Rook and Carlson, 1985; Collins, et a1.,1999). In this chapter, we analyze farmers' subjective perceptions on the benefits of collective pest management, their willingness to participate in it, and identify the factors restricting emergence of collective action.

8.1 Farmers' Perceptions Regarding the Benefits of Collective Action

Whether to participate in collective action or not is the decision of an individual farmer. But, the sum of the individual decisions has collective consequences (White and Runge, 1994). Lack of a collective approach results in inadequate pest management, while collective action yields better pest control and at reduced costs. The necessary condition for the voluntary participation is, thus, individual's expectation about the net benefits from the collective action. To elicit this information, farmers were asked to indicate the benefits they perceived from the participation in the collective action.

Table 8.1: Farmers' perceptions on benefits of collective pest management (%reporting)

Type of benefit	Cotton		Paddy		Cabbage	
	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters
Reduction in cost of control	48.8	41.7	47.5	39.0	62.9	60.0
Access to information at reduced cost	16.3	22.2	42.5	29.3	42.9	40.0
Low yield loss due to pests	47.2	48.8	40.0	29.3	48.6	45.7
Do not know	20.9	16.7	12.5	14.6	8.6	14.3

The respondents envisioned three main advantages of collective action. These include better control of insect pests (saving in yield loss), reduction in pest control costs and improved access to pest management information at reduced cost. Farmers appeared to possess a good understanding of the benefits of collective pest management. The most commonly perceived benefit of the collective approach was the better pest control efficacy (Table 8.1). Reduction in pest control cost was rated second, and the enhanced access to pest management information and at reduced costs was the next.

8.2 Willingness to Participate in Collective Action

Despite high degree of awareness of the benefits of collective pest management among the farmers, it rarely exists in practice. A number of socio-economic, psychological, institutional and technological factors deter farmers to participate in the collective action. Pest management encompasses a number of direct and indirect pest limiting interventions like crop rotation, use of resistant variety, plant spacing, intercropping, synchronicity in sowing operations, avoidance of indiscriminate use of pesticides, use of biopesticides, synchronicity in pest control operations, manual collection of insect larvae, etc. So the collective action covers a wide range of activities. Besides, the collective action also requires financial commitments from the participants to meet the operational expenses collectively.

Whether a farmer would choose to participate in some or all the activities related to collective action would depend on the nature of the activities and their resource requirements. Table 8.2 shows farmers' willingness to participate in different pest management activities. In general, willingness to participate was strong in the case of indirect pest control activities; an overwhelming majority of the cotton farmers was willing to avoid continuous cropping, follow appropriate crop rotations and intercrops, do dry period ploughing, grow border or trap crops, undertake field sanitation, grow recommended crop variety and follow synchronicity in the sowing. There was marginal, if any, difference in the responses of IPM and non-IPM farmers. Similarly, the cabbage farmers' participation rate in most of these activities was also quite high. However, the adopters of IPM exhibited higher willingness to participate. This is because, many of the agronomic activities outlined above are followed by a majority of the farmers as routine farm management practices, and need only slight readjustments as per the requirements of collective action. In the paddy region, farmers' willingness to associate with the group for these activities was not as high as in the cotton and the cabbage regions. This was because of differences in the

Table 8.2: Farmers' willing to participate in collective pest management activity (%)

Activity	Cotton		Paddy		Cabbage	
	Adopters	Non-adopters	Adopters	Non-adopters	Adopters	Non-adopters
Indirect						
Avoid continuous cropping	90.7	77.8	40.0	22.0	40.0	22.9
Follow crop rotation	95.3	88.9	60.0	61.0	74.3	54.3
Follow dry period ploughing	95.3	88.9	62.5	51.2	77.1	74.3
Synchronicity in sowing	79.1	75.0	40.0	61.0	85.7	74.3
Use resistant variety	67.4	80.6	62.5	56.1	51.4	22.9
Follow proper plant spacing	95.3	94.4	60.0	34.1	77.1	82.9
Grow inter/trap/border crops	95.3	88.9	12.5	17.1	48.6	40.0
Keep field clean	95.3	88.9	97.5	95.1	100.0	91.4
Direct						
Judicious use of pesticides	100.0	47.2	97.5	39.0	57.1	51.4
Use biologicals	100.0	61.1	100.0	34.1	100.0	51.4
Collect insect larvae	97.7	88.9	15.0	4.9	5.7	0.0
Expenditure sharing						
Transaction costs	76.7	77.8	92.5	61.0	60.0	42.9
Expert services	60.5	52.8	90.0	87.8	100.0	80.0

agro-climatic conditions and the nature of the crops grown. For instance, in the paddy system growing two crops of paddy in a year is a common practice, and this limits synchronicity in indirect pest management activities.

Farmers evinced keen interest to cooperate in the direct pest control activities. In the cotton system, a majority of farmers was willing to avoid indiscriminate use of chemical pesticides and substitute these with biological products. They were also willing to practice manual insect control and observe synchronicity in the pest management operations. So were the cabbage and paddy farmers. However, compared to IPM farmers, the non-IPM farmers were less willing to cooperate in these activities. Another dimension of the collective action is sharing of the costs of information search, acquisition and dissemination, and expert services by the participants. Except in the cotton system, considerably higher proportion of the farmers was willing to contribute towards these costs.

8.3 Identifying Conditions for Collective Action : Ordered Probit Model

8.3.1 Selection of variables

The above findings indicate prevalence of a latent potential for the collective pest management. However, this could not be translated into reality because of a number of social, economic, psychological and institutional constraints. In order to identify the factors constraining the emergence of collective action in pest management, ordered probit and OLS models were estimated with 'willingness to participate' as dependent variable.

Since collective action encompasses a number of activities, a composite index of willingness to participate can be constructed by summing up the number of activities in which a farmer is willing to participate. But, this attaches equal weights to all the activities, and does not reflect their relative importance. In order to account for the relative importance of different pest management activities a weighted index of the willingness to participate was constructed by assigning suitable weights to different activities. The weights were devised on a scale of 1 to 4 after consultations with entomologists, agronomists and economists.

Sharing of the costs of information search, acquisition and dissemination, and the cost of hiring of the expert services were identified as the most important activities from the point of view of sustainability of the collective approach. Therefore, these were assigned a weight of 4. Direct pest management activities- the avoidance of excessive and indiscriminate use of pesticides and the use of biological pesticides ranked next, and each of these was assigned a weight of 3. The former reflects the concerns of the negative externalities of the chemical pesticides, while the latter indicates farmer's willingness to adopt new technologies. Other direct pest control activities were assigned a weight of 2. Indirect activities were assigned a weight of 1. The weighted index of the willingness to participate was obtained as follows:

$$I_j = (w_i A_{ij}) / \sum w_i$$

Where I_j is the index of willingness of participation of j^{th} respondent. A_{ij} is the i^{th} activity in which the j^{th} respondent is willing to participate, and w_i is the weight of the i^{th} activity.

A number of factors are hypothesized to influence the willingness to participate. These include decision-maker's personal and household characteristics, pest management technology followed, awareness about the negative effects of the pesticides, decision makers' perceptions regarding the benefits of the collective action and the social impediments to collective action.

The success or the failure of any cooperative venture, to a large extent, is determined by the degree of social cohesiveness. Greater the cohesiveness, higher is the probability of success. The Indian rural society is socially and economically differentiated. Social differentiation is a result of different castes and religions of the potential participants, while the economic differentiation results from the inequities in the distribution of resources. It is expected that a high degree of social and economic heterogeneity would have a dampening effect on farmers' willingness to participate in the collective action. Farmers' subjective perception regarding the social heterogeneity is defined as a dichotomous variable, that takes a value of 1 if the respondent considered lack of cooperation among the farmers as a deterrent to the collective action, and a value of 0, otherwise.

