International Research on Natural Resource Management

Advances in Impact Assessment

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International Research on Natural Resource Management: Advances in Impact Assessment

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Published by CABI
On behalf of the Science Council of the
Consultative Group on International Agricultural Research

CABI is a trading name of CAB International

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Library of Congress Cataloging-in-Publication Data

International Research on Natural Resource Management: advances in impact assessment / edited by Herman Waibel & David Zilberman.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-84593-283-1 (alk. paper) -- ISBN 978-1-84593-284-8 (ebook : alk. paper)
1. Consultative Group on International Agricultural Research. 2. Natural resources--Management--Research. I. Waibel, Herman, 1951- II. Zilberman, David, 1947- III. Title.
S946.147 2007
338.1--dc22
2007008079

A catalogue record for this book is available from the British Library, London, UK.

Published jointly by CAB International and FAO.
Food and Agriculture Organization of the United Nations (FAO)
Viale delle Terme di Caracalla, 00100 Rome, Italy
Web site: www.fao.org

ISBN-13: 978 1 84593 283 1

Typeset by MRM Graphics Ltd, Winslow, Bucks
Printed and bound in the UK by Biddles, Kings Lynn.

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Foreword

Investment in agriculture-related natural resource management research (NRMR) has increased significantly over the last two decades; and so have requests from the investors to assess the impacts of their past investments in such research. The Consultative Group on International Agricultural Research (CGIAR) is not an exception, and in 2003 a formal request was made to the Chair of the CGIAR Science Council's Standing Panel on Impact Assessment (SPIA). The request was a response to previously voiced concerns regarding the dearth of documented credible evidence that CGIAR NRMR is contributing to mission-level impacts on a wide scale (see e.g. Raitzer, 2003; World Bank/OED, 2003; Kelley and Gregersen, 2005). SPIA responded with an initiative that involved several elements, including a number of case studies of CGIAR NRMR impact assessment and further development of methods for NRMR impact assessment.

This book presents the outcome of the SPIA initiative. It presents seven case studies detailing the assessment of the impacts of some major NRMR projects undertaken by the CGIAR. The case studies went through a number of stages of review and revision, and the final, peer-reviewed cases are presented in this book. Some of them, in a longer and more detailed form, have already been published by the Centres involved; they are referenced in the book.

The other thrust of the initiative dealing with research methodology development involved input from an internationally recognized natural resource economist, Professor David Zilberman from the University of California, Berkeley, USA. Dr Zilberman also served as co-editor of the present book. He has provided critical guidance on this part of the initiative as well as on the case studies. Retired SPIA member, Dr Hermann Waibel, is the other co-editor and also a recognized expert in the field.

SPIA thanks both of these individuals for their efforts to make this a successful and useful initiative. A special vote of thanks goes to Professor Waibel, now retired from SPIA, who for 4 years acted as the SPIA point person on the project and was the main contact with the case study teams.

The SPIA initiative and the book benefited from the input and involvement of many individuals in addition to Professors Waibel and Zilberman. Thus, we also thank the following persons: centre case study leaders Nancy Johnson and Tim Dalton (International Centre for Tropical Agriculture), Mike Spilsbury (Centre for International Forestry Research), Vijay Laxmi Pandey and Olaf Erenstein (International Maize and Wheat Improvement Centre), Kamel Shideed and Véronique Alary (International Centre for Agricultural Research in the Dry Areas), Meredith Giordano (International Water Management Institute), Olu Ajayi and Frank Place (World Agroforestry Centre) and Madan Dey and Patrick Kambewa (WorldFish Centre). We thank former Science Council and SPIA members, Alain deJanvry and Dick Harwood, and current members, Flavio Avila, Mywish Maredia and Prabhu Pingali, and especially Science Council Secretariat staff Tim Kelley and Ruben Echeverria, SPIA consultant David Raitzer, and Sam Fujisaka and Doug White, who wrote an insightful piece on the state-of-the-art of NRMR impact assessment in the CGIAR; and we also thank Adel El Beltagy and Joachim Voss who interacted with us throughout the initiative. Finally, we want to thank the four anonymous peer reviewers who diligently reviewed the seven case studies and provided the case study teams with insightful and useful suggestions.

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Acknowledgements

As the editors we are indebted to many people who helped to finish this book. Foremost there are those from the Consultative Group on International Agricultural Research (CGIAR) Science Council's Standing Panel on Impact Assessment (SPIA), including former SPIA chair Hans Gregersen and current chair Jim G. Ryan, for their wisdom and guidance, the secretary and man behind the scene Tim Kelley for his extremely valuable constructive criticism, and CGIAR Science Council Executive Director and former SPIA member Ruben Echeverria. We also want to thank the authors of the case studies who always responded positively to our suggestions and criticism.

The book also benefited from several workshops on this topic, namely the Hannover workshop in June 2004, the joint SPIA–Integrated Natural Resource Management Group workshop in 2005 and the mini-symposium at the International Association of Agricultural Economists conference in Brisbane in August 2006. We thank all the respective participants for their useful suggestions.

For invaluable assistance in reading earlier versions of the chapters, revising and editing, special thanks go to the following junior researchers at the University of Hannover: Ms Sabine Liebenehm, who patiently and meticulously put all the chapters together and weeded out a lot of the initial inconsistency; Dr Diemuth Pemsl (also a co-author in Chapter 7) and Mr Rudi Witt who made a number of very good suggestions on several of the chapters. At the University of California at Berkeley we want to thank Ms Amor Nolan and Mr Thomas Sproul for constant help and very constructive contributions.

Many thanks also have to go to Steve Dembner from the Food and Agriculture Organization of the United Nations and Tim Hardwick, Emma Brooks and Kate Hill at CABI.

David Zilberman
Hermann Waibel

Acronyms and Abbreviations

ACTED Agency for Technical Cooperation and Development
ARDN Adaptive Research and Development Network
ATO African Timber Organization
BCR benefit:cost ratio
C&I criteria and indicators
CAR Corrective Action Request
CATIE Centro Agronómico Tropical de Investigación y Enseñanza
CGI crop genetic improvement
CGIAR Consultative Group on International Agricultural Research
CGNET CGIAR Network Services International
CIAT International Centre for Tropical Agriculture
CIFOR Centre for International Forestry Research
CIMMYT International Maize and Wheat Improvement Centre
CT conventional tillage
DM dry matter
DT Tunisian Dinar
EIRR economic (social) internal rate of return
FAO Food and Agriculture Organization of the United Nations
FEMISE Euro-Mediterranean Forum of Economic Institutes (ICARDA)
FIRR financial (private) internal rate of return
FMU forest management unit
FO farmers' organization
FPE farmer participatory extension
FPR farmer participatory research
FSC Forest Stewardship Council
FSRP farmer–scientist research partnership
GARB gross annual research-induced supply shift
GPI germplasm improvement