Size of land holding is a proxy for economic heterogeneity. In the context of pest management, this also reflects differences in the farmers' capacity to invest in pest management technologies and to withstand pest risks. It is hypothesized that the farmers with higher capacity to invest, and to withstand pest risks assign higher value to long-term benefits of the collective action, and therefore would have a greater propensity to participate in it. The collective efforts may be adversely affected if the land holdings are highly fragmented. Non-participation by some tantamounts to the reduced effectiveness of pest control measures. In other words, the problem of free riding cannot be ruled out. Fragmentation may also encourage collective action because of latter's benefits of economies of scale. The effect of land fragmentation is, thus, indeterminate a priori.

To ensure synchronicity in the application pest management technology, collective action requires timely availability of labour. Pest control activities start from the seedbed preparation and last beyond the harvesting of the crop. For instance in the case of cotton pest management, collection and destruction of stalks is an important activity, and non-performance by any one due to labour constraint may diminish the spirit of collective action. The probability of willingness to participate in collective action is expected to be higher among the households having higher labour endowment in relation to land.

Further, the technology of the pest control might itself require collective action to realize its full potential (McCulloch, et al., 1998). Though, collective action is a must for the success of any pest management technology, yet there are technologies that demand greater cooperation for realizing their full potential. For instance, most of the biological pesticides are sensitive to chemicals and their efficacy is adversely affected on application of chemical pesticides in the vicinity. The users of the biological pesticides would, therefore, expect others also to apply biological pesticides. The users are, thus, anticipated to exhibit higher willingness to participate in the collective action. A dichotomous variable with a value of 1 for users of biological pesticides, and a value of 0 for non-users is used in the model.

Personal characteristics of the decision-maker such as, age and education influence their attitudes towards collective action. A priori, effect of age is indeterminate. Age of the decision maker may have both a positive and negative impact on their willingness to cooperate. Younger farmers have a long planning horizon and are expected to be more cooperative. While, the older farmers may or may not be willing to participate in the collective action depending on their past experience in such activities. Likewise, education can have both a positive as well as negative influence on the willingness to participate. A farmer with higher education is anticipated to have a better understanding of the pest and pest related problems and, therefore, an inclination toward participation in the collective pest management. At the same time, an educated farmer also has better access to pest related information and might prefer individual approach rather than the collective one if the social conditions for the latter are not conducive.

Besides, farmers' subjective assessments of the economic and environmental benefits of collective action would also influence their willingness to participate. Two sets of explanatory variables are included in the model to capture these effects. The first set (i.e. direct economic benefits) includes farmers' subjective assessment of the reduction in the cost of pest control inputs, saving in cost of information search and acquisition, and yield advantage. It is hypothesized that these factors are positively related to the participation decisions. Collective action reduces transactions and operational costs of pest management to the individuals (Rook and Carlson, 1985). Pest is a common problem, so are its solutions. In other words, there is a commonality in the pest related information that farmers need. Thus, the acquisition of the common information by the group entails a significant reduction in search and acquisition cost of the information. Besides, the synchronicity in the pest control operations reduces operational cost by reducing the pesticide/biopesticide drifts and the inter-farm pest mobility. Reduction in the inter-farm pest mobility implies better pest control and thereby the higher crop yield. Farmers' subjective perceptions of these variables are defined as dichotomous, that take on a value of 1 if the farmer considered these as benefits of the collective action, and a value of 0, otherwise. Another set of variables relates to the farmers' awareness of the technological failure of chemical pesticides and their externalities to the ecology and human health. Farmers' awareness of these is hypothesized to encourage collective action because of the latter's capacity to internalize such externalities through judicious applications of chemical pesticides and appropriate technologies. Four awareness variables viz., the technological failure of pesticides, externalities to ecology, externalities to human health to pesticide exposure and the pesticide residues in food, were constructed to examine whether these influence farmers' willingness to participate in the collective action. Technological failure of pesticides includes development of pest resistance, resurgence and secondary outbreak. Indiscriminate and excess use of chemicals reduces populations of the natural enemies of insect pests, beneficial insects and soil microorganisms. Human health externalities include effects on the eye, skin, gastro-intenstinal system, cardiovascular system, muscular system and respiratory system. Indirect effect of the pesticides on human health is through their entry into food chain i.e. residues of the pesticides in food. Each of these variables is in the form of an additive awareness score i.e., summation of a farmer's response to an externality.

8.3.2 Model results

Empirical results of the probit and OLS models are given in Table 8.3. The threshold coefficient for the probit model is positive and significant at less than one percent level, implying that there is no specification error in the model. The results show that social heterogeneity (lack of cooperation) has a negative influence on the individual's willingness to participate in the collective action, and the effect is highly significant. Marginal effect of the increase in the social heterogeneity is also quite large for the farmers' towards higher end of the willingness index (29%). This shows that farmers view social cohesion as a critical condition in initiating the collective action.

Coefficient of the land holding size is positive, but insignificant. The marginal effect is also small. Thus, the distribution of land (economic inequality) does not appear to constrain farmers to participate in the collective action. The coefficient of the land fragmentation is also positive and insignificant. The probability of participation of those exhibiting higher willingness to participate increases by 6 percent with one unit increase in the land fragmentation. The inequality in the family labour endowment too does not affect farmers' willingness to participate in a significant manner.

Personal characteristics of the decision makers do not influence their participation decisions significantly. Marginal effects of these variables are

Table 8.3: Determinants of willingness to participate in collective pest management

Explanatory variables	Ordered probit estimates		OLS estimates
	Coefficient	Marginal effect (for index value of 2 or more)	
Personal characteristics			
Age (years)	-0.0032 (0.0119)	-0.0010	-0.0032 (0940)
Years of schooling	0.0058 (0.239)	0.0018	0.0024 (0.303)
Farm characteristics			
Size of land holding (acres)	0.1860 (0.454)	-0.0059	-0.0008 (0.132)
No. of fragments	0.1864 (1.149)	0.0592	0.0352 (0.874)
No. of adult workers/acre	0.1210 (0.468)	0.0384	0.0038 (0.066)
Pest control method			
IPM=1, otherwise=0	1.2810 (3.509)***	0.4068	0.3756 (5.681)***
Lack of cooperation			
Yes=1, otherwise=0	-0.9242 (4.854)***	-0.2935	-0.2987(5.396)***
Awareness of pesticide externalities (score)			
Technological failure	-0.3637 (3.933)***	-0.1155	-0.6405 (2.56)**
Ecological ill effects	-0.0445 (0.425)	-0.0141	-0.0444 (1.473)
Health impairments	0.1395 (1.661)*	0.0443	0.0306 (1.347)
Pesticide residues in food	0.0628 (1.134)	0.002	0.0043 (0.272)
Perceptions on benefits of collective action			
Reduction in cost of control			
Yes=1, otherwise=0	0.5484 (2.830)***	0.1741	0.1913 (3.393)***
Access to information at reduced cost			
Yes=1, otherwise=0	1.2403 (4.673)***	0.3939	0.3036 (4.955)***
Low yield loss due to pests			
Yes=1, otherwise=0	0.9742 (4.070)***	0.3094	0.2738 (4.366)***
Crop system			
Cotton=1, otherwise=0	2.9741 (9.436)***	0.9445	0.8599(11.538)***
Cabbage=1, otherwise=0	0.5754 (1.7530)*	0.1827	0.1260 (1.457)
Threshold coefficient (MU)	2.8598 10.921)***		
Constant	0.1283 (0.162)	0.0407	1.2464 (6.055)***
Log-likelihood function	-120.798		
Restricted log-likelihood	-223.482		
Chi-squared	205.368		
R-squared			0.6483
Adjusted R-squared			0.6219
F-value			24.54
No. of observations	230		230

***, ** and * significant at 1, 5 and 10 percent level respectively

Figures in parentheses are t-values.

also small. This implies that farmers, irrespective of their personal traits, are aware of the transboundary nature of the pests and their damage potential, and therefore they would cooperate in the collective pest management efforts.

Coefficients of the variables reflecting economic benefits of the collective action are positive and significant at less than one percent. These are not unexpected. Collective action reduces the operational and transaction costs of pest control for individual farmers, as well as improves efficiency of pest control. Among these, reduction in the transaction costs of information appears to be the most important motivating factor. Reduction in the crop damage is the next important economic factor. Reduction in the operational cost of pest control, however, is not as important. Marginal effects of the changes in these variables are quite strong. The probability of participation increases by 17, 31 and 39 percent, respectively with one standard deviation increase in the value of these variables. The ranking of these effects is also not unexpected. Individuals lack information on the pest management and incur considerable expenses towards information search and acquisition. Such costs are considerably reduced for the individuals when the information is obtained and used collectively. The technological failure of pesticides results in increased cost of pest control, but without corresponding reduction in the crop damage. Farmers value collective pest management for its better pest control efficiency, even if there were not much saving in the operational cost of pest control.

Effect of the technology of pest management on the willingness to participate is fairly large. As expected, the adopters of IPM exhibit significantly higher willingness to participate. The probability of participation is likely to increase by about 41 percent with one standard deviation increase in the number of adopters of IPM. This implies that making farmers adopt IPM would itself motivate them to cooperate in pest management.

Effects of environmental indicators on the farmers' willingness to participate in the collective action are mixed. Greater awareness about the technological failure of chemical pesticides affects the willingness to participate adversely. Similar results are observed for the ecological externality. These are unexpected, and perhaps could be due to high degree of risk aversion among the farmers. On the other hand, likelihood of participation in the collective action increases with rising public concerns for food safety and human health.

Likelihood of participation in the collective action varies across crop systems. Potential for collective action is significantly higher in the cotton production system. This is also higher in the cabbage production system. This is because, the cotton and cabbage crops are highly prone to a number of insect pests and diseases, which cause considerable damage. Comparatively low potential for the collective action in the paddy system is because of the intensive paddy cropping, and the less pest menace.

The analysis supports the hypothesis that social cohesiveness is critical to emergence of collective action. Heterogeneity is an important characteristic of any society; and a complete cohesiveness is difficult to achieve. However, the rational economic self-interest of different groups could motivate them to join together for the pest management. In particular, the perceived cost economies and yield benefits have significant influence on the farmers' willingness to participate in the collective action. Other economic and demographic factors also do not appear to constrain emergence of the collective action. Further, the results suggest that collective action would be driven by the type of pest management technology. Adoption of technologies such as biological pesticides that require group action for realization of their benefits would act as catalyst in making collective action a reality.

9 CONCLUSIONS AND IMPLICATIONS

By 2030, food grain production in India has to increase at least 2 million tonnes a year to meet the food security needs of the growing population. In the past growth in production resulted from both the area expansion and the yield improvements. Now the prospects of increasing agricultural production through area expansion are severely constrained. The land frontiers are closing down. Green revolution technologies that contributed to the increased agricultural production have now been widely adopted, and the process of diminishing returns to additional input use has set in. The possibilities of additional production from the application of existing technologies thus also appear to be limited. The future growth in food production has to come from yield-enhancing/saving technologies.

Insect pests, diseases and weeds cause considerable loss to the potential agricultural production. Though, the loss cannot be eliminated altogether, reducing these can make important contribution toward achieving the required growth in agricultural production. Farmers, ever since the introduction of green revolution technologies, have increasingly relied on the chemical pesticides to limit the crop loss. Yet, the losses have persisted partly due to technological failure of chemical pesticides. Pest problem too multiplied due to the changes in the production systems (monocropping, decline in crop rotation, reduction in biodiversity, etc) induced by higher profitability of new technologies. Besides, chemical pesticides are a threat to public health and environment.

New biological pest management technologies have been proposed for long. These provide effective solutions to the pest problems, and are benign to ecology and public health. A number of microorganisms and plant species have been identified for their potential use in pest management. Many of these have been standardized into technologies, and some of these like Nuclear polyhedrosis virus, *Trichogramma*, *Bracons*, *Trichoderma*, *Bacillus*, neem products, etc., when integrated with other methods of pest management (IPM) have been proven for their technical efficacy under experimental conditions.

Despite their potential to reduce chemical pesticides, their commercialization and use has remained restricted owing to a number of operating constraints. One of the reasons is the lack of a sound economic analysis of their production and use. Technologists often judge the performance of technology in terms of physical performance (crop yield), which is a necessary, but not a sufficient condition for its commercialization, and use. Biological pest management technologies generate considerable social and environmental benefits, but these are often heavily discounted in the developing countries. The sufficient condition for offtake of a technically efficient IPM technology by the stakeholders is the adequate returns to the investment made in its production and use. This study has attempted to investigate whether the biological pest management technologies have economic potential to substitute the chemical pesticides using experimental and survey data.

Experimental data used to examine the technical and economic efficacy of different methods of pest control were compiled from the annual reports of the Project Directorate on Biological Control (PDBC), Bangalore. PDBC conducts multi-location trials to test the efficacy of different pest management options on a number of crops. After careful screening of the data, we selected three crops viz., cotton, paddy and chickpea for analysis, for which the required information was consistently available for a period of 3-8 years.

Technical performance of different pest management options under experimental conditions, measured in terms of loss avoided, was variable across crops and regions. Technical efficacy of the biological control and IPM in cotton was higher than that of the chemical control in Gujarat and Tamil Nadu, while in Punjab the performance of these options was poor, compared to the chemical control. In Gujarat and Tamil Nadu, economic efficacy of both biological control and IPM was also better. In Punjab, biological control and IPM were not remunerative. The type of biopesticide used appeared to be an important determinant of technical as well as economic efficacy of these options. For instance, use of *Crysoperla* in biological control and IPM was more effective in limiting the yield loss, compared to others. But, its use was uneconomical because of its higher price.

Technical performance of the biological control in paddy in Tamil Nadu was almost at par with that of chemical control, while in Punjab the chemical control was technically more efficient. At both the places, biological control was economically unattractive due to its lower technical efficacy and higher cost of application. However, wherever IPM was experimented it proved better than the biological and the chemical controls.

Technical efficacy of the biological control in chickpea was almost at par with that of chemical control. IPM proved to be the best option in terms of its potential to save yield loss. Economic efficacy of IPM was also better, compared to the biological and chemical controls.

The results from the experimental data were supplemented with field investigations conducted in three districts viz., Coimbatore, Thanjavur and Dharmapuri of Tamil Nadu. Crops selected were: cotton from Coimbatore), paddy from Thanjavur and cabbage from Dharmapuri. Besides, efforts were also made to understand the process of adoption of the new pest control technologies.

Field investigations indicated application of biological pest management technologies (IPM) on 27 percent of the cotton area, 37 percent of the paddy area and 24 percent of the cabbage area. *Trichogramma chilonis*, NPV and neem products were the main biological technologies used in cotton production. Neem products were used in paddy, and *Bacillus thuriengensis* and neem products were applied on cabbage. An overwhelming majority of the farmers, both the users and the non-users of biological technologies, have been using a number of cultural and mechanical methods, which now comprise components of IPM.

Farmers were aware of the biological pest management technologies, as well as the drawbacks of the existing technologies. A number of factors influenced adoption of IPM technologies. Farmers, with higher education level and better land and labour resources, exhibited a greater tendency to adopt IPM technologies. While the fragmentation of land holdings acted as a disincentive to adoption of IPM. Farmers were aware of the negative externalities of chemical pesticides, but these did not influence their adoption decisions in a significant manner.