GTZ German Agency for Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit)
IAA integrated aquaculture–agriculture
IBSRAM International Board for Soil Research and Management
ICAR Indian Council of Agricultural Research
ICARDA International Centre for Agricultural Research in the Dry Areas
ICLARM International Centre for Living Aquatic Resources Management
ICRAF International Centre for Research in Agroforestry
IFDC International Centre for Soil Fertility and Agricultural Development
IGP Indo-Genetic Plains
IIMI International Irrigation Management Institute
IMPSA Irrigation Management Policy Support Activity
IMT irrigation management transfer
INRM integrated natural resource management
INRMR integrated natural resource management research
IPF United Nations Intergovernmental Panel on Forests
IPG international public goods
IPM integrated pest management
IRR internal rate of return
ITTO International Tropical Timber Organization
IWMI International Water Management Institute
LAC Latin America and the Caribbean
MAGFAD Malawi–German Fisheries and Aquaculture Development
MD Moroccan Dirham
M&M Mashreq/Maghreb project
NARES national agricultural research and extension system
NARS national agricultural research system
NGO non-governmental organization
NPV net present value
NRM natural resource management
NRMR natural resource management research
OEP Office de l'Élevage et du Pâturage
O&M operation and maintenance
OXFAM Oxford Committee for Famine Relief
P&C principles and criteria
PIDA Punjab Irrigation and Drainage Authority
RESTORE Research Tools for Natural Resource Management, Monitoring and Evaluation
RET research extension team
RT reduced tillage
RWC Rice Wheat Consortium of the Indo-Gangetic Plains
SAU state agricultural university
SCOR Shared Control of Natural Resources (project)
SCS Scientific Certification System
SCUAF 'Soil Change Under Agro-Forestry' (model)
SFM sustainable forest management
SIDA Sindh Irrigation and Drainage Authority

SPIA Standing Panel on Impact Assessment
S&W soil and water
TAC Technical Advisory Committee of the CGIAR
TFP total factor productivity
TI interspatial Tornqvist Index
UF forage unit
UNCED United Nations Conference on Environment and Development
UNEP United Nations Environment Programme
UP Uttar Pradesh
USAID US Agency for International Development
USFS US Forest Service
WANA West Asia and North Africa
WUA water users' association
ZT zero till/zero tillage

Tables and Figures

1 Why Natural Resource Management Research?

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Increased concern about the environmental and natural resource implications of agriculture has given rise to an emphasis on research that calls attention to these issues in developing countries. National and international agricultural research systems, including the research Centres under the Consultative Group on International Agricultural Research (CGIAR), have intensified research on natural resource management (NRM) both in terms of budget allocation and priority setting. Thus the balance with the still dominant productivity enhancement research through breeding yield-increasing varieties has been changing gradually. Over the past decade CGIAR investments in NRM research (NRMR) have increased substantially both within the older commodity-oriented Centres (e.g. the International Rice Research Institute, the International Maize and Wheat Improvement Centre) and the newer resource management Centres (e.g. the International Centre for Research in Agroforestry[1], the International Centre for Living Aquatic Resources Management[2]) (see Barrett, 2002; Kelley and Gregersen, 2005). In view of the ongoing changes in agricultural R&D globally (e.g. with lower agricultural research intensities in rich countries and lower spillover effects of scientific knowledge and technology), it has been argued that the CGIAR should return to 'the basic objective of enhancing the supply of staple food especially in food deficit countries' (Pardey *et al.*, 2006). One of the resulting challenges for NRMR is the need to develop methodologies that allow conducting meaningful assessments of the economic, social and environmental impacts of these projects.

Following the concerns raised by the CGIAR's major donors (e.g. World Bank, 2003) and prior studies on NRMR (e.g. Barrett, 2003) the

[1]Now called the World Agroforestry Centre.
[2]Now called the WorldFish Centre.

CGIAR Secretariat has asked the Standing Panel on Impact Assessment (SPIA) to initiate a series of impact assessment studies on NRMR. The main objectives of this SPIA initiative were to obtain better information on the demonstrable impacts of CGIAR investments in NRMR, to identify gaps in data and methodology and to provide avenues for better NRM impact assessment in the future. This book presents the results of the SPIA initiative including the case study results. It provides a synthesis of these cases and offers a theoretical framework of NRM impact assessment. The remainder of this chapter describes the nature of NRMR investments and outlines some unique features of such projects in developing countries.

What are Natural Resource Management Research Projects?

The high degree of interdependence of natural and man-made or man-modified resources in the developing countries implies that a wide array of NRMR issues exists. The issues' key characteristic is that they are almost always of a multi-sector and interdisciplinary nature. For example, the introduction of sustainable forest management practices raises not only questions in research on forestry products, but also deals with issues of water resources, carbon sequestration and climate change. However, for impact assessment purposes it is necessary to reduce the complexity and identify categories of typical NRMR projects through their different objectives. Thus, the most common types of NRM projects generally will have the following objectives.

1. *Improved productivity of natural resources for agricultural purposes.* Examples include water conservation, soil and pest management practices.
2. *Improved production and natural resource systems for community use.* Examples include fisheries, aquaculture, forestry and livestock management.
3. *Improved human and environmental health via reduced agricultural pollution.* This includes activities aimed at mitigating the negative impacts of chemicals use in agriculture including reducing the use of pesticides, and addressing problems of animal waste management.
4. *Increased availability of environmental amenities, with a particular focus on preserving traditional ways of life and enhancing ecotourism.* Examples include improved biodiversity and wildlife habitat preservation.
5. *Improved policies that govern NRM regimes.* Examples include standards and incentive schemes for sustainable use of natural resource products such as water, forestry and fisheries.

From the above, it is evident that NRM projects are diverse in terms of their specific focus, the technique and methodologies employed and the types of research products they generate. A common element among all these projects is that their primary output is the enhanced productivity and sustainability of renewable and non-renewable resources and the mitigation of negative environmental side-effects. However, it is useful to distinguish between micro-level NRMR that provides solutions to farm-level problems and macro-level NRMR that addresses problems beyond the plot and farm levels (Fujisaka and White, 2004). Micro NRMR addresses problems of improved management of crop production to increase productivity, conserve natural resources and reduce pollution. The outcome of micro NRMR includes products such as recommendations for crop management and decision rules for farmers. Macro NRMR includes policy questions that influence the sustainable use of natural resources; e.g. research on water resources or forest management policies, the pricing of chemical inputs in agriculture or community rules in open access fisheries and rangelands.

NRM projects differ from traditional germplasm improvement (GPI) research projects, which primarily seek to improve crop yields. Of course, GPI can have indirect natural resources effects. For example, when industries are facing inelastic demand, increased productivity of agricultural land can lead to reduced deforestation and other activities that might increase supply. Similarly, one could consider the development of pest-resistant crop varieties, including genetically modified products such as for pest or chemical (herbicide) resistance, as NRM technology. Also, the selection and combination of different varieties for specific agroecological zones under different cropping situations are NRM questions. We exclude breeding from our classification of NRM projects because there is a large body of research assessing the impacts of GPI projects, while the research findings on the impact of NRMR remain sparse.

Implications of the unique features of natural resource management research projects for impact assessment

Two major characteristics of NRM projects, which strongly affect impact assessment studies, are:

- Missing markets for environmental amenities.
- The importance of dynamics.

Farmers' benefits from changes in agricultural practices resulting from NRMR may not provide sufficient incentives for adoption, leading to a gap between actual levels and socially optimal levels of adoption. For example, many of the gains from improvements in water quality, prevention of soil erosion or preservation of wildlife do not accrue to farmers, so without extra incentives they are less likely to invest in NRM technologies to obtain these outcomes. When assessing the impact of NRM projects, the additional environmental benefits must be taken into account, since these benefits may not be market-valued. An assessment of the non-market benefits and costs of NRM projects requires the application of a wide array of valuation techniques, including contingent valuation, hedonic pricing and travel cost methods. The effectiveness of these techniques is sometimes debatable, and they can be expensive, so they must be used judiciously in evaluating NRMR.