Farmers encountered a number of problems in switching over from the chemical control to IPM. Adequate and timely supply of the biological pesticides, and the lack of timely expert advice were the main impediments. Besides, the slow effect of biological pesticides was one of the major technological problems. A majority of the non-adopters was aware of the biological pest management technologies, but they did not use these due to one or another reason. Nevertheless, they were willing to adopt these technologies provided these provide protection against a wide host range of the insect pests, have a better pest killing efficiency, are available in the right quantity and at the right time, and are cost effective. Besides, they also need more information on the biological pest management in respect of the target pests of the technology and its method of application.

IPM technologies were evaluated for their impact on pesticide use, yield, cost and return. Application of IPM technologies could curtail pesticide use substantially, and without any adverse effect on the agricultural productivity. Reduction in pesticide use was 66 percent in cotton, 45 percent in cabbage, and in paddy it could be reduced to almost zero. Yield advantage due to IPM was 4 percent in cotton, 3 percent in paddy and 5 percent in cabbage.

IPM was also cost-effective. Total cost of pest control with IPM in cotton was about 7 percent less. It was less by about 30 percent in paddy. Unit cost of production was less by 7 percent in cotton, 4 percent in paddy and 5 percent in cabbage. Lower unit cost of production was mainly due to higher yield saving potential of IPM. Net benefits realized with IPM were Rs1531/ha in case of cotton, Rs997/ha in case of paddy and Rs2009/ha in case of cabbage. These indicate that adoption of biological pest management technology results in higher profitability without demanding any additional financial resources.

Farm level effects of IPM when scaled up at the regional level generated considerable economic benefits to the producers as well as to the consumers. Sharing of the benefits, however, varied across crops depending on the level of adoption of IPM, its cost effectiveness, and demand and supply elasticities of the crops under consideration. About half of the benefits of adoption of IPM in cotton, 47 percent in paddy and 79 percent in cabbage accrued to the producers. At present, farmers obtain biological pest management technologies from both the public and private sources. For some technologies, the private sector is the dominant supplier and for others the public sector. The supplies from the latter are cheaper. The sensitivity of farm and market level welfare effects was tested to the changes in the prices of the technologies used by the farmers. Results indicated that raising prices to the market level would reduce the profitability of IPM, while the subsidization of technologies would generate substantial benefits to the producers as well as the consumers.

As the pests do not recognize the spatial and seasonal boundaries, effectiveness of IPM can be improved if the pests were managed area-wide and collectively. But, farmers rarely adopt collective approach. A majority of the farmers, however, was aware of the benefits of collective action, and was also willing to participate in one or other pest management activities, given appropriate socio-economic and institutional environment. Social heterogeneity was the main hindrance to emergence of collective pest management. However, the results suggest that farmers' rational economic self-interest would motivate them to join together to check the pest menace. In particular, the cost economies and yield advantage would impel farmers to participate in collective action, irrespective of their resource endowments and demographic characteristics. Further, it was observed that the farmers practicing IPM had higher willingness to participate in collective approach. Efforts to promote IPM, thus, might act as catalyst in the emergence of collective action.

India adopted IPM as a cardinal principle of plant protection policy in 1985. A number of policy initiatives have been taken to reduce pesticide use in agriculture, and concurrently to promote the concept of IPM. Major initiatives include: ban on hazardous pesticides, phasing out of subsidies on pesticides and appliances, development of infrastructure for the production of biological pesticides, easing out registration norms for the biological pesticides, training of the extension workers and farmers in IPM, establishment of the Farmers Field Schools and IPM demonstrations, etc.

Despite, adoption of IPM technologies remains limited. Biopesticides share only about 1 percent of the agrochemical market. However, the pesticide use in agriculture has reduced by more than one-third since 1990-91, at an annual rate of about 6 percent. The annual rate of decline ranged between 8 to 20 percent a year in Tamil Nadu, Orissa, Madhya Pradesh, Bihar and Andhra Pradesh. In Gujarat, Hrayana, Himachal Pradesh and Rajasthan the rate of decline was less than 1 percent a year. Whether reduction in the pesticide use can be attributed to IPM is ambiguous, considering extremely low share of the biopesticides in agrochemical market. Yet, the IPM promotional efforts seem to have contributed toward this, as one of the objectives of IPM is to make farmers aware of the adverse effects of the indiscriminate use of pesticides on crop economics, ecology and public health. The reduction in pesticide use has, however, not been accompanied by reduction in the agricultural productivity in most of the states.

The current IPM promotional efforts are inadequate and thinly distributed, considering the continental dimensions of the country. Availability of IPM technologies is poor. Further, IPM is a knowledge-intensive technology, and demands extension workers and farmers alike to have an adequate understanding of the IPM processes. To this end, considerable progress has been made in terms of training the agricultural extension workers. Since 1995-96, on an average, an extension worker has been trained, at least, thrice in the tools and methods of IPM. The benefits of these, however, have not trickled down to the actual users of IPM technologies, as only about 0.2 percent of the farmers have been trained in IPM.

Several policy implications emerge from this study. The apprehension that transition from the chemical control to IPM might lead to reduction in crop yields is unconvincing. So is the issue of profitability. There might be some yield reductions in the transition phase, but in the log rum IPM would contribute to the sustainability of the agricultural production system and the food security, besides yielding substantial social and environmental benefits. This, however, would require appropriate policy support for the production and use of IPM technologies.

Though, the plant protection research has produced a number of biological pest management technologies, many of these are not applicable under the field conditions because of high cost of their application. This necessitates the need to develop low cost technologies for their greater commercialization and use. Further, most of the biological technologies have, a narrow host range, are slow in action, have short shelf life, and are sensitive to the chemical pesticides. Such characteristics act as disincentives to their commercialization and adoption. Basic research should address these issues. Genetic engineering offers great scope to do this.

A majority of the farmers is willing to substitute the chemical pesticides with the biological technologies, despite their drawbacks. But, supply is a limiting factor. Market for biological products is underdeveloped. Most of the supply comes from the public sector manufacturing units, and the initiatives from the private sector are lacking. Further, uncertainty in the supplies of biological technologies discourages farmers to adopt these. Improvements in the supplies would help accelerate their adoption. This can be achieved by involving the private sector. Relaxation in the registration norms for biopesticides, provision of institutional credit for the establishment of manufacturing units, insurance cover in the periods of low demand for biopesticides (particularly of those having short shelf life), exemption from the taxes etc. would improve private sector participation.

Given the incentives, the bioagents and biopesticides such as, *Trichogramma*, NPV and neem products can be produced at the village/ block level in a cost-effective manner, because of local availability of the raw material and cheap labour. Local manufacturers also have the advantage of accurate assessment of the demand for these products. Small-scale manufacturing would help generate income and employment opportunities for the unemployed educated youths and the poor labour households.

One of the main hurdles in the widespread dissemination of IPM technologies is, the inadequate information support to the farmers. IPM technologies are complex, and require considerable knowledge for their proper application. Human resource development efforts have, by and large, remained focused on improving skills of the extension agents, but these have not been translated at the user level. Henceforth, the priority in human resource development should be to empower the users in the tools and methodologies of IPM. To make IPM adoption widespread, the extension system should document the success stories, and widely publicize their improved benefit-cost ratios, and also to develop local leadership to motivate the farmers for effective participation in the IPM programs.

Economic incentives to the farmers could be a powerful tool in the faster dissemination of IPM technologies. Input subsidy has been used as a common tool in promoting agricultural technologies in the past. At current prices, use of biological inputs is marginally attractive to the farmers, and an increase in the prices of biological pesticides would adversely affect their adoption. Since the biological pest management technologies are benign to the environment and public health, provision of ‘green box’ subsidies, at least in the transition phase, can be thought of.

In many developed countries, market for pesticide-free products is expanding, and producers get premium prices. This, however, is lacking in India due to the lack of market. Creating a market for pesticide-free products would require development of the certification procedures and the labeling system, the cost of which may be quite high if pursued by the farmers or crop procurement agencies individually. Such costs can be brought down considerably, if the group approach is followed for adoption of the technologies. Some export houses follow this approach to ensure a pesticide-free produce. Thus, the concept of IPM village should be promoted rather following individual-centered approach. Nevertheless, there are successful cases, where the entire community has been mobilized by the implementing agencies to tackle the pest problem in a collective manner. The community participation approach adopted by the National Centre for Integrated Pest Management, New Delhi in Ashta village of Nanded district, Mahrashtra is one such case (Birthal et al.2000).

Institutional issues such as, community participation, are often overlooked in the technology dissemination processes. Development of the grassroot level community based institutions is going be a major challenge in the implementation of IPM programs, particularly in the societies characterized by high degree of social and economic inequities. Yet, there is a latent potential for the emergence of collective action, but it requires commitment and dedication from the implementing agencies. The role of extension systems, thus, need to be redefined to bring about changes in the socio-political conditions in the direction that encourage greater collective participation of the farmers.

REFERENCES

Adesina, A.A., and J. Baidu-Forson.1995. Farmers' perceptions and adoption of new agricultural technology: Evidence from analysis in Burkina Faso and Guinea, West Africa. Agricultural Economics 13:1-9.

Adesina, A.A., and M.M. Zinnah.1993.Technology characteristics, farmer perceptions and adoption decisions: A Tobit model application in Sierra Leone. Agricultural Economics 9: 297-311.

Agnihotri, N.P.1983. Monitoring of pesticides residues in the environment. Pesticide Information 9(3): 64-80.

Alam, G.1994. *Biotechnology and sustainable agriculture: Lessons from India*. Technical Paper No. 103. OECD Development Centre, Paris.

Alam, G. 2000. *A study of biopesticides and biofertilisers in Haryana, India*. Gatekeeper Series 93. International Institute for Environment and Development, London.

Alston, J.M., G.W. Norton and P.G. Pardey. 1995. *Science under scarcity: Principles and practices for agricultural research evaluation and priority setting*. Cornell University Press, Ithaca and London.

Atwal, A.S.1986.Future of pesticides in plant protection. In*: Plant protection in the year 2000 A.D*. (Ed. G.S. Venkataraman). Indian National Science Academy, New Delhi.

Beddow, J.M. 2000. *Protocols for the assessment of economic and environmental effects of integrated pest management programs*. M.Sc thesis. Virginia Polytechnic Institute and State University, Blacksburg.

Birthal, P.S., O. P. Sharma, and Sant Kumar. 2000a. Economics of integrated pest management: Evidences and issues. Indian Journal of Agricultural Economics 55(4): 644-659.

Birthal, P.S., O.P. Shrama, Sant Kumar, and A. Dhanadapani. 2000b. Pesticide use in rainfed cotton: Frequency, intensity and determinants. Agricultural Economics Research Review 13(2): 107-122.

Borlaug, N.E.1972. Mankind and civilization at another crossroad in balance with nature-A biological myth. Bio-Science 1: 41-47.

Carson, R.1962. *Silent spring*. Houghton Miffin and Company. The Riverside Press, Boston, USA.

Chand R., and P.S. Birthal. 1997.Pesticide use in Indian agriculture in relation to growth in area and production and technological change. Indian Journal of Agricultural Economics 52(3): 488-498.

Chowdry, K.R. and S. Seetharaman.1997. Economic evaluation of integrated pest management technology in cotton farming in Guntur district, Andhra Pradesh. Indian Journal of Agricultural Economics 52(3): 544-545.

Collins, R.L., J.A. Larson, R.K. Roberts, and B.C. English. 1999. Factors influencing Southwestern Tennessee farmers' willingness to participate in the boll weevil eradication program. The Journal of Cotton Science 3: 1-10.

Dhaliwal, G.S. and R. Arora.1993. Changing status of insect pests and their management strategies. In: *Changing scenario of Indian agriculture* (Eds: K.S. Gill, G.S. Dhaliwal and B.S. Hansara). Commonwealth Publishers, New Delhi.

Dhaliwal, G.S. and R. Arora.1996. *Principles of insect pest management*. Commonwealth Publishers, New Delhi.

Dhaliwal, G.S. and R.L. Kalra. 1977. DDT residues in milk samples from Ludhiana and surrounding areas. Indian Journal of Ecology 4(1): 13-22.

FAO. 1967. *Report of the first session of the FAO panel of experts on integrated pest control*. Rome, Italy.

FAO. 1992. *Field Program Circular No. 8/92*. December. Rome, Italy.

Feder, G. 1985. Adoption of agricultural innovations in developing countries: a survey. Economic Development and Cultural Change 32: 255-298.

Fernandez-Carnejo, J., E. D. Beach, and W.Y. Huang. 1994. The adoption of integrated pest management technologies by vegetable growers in Florida, Michigan and Texas. Journal of Agricultural and Applied Economics 26: 158-172.

Glass, E.H. 1975. Integrated pest management: Rationale, potential, needs and implementation. Entomological Society of America. Special publication 75 (2): 141.

Govt. of Indonesia.1994. *Farmers as experts*. Ministry of Agriculture.

Govt. of Philippine. 1993. *The Philippine National IPM Program, Kasakalikasan*. Manila.

Gulati, A., and Kelley, T. G. 1999. *Trade liberalization and Indian agriculture*. Oxford University Press, New Delhi.

Harper, J.K., M. E. Rister, J.W. Mjelde, B.M. Drees, and M.O. Way. 1990. Factors influencing the adoption of insect management technology. American Journal of Agricultural Economics 72 (4):997-1005.

ICMR.1993. *Report on pesticides surveillance in food contaminants in India*. Indian Council of Medical Research, New Delhi.

ICRISAT-ICAR.1999. *Typology construction and economic policy analysis for sustainable rainfed agriculture*. Intenational Crops Research Institute for the Semi-Arid Tropics, Patancheru (India), and Indian Council of Agricultural Research, new Delhi.

Jayaraj, S. 1989. Advances in biological means of pest control. The Hindu Survey of Indian Agriculture. Hindu Newspaper Group, India.

Kalra, R.L. and R.P. Chawla. 1981. Impact of pesticidal pollution in the environment. Journal of the Bombay Natural History Society 78(1): 1-15.

Kenmore, P.E. 1996. Integrated pest management in rice. In: *Biotechnology and integrated pest management* (Ed. G.J. Persley). CAB International, Wallingford, U.K.

Kishor, N.M.1997. Pesticide externalities in coastal Andhra Prades. In: *Natural resource economics: Theory and application in India* (Eds. J.M. Kerr, D.K. Marothia, Katar Singh, C. Ramasamy, and W.R. Bentley). Oxford and IBH Publishing Company Pvt. Ltd., New Delhi.

Kivlin, J.E. and F.C. Fliegel. 1966. Attributes of innovations as factors in diffusion. American Journal of Sociology 72: 235-248.

Kumar, N.1992. Biological control becomes established technique in Asia. Biotechnology and Development Monitor 13(9).

Kumar, P. *Food demand-supply projections*. Indian Agricultural Research Institute, New Delhi.

Lapar, M.L.A. and S. Pandey. 1999. Adoption of soil conservation: the case of the Philippine uplands. Agricultural Economics 21: 241-256.

Lichtenberg, E. and D. Zilberman. 1986. The econometrics of damage control: why specification matters. American Journal of Agricultural Economics, May.

Linder, R.K., and F.G. Jarret. 1978. Supply shifts and the size of research benefits. American Journal of Agricultural Economics 60 (1): 48-58.