Assessment of the impacts of NRMR frequently needs to explicitly consider the dynamics of natural resource stocks. It also has to consider the dynamic costs of NRM. Forestry, livestock and water resource management all involve temporal actions that affect future states of nature. 'User cost', the discounted future cost of extracting natural resources at the present (Hotelling, 1931), has to be incorporated in assessing the social impact of NRM. The benefits provided by natural resources in stabilizing shocks to natural systems also need to be recognized. For example, wetlands may lessen flood losses in surrounding areas by acting as a buffer for excess water, and this must be addressed when actions affect these systems.

Ecological relationships in natural resource systems should be incorporated when modelling and assessing NRM projects. An analysis of the impact of water conservation technologies, for example, requires the incorporation of material–balance relationships, their implications for water use efficiency and the third-party effects of water (Schoengold and Zilberman, 2006). Similarly, quantitative assessment of potential pesticide resistance may be an important aspect in evaluating new pest control strategies.

Projects aiming to develop technology are often comprised of sequential sub-processes from a common body of knowledge; each specific effort aims to fill the gaps in the knowledge base, by developing new technologies or applying existing technologies to new circumstances. Unlike crop genetic improvement (CGI) technologies, which are embodied (see Fig. 1.1), NRM innovations often are disembodied technologies like management rules and strategies, so they are similar to 'software packages' produced by the information technology industry. The unique nature of disembodied innovations resulting from micro and macro NRMR may require creative mechanisms for dissemination and outreach.

Components of natural resource management research

The main components of NRMR projects implemented by the CGIAR and its partners (non-governmental organizations, NSRs, etc.) are: (i) research, with the purpose of establishing a new technology or management method; (ii) development and testing, which aims to scale up the technology and lay the groundwork for its future application; and (iii) outreach, which involves educating the potential users about the technology in order to contribute to its adoption efforts. When a new technology relies upon new equipment or capital goods, a commercial marketing

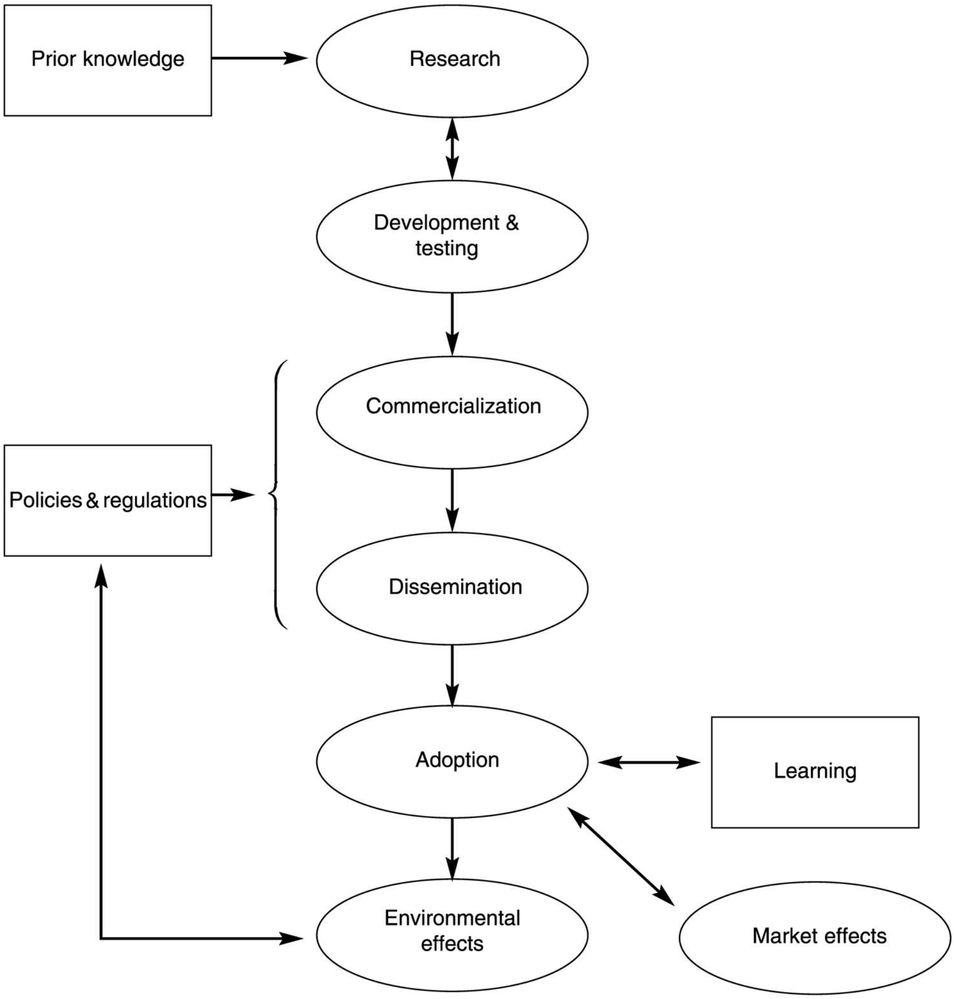

Fig. 1.1. The components of a natural resource management reasearch project and its impacts.

system is required to sell the technology. Sellers of such products will therefore engage in marketing efforts that frequently build upon the ongoing extension activities of the project. Dissemination efforts will lead to adoption, and the use of the technologies by the population will lead to network externalities that will further enhance the adoption process. Adoption therefore affects output and input markets, as well as the welfare of those who adopt the technology (producers), the welfare of the manufacturers and sellers of inputs required by the technology, and the welfare of consumers. In the case of NRMR projects, it is also important to consider the new technology's impacts – both positive and negative – on natural resources and the environment.

The implications of the dynamic nature of NRMR projects are that their economics depend heavily on the choice of the discount rate. Sometimes benefits may occur in the distant future while the cost of NRMR and adaptation to new agroecological environments occurs now. Furthermore, the outcomes of such projects are uncertain, due to the time horizon and constraints to adoption. Unlike higher-yielding varieties, for which adoption is generally advantageous if the necessary infrastructure for inputs distribution is in place, adoption of NRM technologies may depend on the existing stock of knowledge and policy conditions. For example, as demonstrated in one of the cases presented in this book, the adoption of soil fertility management practices that rely on indigenous natural resources depends on the price of fertilizer. Similarly, pollution penalties and payment for improved environmental qualities may induce adoption of NRM technologies that would not have been adopted otherwise.

Some researchers believe that, because NRMR is so complex, the assessment of its impacts in terms of economics is not possible. However, there are at least three reasons why economic impact assessment of NRM is crucial. First, funding agencies and research managers are being held accountable for their allocation decisions and therefore demand estimates of the rates of return on their research investments. Second, *ex ante* impact assessment can stimulate a useful dialogue among researchers that can improve the design of the NRMR. Third, rates of return have been demonstrated for investment on CGI research in the CGIAR (Evenson and Gollin, 2003). Hence, the growing proportion of NRM investments in the Centres is challenged in light of the discussion to identify future research priorities in the CGIAR (e.g. Lele, 2005).