Manski, C. and McFadden, D. 1981. *Structural analysis of discrete data with econometric applications*. MIT Press, Cambridge, Massachutes.

Marothia, D.K. 1997. Agricultural technology and environmental quality: an institutional perspective. Indian Journal of Agricultural Economics 52 (3): 473-487.

McCulloch, A.K., R. Meinzen-Dick, and P. Hazell. 1998. *Property rights, collective action and technologies for natural resource management: A conceptual framework*. SP-PRCA Working Paper No. 1. International Food Policy Research Institute, Washington, D.C.

McNamara, K.T., M.E. Wetzstein, and G.K. Douce. 1991. Factors affecting peanut producer adoption of integrated pest management. Review of Agricultural Economics 13: 129-139.

Mehrotra, K.N.1989. Pesticide resistance in insect pests: Indian scenario. Pesticide Research Journal 1(2): 95-103.

Mencher, J.P.1981. Agricultural labour and pesticides in rice regions of India: Some health considerations. Economic and Political Weekly 26(39).

Mohan, D. 1987. Food vs limbs: Pesticides and physical disability in India. Economic and Political Weekly 22 (13): A23-A28.

Napit. K.B., G.W. Norton, R.F. Kazmierczak Jr., and E.G. Rajotte. 1988. Economic impacts of extension integrated pest management programs in several states. Journal of Economic Entomology 81(1): 251-256.

NCAER.1967. Pesticides in Indian agriculture. National Council of Applied Economic Research, New Delhi.

Nkoyna, E., T. Schroeder and D. Norman. 1997. Factors affecting adoption of improved maize seed and fertilizer in northern Tanzania. Journal of Agricultural Economics 48: 1-12.

Nowak, P. 1992. Why farmers adopt production technology. Journal of Soil and Water Conservation 47: 14-16.

Oerke, E.C., H.W. Dehne, F. Schohnbeck, and A. Weber.1995. *Crop production and crop protection: Estimated losses in major food and cash crops*. Elsevier, Amsterdam.

Office of the Technology Assessment.1979. *Pest management strategies for crop protection*, vol. 1. Congress of the United States. Washington, D.C.

Palladino, P.S.A. 1989. *Entomology and ecology: the ecology of entomology. "The insecticide crisis" and the entomological research in the United States in the 1960s and 1970s: Political, institutional, and conceptual dimensions*. Ph.D. Thesis. University of Minnesota.

Pawar, C.S.1998. Helicoverpa- A national problem which needs a national policy and commitment for its management. Pestology 22(7):51-57.

Pimental, D., L. McLaughlin, A. Zepp, B. Lakitan, T. Kraus, P. Kleinman, F. Vancini, W. J. Roach, E. Graap, W.S. Keeton, and G. Selig. 1993a. Environmental and economic impacts of reducing U.S. agriculture pesticide use. In: *The pesticide question: environment, economics and ethics* (Eds:D. Pimental and H. Lehman). Chapman and Hall: New York and London.

Pimental, D., H. Acquay, M. Biltonen, P. Rice, M.Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz and M. D'Amore. 1993b. Assessment of environmental and economic impacts of pesticide use. In: *The pesticide question: environment, economics and ethics* (Eds: D. Pimental and H. Lehman). Chapman and Hall: New York and London.

Polson, R.A. and S.C. Spencer. 1991. The technology adoption process in subsistence agriculture: The case of cassava in southwestern Nigeria. Agricultural Systems 36: 65-78.

Pradhan, S. 1983. *Agricultural entomology and pest control*. Indian Council of Agricultural Research, New Delhi.

Paroda, R.S., and P. Kumar. 2000. Food production and demand situations in South Asia. Agricultural Economics Research Review 13(1):1-26.

Rao, M.V.1988. Changing pest situation in the current agricultural scenario in India. In the seminar: *Changing pest situation in the current* *agricultural scenario in India*. Indian Agricultural Research Institute, New Delhi.

Ravnborg, H.M., A.M. de la Cruz, M. del Pilar Guerrero, and O. Westermann. 2000. *Collective action in ant control*. CAPRi Working Paper No. 7. International Food Policy Research Institute, Washington, D.C.

Regev, U., A.P. Gutierrez, and G.Feder. 1976. Pests as a common property resource: A case study of Alfalfa weevil control. American Journal of Agricultural Economics 58(2): 186-197.

Robinson, W.E., R. Nowogrodzki and R.A. Morse. 1989. The value of honey bee as pollinators of U.S. crops. American Bee Journal 129: 477-487.

Rola, A.C. and P.L. Pingali. 1993. *Pesticides, rice productivity and farmers' health: an economic assessment*. International Rice Research Institute, Manila, Philippines and World Resources Institute, Washington, USA.

Rook, S.P., and G.A. Carlson.1985. Participation in pest management groups. American Journal of Agricultural Economics 67(3): 563-566.

Saini, R.K. and R.S. Jaglan. 1998. Adoption of insect-pest control practices by Haryana farmers in cotton: A survey. Journal of Cotton Research and Development 12(2): 198.

Saleth, R.M. 1999. *Shift in cropping pattern from cereals to non-cereals*. Institute of Economic Growth, New Delhi.

Saxena, S. 2001. Pesticide industry in a climate of signal shifts. Agriculture Today, April.

Singh, S.P. 1997. Progress and problems in the use of biocontrol agents. In: *The national conference on biopesticides.* Ministry of Agriculture, Govt of India, New Delhi, and All India Biotech Association, New Delhi. April 10, 1997.

Shiyani, R.L., P.K. Joshi, M.Asokan and M.C.S. Bantilan. 2000. Adoption of improved chickpea varieties: evidences from tribal region of Gujarat. Indian Journal of Agricultural Economics 55: 159-171.

Stern,V.M., R.F. Smith, R. van den Bosch, and K.S. Hagen. 1959. The integrated control concept. Hilgardia 29: 81-101.

Thomas, J.K., H. Ladewig and W.A. McIntosh. 1990. The adoption of integrated pest management practices among Texas cotton growers. Rural Sociology 55 (3): 395-410.

Thrupp, L.A.1996.*New partnerships for sustainable agriculture*. World Resources Institute, Washington, D.C.

Tweedy, B.G. 1979. *The role of chemicals in integrated pest management.* In: *Pest mamangement in transition: with regional focus on the interior west* (Ed. Pieter de Jong). Westview Press/Boulder, Colarado.

Vandeman , A., J. Fernandez-Carnejo, S.Jans, and B. H. Lin. 1994. *Adoption of integrated pest amangement in U.S. agriculture*. USDA/ERS Agriculture Information Bulletin No. 707. September.

Waage, J. 1995. Divergent perspectives on the future of IPM. In the workshop '*Pest management, food security, and the environment: The future to 2020*. IFPRI, Washington, D.C., May 10-11.

Waibel, H. 1986.*The economics of integrated pest control in irrigated rice*. Springer-Velag, Germany.

Waibel and Zadoks.1996. Institutional constraints to IPM. In :'XIIIth International plant protection congress. The Hague, The Netherlands. July 2-7.

White, T.A., and C.F. Runge. 1994. Common property and collective action: Lessons from cooperative watershed management in Haiti. Economic Development and Cultural Change.

World Bank. 1997. *Integrated pest management: strategies and policies for effective implementation of IPM*. World Bank, Washington, D.C.

WHO/UNEP. 1989. *Public health impact of pesticides used in agriculture*. WHO/UNEP, Geneva, Switzerland.

ANNEXURES

Annexure I: Inputs used and their application rates (per hectare) in cotton under different of cotton pest control strategies in Gujarat, 1990-91 to 1997-98.

Inputs	Unit	Chemical control	Biolo-gical control-I	Biolo-gical control–II	IPM-I	IPM-II	Un-treated
Variety: CH6							
Number of trials		5	2	2	3	3	6
Mean number of applications per hectare							
Pesticides	No.	6.80	1.00	0.50	4.67	3.00	0.33
T. Chilonis	No.	-	11.00	8.00	11.00	8.00	-
C. Carnea	No.	-	-	3.00	-	3.00	-
Mean application rate per hectare							
Pesticides	Kg a.i	2.50	0.71	0.36	2.37	0.96	0.24
T. Chilonis	Lakhs No.	-	11.00	10.00	11.00	12.00	
C. Carnea	Lakhs No.	-	-	1.50	-	1.50	-
Variety : CH8							
Number of trials		2	-	2	-	3	2
Mean number of applications per hectare							
Pesticides	No.	7.00	-	-	-	1.00	-
T. Chilonis	No.	-	-	8.00	-	8.00	-
C. Carnea	No.	-	-	3.00	-	3.00	-
Mean application rate per hectare							
Pesticides	Kg a.i	2.38	-	-	-	0.70	-
T. Chilonis	Lakhs No.	-	-	12.00	-	12.00	-
C. Carnea	Lakhs No.	-	-	0.30	-	0.30	

Note: Biological control –I excludes observations having C. carnea as an input because of its very high price.

This is analysed under Biological control –II situation.

Annexure II: Inputs used and their application rates (per hectare) in cotton under different pest control strategies inTamilnadu, 1992-93 to 1996-97.

Inputs	Unit	Bio-intensive IPM	Moderately Chemical-Intensive IPM	Biological Control	Chemical-Intensive IPM
Variety: LRA5166					
Number of trials		3	2	1	3
Mean number of applications					
Pesticides	No.	0.33	6.00		8.00
T. Chilonis	No.	6.67	-	4.00	
C. Carnea	No.	2.33	-	2.00	
NPV	No.	1.00	1.00	3.00	0.67
Neem oil	No.	1.67	1.00		1.00
Mean application rates					
Pesticides	Kg a.i	0.66	3.95	-	4.30
T. Chilonis	Lakh No.	8.00	-	6.00	
C. Carnea	Lakh No.	11.67	-	10.00	
NPV	LE	467	450	350	300
Neem oil	Lt	1.67	5.00		5.0
Variety : MCU 5					
Number of trials		2	2	-	2
Mean number of applications					
Pesticides	No.	2.5	7.00		10.00
T. Chilonis	No.	8.00			
C. Carnea	No.	2.50			
NPV	No.	1.00	1.00		
Neem oil	No.	0.50	1.00		1.00
Mean application rates					
Pesticides	Kg a.i	1.27	4.88		5.76
T. Chilonis	Lakh No.	10.00			
C. Carnea	Lakh No.	1.25			
NPV	LE	475	450		
Neem oil	Lt	2.50	5.00		5.00

Annexure III: Inputs used and their application rates (per hectare) in cotton under different of cotton pest control strategies in Punjab, 1990-91 to 1997-98.

Inputs	Unit	Chemical control	Biological control-I	Biological control–II	IPM-I	IPM-II	Un-treated
Variety: F846							
Number of trials		6	3	-	1	2	3
Mean number of applications							
Pesticides	No.	7.17	-	-	1	3.5	-
T. Chilonis	No.	-	1.33	-	6.33	5.5	
C. Carnea	No.	-	-	-	-	1	
Bt products	No.		1.33		-		
Mean application rate							
Pesticides	Kg a.i	3.81	-		0.19	2.13	
T. Chilonis	Lakhs no.	-	26.76		16.00	8.25	
C. Carnea	Lakhs no.	-	-		-	0.10	
Bt products	Kg	-	1.33		-		
Variety : F414							
Number of trials		1	-	1	1	-	1
Mean number of applications							
Pesticides	No.	7.00			4.00		
T. Chilonis	No.			8.00	3.00		
C. Carnea	No.			1.00			
Mean application rate							
Pesticides	Kg a.i	2.25			1.56		
T. Chilonis	Lakh no.			12.00	4.50		
C. Carnea	Lakh no			0.10			
Variety: LH1134							
Number of trials		2	2	-	3	-	2
Mean number of applications							
Pesticides	No.	6.50	2.00		4.67		0.5
T. Chilonis	No.		7.50		7.50		
C. Carnea	No.						
Bt products	No.						
Mean application rate							
Pesticides	Kg a.i	2.15	0.36		1.24		0.08
T. Chilonis	Lakh no.		9.50		8.67		
C. Carnea	Lakh no						
Variety: F1054							
Number of trials		6	4	1	3	2	4
Mean number of applications							
Pesticides	No.	9.00	1.25	3.00	4.50	4.00	0.75
T. Chilonis	No.		5.00	12.00	9.00	6.00	
C. Carnea	No.			1.00		1.00	
Bt products	No.		1.00				
NPV	No.			1.00			
Mean application rate							
Pesticides	Kg a.i	4.76	0.33	0.56	3.02	2.11	0.23
T. Chilonis	Lakh no.		8.50	18.00	1.35	9.00	
C. Carnea	Lakh no			0.10		0.30	
Bt products	Kg		0.40				
NPV	LE			500			

Annexure IV: Inputs used and their application rates (per hectare) in rice under different of rice pest control strategies in Tamilnadu , 1994-95 to 1997-98.

Inputs	Unit	Chemical control	Biological control	IPM	Untreated
Variety: ADT36					
Number of trials		3	7	-	3
Mean number of applications					
Pesticides	No.	3.00			
T. Chilonis	No.		1.43		
T. japonicum	No.		1.29		
Bt	No.		0.71		
Neem oil	No.		0.14		
Mean application rates					
Pesticides	Kg a.i	0.99			
T. Chilonis	Lakh no.		1.10		
T. japonicum	Lakh no.		0.99		
Bt	Kg		0.50		
Neem oil	Lt		0.40		
Variety: ASD 18					
Number of trials		1	3	-	1
Mean number of applications					
Pesticides	No.	3.00			
T. Chilonis	No.		2.00		
T. japonicum	No.		1.67		
Bt	No.		1.00		
Neem oil	No.				
Mean application rates					
Pesticides	Kg a.i	0.96			
T. Chilonis	Lakh no.		1.33		
T. japonicum	Lakh no.		1.67		
Bt	Kg		1.00		
Neem oil	Lt				
Variety: CO45					
Number of trials		5	16	3	6
Mean number of applications					
Pesticides	No.	3.40		2	
T. Chilonis	No.		1.06	1	
T. japonicum	No.		1.56	3	
Bt	No.		1.56		
Neem oil	No.				
Mean application rates					
Pesticides	Kg a.i	1.10		0.64	
T. Chilonis	Lakh no.		0.83	0.80	
T. japonicum	Lakh no.		1.26	2.10	
Bt	Kg		1.69		
Neem oil	Lt				
Variety:IR 20					
Number of trials		2	8	-	2
Mean number of applications					
Pesticides	No.	3.00			
T. Chilonis	No.		0.38		
T. japonicum	No.		0.38		
Bt	No.		2.5		
Neem oil	No.				
Mean application rates					
Pesticides	Kg a.i	1.00			
T. Chilonis	Lakh no.		0.38		
T. japonicum	Lakh no.		0.38		
Bt	Kg		2.75		
Neem oil	Lt				
Variety: IR50					
Number of trials		2	9		3
Mean number of applications					
Pesticides	No.	3.00			
T. Chilonis	No.		0.33		
T. japonicum	No.		0.89		
Bt	No.		2.22		
Neem oil	No.		0.22		
Mean application rates					
Pesticides	Kg a.i	1.00			
T. Chilonis	Lakh no.		3.33		
T. japonicum	Lakh no.		8.89		
Bt	Kg		2.44		
Neem oil	Lt		0.39		

Annexure V: Inputs used and their application rates (per hectare) in rice under different pest control strategies in Punjab, 1994-95 to 1997-98.