While the analysis of rates of return has several shortcomings and is not the only measure of project success – i.e. the danger of a 'garbage in–garbage out' situation exists – it is still the most objective way of assessment provided the analysis is conducted with care. It is only through a rate of return analysis that questions on impact are raised in a systematic and causal manner. Economic analysis allows funding agencies to compare the rate of return of a research project with a defined minimum rate and thus provides a basis for further assessment. In other words, while the rate of return is not the only decision criterion for donors, funding of a project with a non-satisfactory rate of return would imply the making of subjective value judgements. These usually are more difficult to defend to the scientific community and the general public than measures which rely on values that are revealed from decisions made by economic agents.

The specific features of NRM projects suggest that the rate of return of NRMR may be highly variable and may well be lower than those of investments in GPI. One of the challenges for NRM impact assessment is thus to identify the reasons for this and thoroughly explore the feasibility of additional impact indicators.

In principle, impact assessment of NRM is not different from that of other R&D investments; however a number of challenges must be expected. These are addressed briefly in this introductory chapter to draw attention to some of the problems that will be illustrated later in the chapters that present the case study results (Chapters 5–11).

Because of the specific features of NRM projects, the rate of return of NRM projects is affected by a number of factors that are normally beyond the control of the researcher.

1. *Existence of input marketing networks.* One reason why GPI projects have a high rate of return is that, in most cases, the marketing network for improved seeds, even in developing countries, exists and functions. Marketing networks for NRMR products, such as conservation technologies, may be absent or may exist only informally.

2. *Marketing for final outputs.* In a GPI research project, research eventually leads to increased supply of old products or the introduction of new ones. The existing marketing system usually will allow consumers to express demand for the product (new variety). When NRMR results in new products, consumer demand can be insufficient. Also, farmers are less likely to adopt a new technology if they do not have a reliable input supply and demand for their outputs. In many industries, this may lead to the establishment of contractual relationships between marketing firms and producers. For example, the dramatic expansion of poultry production for meat (broilers) in the USA, Europe and emerging Asian economies would not have occurred without contracts where farmers who raised the new animals had an assured input supply and output market. Unfortunately, introducing new NRM technologies is often constrained by high set-up and learning costs.

3. *Market size.* The literature that exists on the rates of return to agricultural research (e.g. Alston *et al.*, 1997) has recognized that the rate of return tends to be higher for research directed at crops with greater market shares (in terms of acreage value). This larger market share will not only affect consumer and farmer surplus, but also manufacturer's surplus. Furthermore, if a product has a larger market share, manufacturers are more likely to increase their marketing expenditures, thus contributing further to increased adoption and technological gains. If the market share is limited – as is the case with orphan crops, which may be typical for many NRMR projects – then the marketing will be a limiting factor on the rate of return of these projects. Consequently, the heterogeneity of the final product market's size may be a source of variation in the rates of return for NRM projects.

4. *Willingness to pay for environmental amenities.* One of the unique features of NRM projects is the difference between public and private calculation of impacts. NRM projects may provide high levels of benefits by reducing human and environmental health risks, e.g. by reducing the water pollution due to toxic chemicals. They can also provide environmental amenities in terms of increased soil carbon sequestration, such as when low tillage is adopted. However, a farmer's decision to adopt may ignore some of the benefits of the project, especially when such benefits are external to farmers and there are no mechanisms to internalize them. Consequently, there will be under-adoption of NRM technologies if the farmer's incentives reflect the (private) value of these gains.

5. *Payment for natural resources.* As outlined above, NRM projects may lead to improved natural resource conservation. In many cases, this conservation – such as increased access to water or lower resistance to pesticides – is similar to a public good. Unless the producer is compensated for the additional benefit generated, the technologies will be under-adopted and the rate of return will be relatively lower.

6. *Calculating the costs of extra efforts.* Producer surplus from the project is defined as extra revenue (if some of the food is consumed by the household, revenue is imputed), plus the imputed cost of the extra effort that may be required to implement the new technology. Some NRM projects may lead to increased revenue and improved natural capital, but require extra effort in terms of rigorous soil erosion and pest management practices. As these costs can be easily forgotten or are sometimes difficult to quantify, overestimation of the adoption rate may occur.

7. *Prior knowledge.* The amount that needs to be spent on R&D for NRM innovations depends upon prior knowledge. Thus, greater prior knowledge tends to increase the rates of return of technology development projects. As there was less investment in NRM technologies in agriculture, the knowledge base tends to be thinner than in breeding projects, which can reduce the rate of return for NRM. On the other hand, NRM projects may generate knowledge that can be used in future research and product development, but it will be difficult to assess.

8. *Health effects.* An important objective of many NRM projects is health improvements. In such cases, impact assessments must use modelling tools that quantify the value of health gains. Health improvements may be measured by a reduction in the probability of diseases, using tools of risk assessment (Lichtenberg and Zilberman, 1988). Policies regulating chemical applications can therefore affect risk by mandating how a chemical can be applied or by taking additional actions to reduce exposure. Thus, the rate of return of NRMR that reduces chemical use may therefore be significantly affected by the regulatory environment; i.e. the less protection against chemical use is exercised, the greater the value of technologies that reduce chemical use. In assessing the gains from health improvements, therefore, it is not sufficient to have a measure of the reduction of the health risks; rather, it is also necessary to compute the monetary value of health and lives saved (or life-years saved). Rate of return analysis that ignores such health gains or underestimates the value of lives saved may lead to significant underestimation of the rate of return of NRM.

While economic theory provides well-defined principles for impact assessment, the complexity and specific features of NRM projects require some creativity to apply theory to reality. Much of the literature on the productivity of R&D in agriculture has focused on projects that seek to increase yields, reduce costs, or both. Griliches' (1958) work presents a standard framework with a supply shifter, so that the overall effect of technology is captured by expanding standard consumer and producer surplus within a partial equilibrium model with full certainty. NRM projects may affect consumer and farmers' surplus beyond the traditional supply-shifting effects associated with increased yields or reduced costs and should take into account externalities. In addition, effects like risk reduction, stabilization of ecosystems, quality enhancement of food and institutional and policy changes should be considered. To capture such variables may require creative modelling of the technological impacts of NRM projects. While NRMR impact assessment must be expanded beyond internal rate of return analysis this measure is nevertheless needed, if only to compare NRMR with other investments in agricultural research. However, such analysis should be accompanied by additional information that assesses specific aspects of the project design and management. Because of their diversity, NRMR projects offer good opportunities for lessons learned, which add additional value to impact assessment studies compared with those conducted in the field of CGI.

Objectives of the Book

This book is addressed to scientists, researchers, development specialists and policy makers who deal with natural resources and agriculture in the developing countries. We hope that the issues discussed in the book will provide some guidance for those who are interested in how the effects of NRMR can be measured and evaluated and will stimulate further studies in NRM impact assessment.

The book has three major objectives.

1. To provide evidence of the impact of NRMR in the CGIAR.
2. To establish a methodological foundation for impact assessments of NRMR.
3. To draw up a set of lessons for future impact assessment studies.