Inputs	Unit	Chemical Control	Biological Control	IPM	Untreated
Variety:PR106					
Number of trials		3	11	-	3
Mean number of applications					
Pesticides	No.	1.33		-	
T. Chilonis	No.		4.09	-	
T. japonicum	No.		4.09	-	
Bt	No.		0.82	-	
Mean application rates					
Pesticides	Kg a.i	0.56		-	
T. Chilonis	No.		3.07	-	
T. japonicum	No.		3.07	-	
Bt	Kg		0.91	-	

Annexure VI: Inputs used and their application rates (per hectare) in chickpea under different pest control strategies in Andhra Pradesh , 1992-93 to 1995-96.

Inputs	Unit	Chemical Control	Biological Control	IPM	Untreated
Variety: Annegiri					
Number of trials		8	20	4	4
Mean number of applications					
Pesticides	No.	3.25		3.25	
NPV	No.		1.30	3.25	
Bt	No.		1.60		
Mean application rates					
Pesticides	Kg a.i	1.09		1.39	
NPV	LE		244	406	
Bt	Kg		1.60		

Annexure VII: Inputs used and their application rates (per hectare) in chickpea under different pest control strategies in Tamilnadu, 1992-93 to 1995-96.

Inputs	Unit	Chemical Control	Biological Control	IPM	Untreated
Number of trials		8	17	5	4
Mean number of applications					
Pesticides	No.	3.00		3.00	
NPV	No.		2.65	3.00	
Bt	No.		0.71	-	
Mean application rates					
Pesticides	Kg a.i	1.93		1.29	
NPV	LE		485	375	
Bt	Kg		0.53		

Annexure VIII: Farmers' awareness of negative externalities of chemical pesticides (% reporting)

Type of benefit	Cotton		Paddy		Cabbage	
	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters	Adopt-ers	Non-adopters
Technological failure of pesticides						
Insecticide resistance	69.8	66.7	65.9	37.5	82.9	62.9
Pest resurgence	83.7	77.8	26.8	35.0	71.4	57.1
Secondary pest outbreak	41.9	50.0	21.9	35.0	0.0	0.0
Ecological damage						
Beneficial insects	90.7	80.6	90.0	65.9	74.3	31.4
Natural enemies of pests	90.7	63.9	90.0	31.7	74.3	31.4
Soil micro-organisms	58.1	25.0	52.5	19.5	42.9	20.0
Human health						
Eyes (irritation, blind, etc)	81.4	80.6	67.5	56.1	97.1	82.9
Skin (burn, rupture, etc)	74.4	75.0	65.0	53.7	91.4	77.1
Muscle strain	2.3	2.8	25.0	14.6	40.0	25.7
Respiration (Cough)	7.0	13.9	27.5	14.6	62.9	37.1
Cardio-vascular (blood pressure)	0.0	0.0	17.5	9.8	31.4	5.7
Gastro-intenstinal (indigestion, nausea, vomitting, etc.)	4.7	5.6	17.5	19.5	51.4	11.4
Residues in food and fodder						
Grains	65.1	33.3	60.0	46.3	71.4	40.0
Milk	65.1	33.3	55.0	41.5	54.3	28.6
Meat and eggs	62.8	30.6	42.5	24.4	34.3	25.7
Fodder	88.4	83.3	57.5	36.6	62.9	40.0

NCAP Publications

Policy Papers

4. Maji, C.C. and A .Bhattacharya. 1995. GATT and Agricultural Exports-Hopes and Realities.
5. Maji, C.C., T. Haque and A. Bhattacharya. 1995. Small Farms. Employment and Surplus Generation : A Case of West Bengal.
6. Chand, Ramesh. 1997. Import Liberalization and Indian Agriculture: The Challenge and Strategy.
7. Suresh Pal and Alka Singh. 1997. Agricultural Research and Extension in India: Institutional Structure and Investments.
8. Farrington, J., Rasheed Sulaiman V. and Suresh Pal. 1998. Improving the Effectiveness of Agricultural Research and Extension in India: An Analysis of Institutional and Socio-Economic Issues in Rainfed Areas.
9. Birthal, P. S., Anjani Kumar, A. Ravishankar and U. K. Pandey, 1999. Sources of Growth in the Livestock Sector.
10. Sulaiman V., Rasheed and V. V. Sadamate. 2000. Privatising Agricultural Extension in India.
11. Chand, Ramesh. 2000. Emerging Trends and Regional Variations in Agricultural Investments and Their Implications for Growth and Equity.
12. Pal Suresh, Robert Tripp. and A. Janaiah. 2000. The Public-Private Interface and Information Flow in the Rico Seed System of Andhra Pradesh (India)
13. Haque. T. 2001. Impact on Tenancy Reforms on Productivity Improvement and Socio-Economic Status of Poor Tenants.
14. Selvarajan, S. A. Ravishankar, and P. A. Lakshmi Prasanna. 2001. Irrigation Development and Equity Impacts in India.
15. Birthal, P. S., P. K. Joshi, and Anjani Kumar. 2002. Assessment of Research Priorities for Livestock Sector in India.
16. Pal Suresh and Derek Byerlee. 2003. The Funding and Organisation of Agricultural Research in India: Evolution and Emerging Policy Issues
17. Adhiguru, P. and Ramasamy, C. 2003. Agricultural-based Interventions for Sustainable Nutritional Security.

Policy Briefs

4. Ravishankar. A., 1996. Intellectual Property Rights and Indian Agriculture: Some Issues.
5. Farrington, J., Rasheed Sulaiman V. and Suresh Pal. 1997. Strengthening Research and Extension for Rainfed Farming: Role of Social Science and Institutional Factors.
6. Jha. D. 1999. On the New Agricultural Policy.
7. Ravishankar, A. and Pratap S. Birthal. 1999. Livestock Sector in India: Agenda for the future.
8. Chand, Ramesh and Sonia Chauhan. 1999. Are Disparities in Indian Agriculture Growing?
9. Sulaiman V., Rasheed and A. W. van den Ban. 2000. Agricultural Extension in India- The Next Step.
10. Ravishankar, A. and Sunil Archak. 2000. IPRs and Agricultural Technology : Interplay and Implications for India.
11. Ravishankar, A. and Sunil Archak. 2000. Plant Variety Protection Technology: Interplay and Implications for India.
12. Gill, Gerard J., Diana Carney and Suresh Pal. 2000. Improving Competitive Agricultural Research Funding in India.
13. Andy Hall, Norman Clark and Rasheed Sulaiman V. MVS Sivamohan and B. Yoganand. 2000. Coping with New Policy Agendas for Agricultural Research: The Role of Institutional Innovations.
14. Chand, Ramesh and Linu Mathew Philip. 2001. Subsidies and Support in World Agriculture: Is WTO Providing Level Playing Field ?
15. Selvarajan, S. 2001. Sustaining India's Irrigation Infrastructure.
16. Sulaiman. V., Rasheed and Andy Hall. 2002. Beyond Technology Dissemination-Can Indian Agricultural Extension Re-invent itself?

राष्ट्रीय कृषि आर्थिकी एवं नीति अनुसंधान केन्द्र
NATIONAL CENTRE FOR AGRICULTURAL ECONOMICS AND POLICY RESEARCH
(Indian Council of Agricultural Research)
POST BOX No. 11305, LIBRARY AVENUE, PUSA, NEW DELHI-110012.
Phone : 91-11-25713628,25819731 Fax : 91-11-25822684 E-mail : ncap@iasri.delhi.nic.in
http: // www.nic.in/icar/ncap/index.htm