The book consists of three main parts. Part I offers an introductory section with three chapters. These provide the definitional, historical and theoretical background for NRMR impact assessment in the CGIAR. In the first chapter (this one), some descriptions and definition issues of NRMR are handled. In Chapter 2, the history of NRMR in the CGIAR is described. It introduces the different viewpoints and interpretations of NRMR in the CGIAR. In Chapter 3, the theoretical and methodological foundation for conducting impact assessment of NRMR is laid out. Chapter 3 goes well beyond the empirical part of the book and offers a framework for a thorough analysis of the connection that exists between NRM and productivity enhancement research. However, the actual cases do not necessarily follow the framework proposed in this chapter.

Part II is the core of the book. Here, in eight chapters, the methods and results of seven cases studies on the impact of NRMR projects carried out in the CGIAR are presented. The case studies were conducted by economists at the participating Centres and were guided by the SPIA and editors of this book. Therefore, prior to the chapters that present the case studies (Chapters 5 to 11), an overview is provided in Chapter 4 that briefly introduces the cases. Chapter 4 aims to draw the reader's attention to some common features of the studies. Chapters 5 to 11 present the case studies of NRMR conducted at seven different CGIAR Centres. Five cases are farm-level, micro NRM projects and the remaining two cases are macro projects.

Part III consists of two summary chapters. Chapter 12 synthesizes the case studies and draws some conclusions in the light of the theoretical outline provided in Chapter 3. The last chapter (Chapter 13) offers avenues on how to improve impact assessment of NRMR in the future.

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2 The History of Natural Resource Management Research in the CGIAR

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This chapter draws on a number of past assessments of natural resource management research (NRMR) in the Consultative Group on International Agricultural Research (CGIAR), as listed in the references at the end of the chapter. The evolution of NRMR in the CGIAR parallels that in many other national and international NRMR institutions, having started from a very narrow concept of NRMR, focused strictly on productivity-related soil, water and vegetation management issues in the early days, to the current, broader perspective which seeks to integrate the physical, economic, social and environmental dimensions more effectively. During the transition to this more integrated view, there have been forays into such areas as farming systems research – essentially a first move towards a more integrated NRMR – and into various forms of environmental research related to natural resources and their management.

This chapter starts with a review of the evolution of NRMR in the CGIAR system and concludes with a discussion of the implications for such research in the CGIAR and for impact assessment.

The Changing Perspective on Natural Resource Management and Environment-related Research in the CGIAR

Traditionally, NRMR in the CGIAR included agronomy-related themes such as soil and nutrient management, irrigation and land cover management, water harvesting and so on. It had a strong emphasis on maintaining or increasing natural resource productivity, and focused on complementing the CGIAR genetic improvement research to exploit the benefits of the new cultivars. While NRMR is equated with ecological research in some other contexts, in the CGIAR it includes productivity-oriented research as well.

More recent perspectives on NRMR, that affected the perspective taken in this study, assume that NRMR encompasses research on land, water and biodiversity resources management, and is typically focused on producing knowledge that results in technology options, information and methods/processes that enhance, or have a clear potential to enhance, the productivity and stability of ecosystem resources in a sustainable manner. Research results for the most part are supposed, actually or potentially, to be applicable across national boundaries, i.e. research outputs are, for the most part, international public goods (IPGs). The primary clients of the research are departments of agriculture, forestry and fisheries, government policy makers, non-governmental organizations and other agricultural research and extension organizations. Farmers, forest dwellers, fisher folk and agricultural communities are, of course, the intended ultimate beneficiaries.

Early Natural Resource Management Research in the CGIAR up to 1989

Through the late 1960s and early 1970s, NRMR in the CGIAR focused primarily on the efficient use of fertilizer and other nutrient sources, effective pesticide use and on issues related to water distribution networks and crop adaptation to water stress. There was little specific research related to reduction of environmental impacts, although the thinking in the CGIAR was moving that way.

Through the late 1970s and the 1980s, NRMR broadened and a farming systems focus was added to the agenda, such that natural resource management (NRM) issues were looked at within a systems context. Some programmes researched entire farming systems, including animal feed and other components, while others focused on the mandate crops 'in a farming systems context'. These efforts broadened the CGIAR's crop mandate and the range of research on the agronomic management of these crops. Varietal selection was often done, but genetic improvement by breeding was not included for those 'companion' crops. Farmer-participant methods became central to that work, as much of the applied research was conducted on-farm, by farmers. In all cases the 'systems' researched were based on mandate crops – upland rice, irrigated lowland rice, cassava, maize, etc. Productivity-related research increasingly extended beyond individual crops to include farming systems impacts on farm family incomes, labour use and food security. Water research emphasized water management and operations at the district level. Research on genetic improvement and on related agronomic practices continued for the mandate crops.

The concept of 'sustainability' came into the CGIAR language in 1987, when sustainability and NRM concerns came to the forefront. In 1988, the Technical Advisory Committee of the CGIAR (TAC) produced a paper on sustainability, conservation and management of natural resources, 'Sustainable agricultural production: implications for international agricultural research' (TAC, 1988). Sustainable agriculture was defined therein as the successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources.

1989 and Beyond: Expansion into Broader and more Integrated Natural Resource Management Research

The CGIAR meeting in Canberra, Australia in 1989 was a turning point in terms of opening the doors to a broader and more NRM-focused mandate for the CGIAR. At this meeting, the CGIAR decided to move ahead with preparations to add new research Centres dealing with forestry, agroforestry, water management and fisheries. In 1990, the role of some non-CGIAR, international NRM-focused Centres (International Board for Soil Research and Management (IBSRAM), International Centre for Soil Fertility and Agricultural Development (IFDC), International Irrigation Management Institute (IIMI), International Centre for Research in Agroforestry (ICRAF), International Centre for Living Aquatic Resources Management (ICLARM)) was reviewed, and options for adding forestry to the system were considered. At the same time, TAC reviewed the strengths and weaknesses of NRMR in the system and considered the need to broaden the CGIAR's NRM mandate. IFDC and IBSRAM were not brought into the system, but the rest were; and the Centre for International Forestry Research (CIFOR) was created to deal with forest-related issues.

During that same time frame, the 'ecoregional' approach emerged from TAC as a means for Centres to focus together on integrated crop and natural resources questions within broad ecoregional-focused policy contexts. At its annual meeting in 1990, the CGIAR endorsed the concept; and this broadened the mandate beyond geographical areas delineated by commodity systems (upland rice, lowland rainfed rice, highland maize, etc.) to areas delineated by other (non-commodity) factors.

Research in the CGIAR evolved. Some of the key characteristics of soil and water (S&W)-related NRMR – still at the core of NRMR in the CGIAR System in 1996 – were as follows (TAC, 1996):

- The CGIAR System was investing about US$49 million, or a little over one-sixth of its total resources, in S&W research. The proportion of budget allocated by different Centres to S&W research ranged between 5 and 40%.
- Over one-third of the total CGIAR investment in S&W research was directed towards irrigated lands and rainfed lowlands, proxies for well-endowed lands. The so-called 'fragile' or 'marginal' lands, e.g. the warm semiarid savannahs and forest margins, each accounted for about 15% of the resources, while the cool semiarid highlands and hillsides each accounted for about 5% of the total. The rest went into policy and

other research that could not be attributed easily to any given ecosystem.
- On average, Centres devoted about three-quarters of their S&W efforts to on-site research. The rest was largely focused on policy and management research related to other natural resources. This implied very little research was being done off-site on landscape linkages, an important component of integrated natural resource management research (INRMR) that now has come to the forefront.
- On average, Centres were allocating some two-thirds of their S&W budget to research of an applied nature. This allocation, taken together with the on-site nature of the research, suggested a strong concentration of research efforts on location-specific, production systems-oriented activities, many of which had very low IPG content. Many Centres recognized then that, to meet the IPG requirement, it was necessary to do comparative research across locations and countries. The extent to which they were explicitly building this into their programmes is not clear from the data available, although some were clearly focused on this aspect, e.g. the ASB (Alternatives to Slash and Burn) Programme.

In 1996, TAC also put forth the first formal call in the CGIAR for an 'integrated' natural resources management research approach, based first and foremost on S&W resource management (TAC, 1996). The S&W paper emphasized that the CGIAR System needed a more consistent, systematic and environmentally sensitive integrated natural resource management (INRM) framework for research. This would provide a logical framework for linking the various NRM activities in the system. Four sets of interrelated linkages were identified:

- Links between productivity-enhancing and resource-conserving research (e.g. crop improvement and NRM).
- Spatial or landscape-level linkages (e.g. upstream–downstream linkages in a watershed management framework).
- Temporal linkages (e.g. links between present and future, or sustainability considerations).
- Linkages between research and the diffusion/adoption of results from such research.

Research within this INRM framework sought to incorporate a broad spectrum of disciplines and activities outside the S&W focus, including those related to forestry, fisheries and genetic resources. These other areas of activity were rightly recognized as being critical to the successful use of an INRM framework as an integrating tool. One example of an INRM framework focusing on the spatial (in this case watershed) linkages is provided by an integrated watershed management framework.[1]

This set the stage for a much broader approach to NRMR in the CGIAR. Since that time, a number of key meetings has taken place and a

[1] A detailed model is presented in Annex 1 of the S&W study.

number of important decisions have been made regarding NRMR in the CGIAR. All have led to the conclusion that a broad, integrated approach to NRMR is needed, one that links natural resources to people and to the policies that guide the ways in which they use and manage resources; one that recognizes the explicit links between NRM and sustainability; and one that recognizes the links between the biophysical aspects of natural resources and the strong socio-economic and political pressures that exist related to natural resource ownership, management and use.

The growing interest in the CGIAR in what is called INRMR has taken a slightly different and broader path than that envisioned initially by TAC. This broad research paradigm emphasizes the nexus of productivity enhancement – environmental protection – human development as a multiple research objective across different time and spatial scales, from field plot to landscape levels (Maredia and Pingali, 2001; Sayer and Campbell, 2001; Turkelboom *et al.*, 2003). This is parallel to the integrated watershed management paradigm, which has been in use for many years (TAC, 1997, 2001; Brooks *et al.*, 2003) (see Box 2.1).

Box 2.1. Time line of developments in natural resource management research in the Consultative Group on International Agricultural Research

- Late 1960s/early 1970s
  Natural resource management (NRM) research at the four international agricultural research Centres mainly supporting germplasm improvement activities and focused on fertilizer/nutrient-use efficiency.
- Mid/late 1970s
  The consultative Group on International Agricultural Research (CGIAR) branches out into several new areas of NRM embracing livestock research, farming systems, conservation of genetic resources, plant nutrition, water management and policy research. Number of international Centres in the CGIAR grows from four to 13.
- Late 1980s/early 1990s
  CGIAR launches an inquiry into the need for further expansion of the number of Centres, so as to strengthen the CGIAR System's capacity for sustainability-related research. Group decides that agroforestry should be included in the CGIAR research portfolio, and shortly thereafter, irrigation management and aquatic resources.
- Late 1990s
  Productivity and NRM are adopted as the twin pillars of research on aquatic resources, conservation of genetic resources (biodiversity), food crops, forestry/agroforestry, livestock, soil and water nutrients, water management and policy research. Investments in 'protecting the environment/sustainable production' increase dramatically as concern about the environment dominates.

Investment in Natural Resource Management Research at the CGIAR over the Years[2]

It is difficult to be precise about the cumulative level of CGIAR investments in NRM-type research activities since the System's inception, principally because of two elements. First, as noted above, there is the shift in thinking by some within the System regarding what NRM and INRMR actually encompass. As one moves closer towards the INRM concept, one comes up against the problem of identifying specific resource allocations. Thus, for example, a significant portion of INRMR could also be labelled as policy research within the more conventional definitions of such used in the System. Second, the 'official' CGIAR *Activity* (or 'Undertaking') definitions have changed over time and these definitions encompass different and changing aspects of NRM-related research. For example, of the five principal CGIAR activities used for classification purposes between 1992 and 2001, two of these – 'Protecting the Environment' and 'Increasing Productivity through Production Systems Development and Management' – captured different aspects of NRMR. The CGIAR investment allocated to 'Protecting the Environment' amounted to almost US$500 million (in nominal dollar values) between 1992 and 2001 – based on an average investment share of 16.5%. Over the same period, investments in 'Production Systems Development and Management' accounted for roughly US$630 million (averaging 21% of the total investment). Certainly not all of this can be defined strictly under NRMR, but these figures offer some indication of the significant level of investment in NRM-related research since 1992.[3]

CGIAR investments in 'Increasing Productivity' fell from 47% of the total in 1994 to 34% in 2002, and are expected to fall another 3% by 2006 (based on data released by the CGIAR Secretariat). Within this main activity, the sub-activity 'Germplasm Enhancement and Breeding' investments fell from 23% (1994) to 18% (2002) and are projected to fall to 15% in 2006, while the sub-activity 'Production Systems Development and Management' dropped from 24 to 17% between 1994 and 2002 (projected at 16% in 2006).[4] At the same time, CGIAR investments in 'Protecting the Environment' and 'Improving Policies' rose from 15 to 18% and from 10 to 15%, respectively, over this period. Under the current system where CGIAR *Outputs* are now tracked, 'Sustainable Production' accounts for

[2]Draws on Kelley and Gregersen (2005).

[3]Since 2002, the CGIAR reports only by Output category (germplasm improvement; germplasm collection; sustainable production; policy; enhancing national agricultural research systems) and no longer by CGIAR Activity. Thus, the figures could not meaningfully be updated beyond 2002.

[4]The two largest components within the 'Production Systems' sub-activity, cropping systems and livestock systems, saw their investments shares fall the most, from 16 to 9% and from 6 to 4%, respectively. At the same time, investments in tree systems fluctuated around 3% while investments in fish systems actually rose.

33% and ‘Policy’ for 18% of the total CGIAR investment.[5] Thus, whether judged by CGIAR *Activities* or *Outputs*, there is clearly a trend in CGIAR investment away from the more direct productivity-enhancing type activities, for which there have been proven impacts on poverty. This has raised questions about the current direction and focus of the CGIAR (World Bank, 2003).

Investments by the CGIAR across the 16 CGIAR Centres from 1994 to 2005 show a similar trend. Many of the major commodity Centres and the ecoregional Centres – those Centres that are strongly productivity enhancement-focused – have seen their investment levels reduced significantly, both in nominal and real terms, consistent with the trend towards less investment in crop germplasm and increasing productivity. When viewed in real terms, i.e. after adjusting for inflation, the impact of these reduced resources is even more significant. The Centres which expanded during this period were usually those that focused on NRMR (particularly environmental protection aspects) and policy. Thus, the annual budget of the International Water Management Institute rose from US$9.7 million (1994–1996) to US$23.0 million (2003–2005) during the last 9 years. ICLARM’s (now the WorldFish Centre) budget rose from US$8.0 to US$14.8 million over the same period. ICRAF’s budget went from US$17.1 to US$29.1 million; CIFOR’s from US$8.0 to US$14.8 million; the International Food Policy Research Institute’s budget went from US$14.5 to US$30.6 million; and that of the International Plant Genetic Resources Institute from US$14.5 to US$33.9 million.

Although the CGIAR activity ‘Protecting the Environment’ has been one of the fastest-growing areas of research activity within the CGIAR, it is also an area for which there is only limited documented impact to date. As noted by the World Bank (2003), NRMR in the CGIAR is ‘under-evaluated’ and requires more accountability. ‘Under-evaluated’ relates to four distinct aspects of CGIAR NRMR: productivity/efficiency of resource use; science quality; comparative advantage; and impacts on the ground.

Concluding Comments

Notwithstanding the lack of precise data, it is obvious from the above that the CGIAR’s investment in NRMR has been and remains substantial and that there is a need to document the impacts of the CGIAR’s NRMR. That is the main purpose of the Standing Panel on Impact Assessment’s NRMR initiative reported on in this book. Yet this only represents a start, a snapshot in time of selected NRM types of projects commonly undertaken by the CGIAR Centres with their partners. There is obviously a need for more

[5]Beginning in 2006, in addition to tracking *Outputs*, investments by *Activities* will also be tracked. Preliminary data for 2006 (projected) show a continuation in the trend observed from 1992 to 2002; i.e. investments in ‘Increasing Productivity’ continue to fall, while investments in ‘Sustainable Production’ (or ‘Protecting the Environment’), as with ‘Policies’, are increasing.

work to provide a comprehensive picture of the impacts of the CGIAR in this area, which forms an important part of the overall agricultural development research agenda.

An additional factor is the emergence and rapid growth of the INRM paradigm. There are many welcome features to the INRM approach, as discussed by Fujisaka and White (2004). It addresses a range of highly important, heretofore neglected topics and dimensions of NRMR in the CGIAR related to social and livelihood security impacts. But there are concerns as well, particularly related to the highly conceptual nature of the definition of INRM and, thus, the problems introduced in attempting to do specific, quantitative impact assessment. Kelley and Gregersen (2005) raise a number of other issues about INRM, particularly related to assessment and evaluation.

While the INRMR concept is conceptually more inclusive, comprehensive and process-oriented than conventional and more focused NRMR, the concept is new enough that lag times have not passed for impacts to be measurable. One of the fundamental issues that will soon require debate is the nature of the impacts that need to be measured for INRMR.[6] Conducting conventional quantitative impact assessment of INRM investment (related particularly to the accountability function of impact assessment) poses substantial challenges. As indicated by the case studies in this book, this conclusion holds as well for the more focused, narrowly defined NRMR. We are moving down the pathway of learning in this area; but much of the path remains to be covered before we can sit back and be satisfied with our approach to NRM impact assessment. What is clear at this point is that much more serious attention must be given to measuring the benefits and value of information generated through INRMR, in particular within the context of its specific contribution to achieving CGIAR goals. The final chapter in the book comes back to this point.

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[6]While the use of impact assessment as a learning tool for those doing research is quite clear in the case of INRM, it is less clear exactly what the INRM thinking is with regard to the accountability function of impact assessment for the investors in the research.

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3 Productivity Enhancement and Natural Resource Management

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There has been a strong body of research on agricultural productivity over time. The recent study by Mundlak (2005) presents the median outcomes based on data from 1967 to 1992 for 130 countries. The median outcomes have increased annually as follows: total output by 2.2%, per capita output by 7%, yield:land ratio by 1.9% and yield per worker by 2.8%. In addition, median agricultural prices have declined by 0.4%. These and other results in the Mundlak (2005) study suggest that over the last two centuries agriculture has gone through a significant growth in its output. However, particularly over the last 50 years, this increase in productivity has been associated with significant changes in decomposition of agricultural inputs. The use of labour has not grown much, and in some countries even declined. Expansion of land in agriculture has decelerated, but there is an increased reliance on mechanical inputs, chemicals including pesticides and fertilizers and irrigation.

The literature on agricultural productivity (see Mundlak, 2000) mostly decomposes the growth of agricultural output into growth in the use of factors of production and growth of total factor productivity. Most studies identify the contribution of changes in use and productivity of labour, capital and land to the growth of agricultural output. Yet other bodies of literature have emerged and have shed new light on the evolution and dynamics of agricultural systems and their future. Diamond's (1997) history of humanity over the last 40,000 years also stresses the key role of the introduction, adaptation and adoption of new technologies in explaining the relative well-being of various societies. However, his analysis emphasizes that technological change has occurred in the context of environments with unique geophysical and biological features. For example, he uses the relative ease of transfer and adaptation of farming systems across locations with the same latitudes versus the relative difficulty of transfer across locations of the same longitudes to

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explain the faster growth of production systems in Europe and Central Asia versus Africa and Latin America. Diamond (1997) suggests that agricultural, technological and natural systems co-evolve, and he emphasizes that agricultural and other production practices that ignore its interaction with the environment may lead to failure and even collapse. While Diamond's analysis underemphasizes the capacity of markets and modern institutions to adjust to changes in environmental conditions, his concerns are shared by economists (Page, 2005).

The emerging literature on agriculture, natural resources and the environment (Carlson and Wetzstein, 1993; Lichtenberg, 2002; Shiferaw *et al.*, 2004) has expanded the tools (models) of economics to incorporate environmental and natural resource management (NRM) considerations in analysing the performance of agricultural sectors and markets. Relying on that literature, this chapter presents conceptual frameworks to analyse NRM research (NRMR) projects and their impacts. The frameworks will allow analysts to better categorize and analyse the diffusion and impacts of NRM innovations. It will provide a context to introduce and position the research project analysed in the book. We develop mostly frameworks to analyse micro-level NRMR projects, but we also provide an economic perspective on macro-level projects that develop policies and provide standards for product certification programmes. The next section presents an overview of adoption processes and their impacts, and is followed by an introduction of several modelling frameworks of different types of micro-level NRM projects. Finally, we discuss the economic rationale for, and some of the basic features of, macro-level NRM projects.

Innovation and Adoption

Economists have realized that there is a significant gap between the moment a technology is introduced and the time that it is adopted by farmers. The diffusion of a new technology among the population of potential adopters is gradual, sometimes measured in years. Therefore, assessment of the impacts of a new innovation has to take into account the diffusion process. Early empirical studies found the diffusion curve (measuring the fraction of the potential population that actually adopts the technology) to be an S-shaped function of time. Initial studies (Griliches, 1957; Mansfield, 1963) modelled diffusion as a process of imitation and communication among homogeneous units. Griliches' empirical analysis showed that the parameters of this imitation process are affected by profitability considerations. However, the analysis of the imitation model lacked an explicit economic decision framework of individual units, and the homogeneity assumption is hardly met in reality. Marketers of new technologies frequently divide the potential adopters into market segments with different features and likelihood of purchase. The introduction of statistical tools (such as Logit and Probit) to analyse discrete choices by producers has provided the means of identifying the features of early and late adopters from empirical observations.

Paul David (1969) introduced an alternative to the imitation model, the threshold model of diffusion. The threshold model has an explicit economic micro-level decision-making mechanism, recognizes heterogeneity among economic agents and incorporates dynamic processes that drive the diffusion process forward over time. This model is very flexible and allows the introduction of market-clearing mechanisms as well as policies into the analysis, and assesses their impacts on technological change. The key elements in adjusting the model for specific situations include the following.

The micro-level behaviour

This includes the decision criteria of the micro-unit, which may be a firm, farm or family. Profit maximization is frequently used as the decision criterion among technologies, especially for those that are non-divisible (tractors). Feder *et al.* (1985) suggest that household production models and expected utility maximizations have been used to analyse divisible choices, e.g. allocation of seed varieties or crops. In these cases risk aversion or time constraints have been the main cause for partial adoption and diversification. In some adoption studies, the adopter's choice is dynamic, and the decision criterion is maximization of expected net present value of profit or utility. Some studies have applied Dixit and Pindyck's (1994) real-option techniques to analyse adoption of technologies under risky conditions (see survey by Sunding and Zilberman, 2001). In these cases adoption does not occur at the moment when a new technology becomes profitable but, rather, at the moment when it is most profitable or worthwhile to adopt. In addition to the specification of the decision criteria of the adopters, the micro-modelling framework must specify the constraints facing the decision makers, be it availability of credit, environmental regulation, etc.

The specifications of the technology

The key to modelling adoption choices is realistic modelling of the features of the technology being considered. New seed varieties have been frequently modelled as divisible innovations that increase per unit of land mean and variance of profits and required fixed costs (Feder *et al.*, 1985). These specifications combined with risk aversion were used to explain situations where larger firms were the earlier adopters of new varieties, but eventually the land shares of new seed varieties among smaller farms became larger. Similarly, mechanical innovations were modelled frequently as labour-saving, which led to the prediction that farms with tighter time constraints or higher opportunity costs of time would be early adopters. The studies on impacts of NRM have to emphasize the features of technologies resulting from these innovations.

Sources of heterogeneity

The challenge of modelling is to obtain the correct result with the simplest modelling framework. Farms and individuals are different in many ways, but the analysis of diffusion of specific technologies requires identifying the one or two dimensions of heterogeneity that are most pertinent for the adoption choices. The heterogeneity results in differences in technology choices among farmers. At every moment there is a threshold level of the variable that is the source of heterogeneity separating adopters and non-adopters. Within adopters, the intensity of adoption may vary. Differences in landholding have been found to explain adoption of various mechanical and biological innovations, and differences in education have been important in explaining differences in adoption of many technologies as well. Climatic conditions and locations are other sources of heterogeneity that may explain the timing and extent of adoption of various technologies.

Aggregation procedures

For each given combination of prices and policy parameters, aggregation of outputs and inputs over all of the micro-units will result in aggregate output supplies and input demand functions. These aggregate output supplies and input demand are then equated to output demands and input supplies to establish equilibrium prices. In cases of NRM technologies, the aggregation over micro-units will also result in aggregate pollution and natural resource use as functions of prices and policy variables. These functions will be crucial for policy analysis.

Dynamic drivers

The spread of the technology among individuals over time is likely to be triggered by changes that make the technology more appealing. Some of the processes used in the literature to explain these changes in the valuation of a new technology leading to its adoption include learning about the performance of the technology that reduces the risk of the potential adopter, learning by doing by a manufacturer of the technology that leads to reduction in its cost to adopters, learning by using by the adopters that reduces the gains from adoption, and network externalities in cases where benefits depend on the number of users. In cases of NRM projects, the dynamics of the natural resources can trigger adoption. For example, Shah *et al.* (1995) show that decline in groundwater aquifers due to pumping induces the continuous adoption of water-conserving technologies.

Policies and other institutions

The adoption choices of the micro-units are affected by economic and technical parameters. The key variables affecting choices include prices, support policies, marketing efforts and climatic and agronomic conditions. There is ample evidence that price-support policies are major incentives to increase supply-enhancing policies. As shown in subsequent chapters, subsidies were important in enhancing adoption of the alley-cropping technology of the International Centre for Agricultural Research in the Dry Areas (ICARDA). Adoption of NRM innovations is likely to be enhanced by resource and environmental policies. Trading in water that will lead to a price increase for farmers may lead to adoption of water conservation. Extension and marketing efforts are also crucial in enhancing adoption. Farmers may be uncertain about the performance of a new technology and its fit to their circumstances, and demonstration and assurance from a trusted dealer or extension agent may enhance their likelihood to adopt. The lack of well-functioning marketing channels for NRM technologies may put them at a disadvantage compared with seed technologies.

Information and education

A decision about technology adoption has to overcome lack of knowledge about various aspects of the technology. Uncertainty about the characteristics of the technology combined with risk aversion is a major barrier to adoption, and there are several mechanisms that are used for uncertainty reduction, including demonstration by the technology supplier or extension. Informal learning by actions of neighbours and word of mouth are probably the most effective means of sustainable diffusion. Indeed, informal networks can have a major effect on adoption (Rogers, 1983). Sunding and Zilberman (2001) argue that introduction of new technologies is associated with introduction of various types of risks to the systems, risks that can be reduced by informational efforts provided by extension or effective marketing services. Potential adopters are concerned about whether a new technology is performing what it is supposed to do. They are also concerned about risk fit, i.e. the technology may not fit their unique situations. Product demonstrations and mechanisms to assist in technology adjustments and adaptation are likely to increase the value of a technology and increase the likelihood of adoption. The quality of the organization marketing or dissemination of a technology has a lot to say about the extent to which it is adopted. Likelihood of adoption and the gain from technology depend on the capacity of the potential adopters.

Schultz (1975) emphasizes the importance of allocative ability and the capacity to quantify and evaluate the alternative technologies. This provides a strong case for educational efforts that provide basic analytical skills. Some technologies require farmers to have basic knowledge and skills, and there is a challenge to develop various educational efforts that can enhance human capital and contribute to overall gain from technological change. This suggests that the Consultative Group on International Agricultural Research (CGIAR) needs a strategy that aims to develop capacity amongst national agricultural research systems (NARSs) and non-governmental organizations (NGOs) to institutionalize NRMR and related farmer-based knowledge enhancement and learning systems.

Rate of Return of Natural Resource Management Micro Projects

Net present value (NPV) and rates of return are used as indicators for productivity of research projects, and will be analysed for the NRM projects considered in this book. The rates of return are based on a comprehensive cost–benefit analysis of a project that takes into account economic and, in theory, environmental costs as well. In this section we present a general formulation to assess the rates of return of NRM projects that will be adjusted to accommodate specific technologies.

The concept of cost–benefit analysis for a micro NRM project can be formalized following well-established procedures. Consider a project comprising an embodied technology that requires external inputs and local knowledge. Adoption of the technology results in shifting the supply curve of a homogeneous agricultural commodity and, in addition, generates positive human health, natural resource and environmental externalities. The market benefits (MB_t) of technology adoption can be divided into three categories: farmers' surplus (FS_t), manufacturers' surplus (MS_t) and consumers' surplus (CS_t). These rents accrue to agricultural producers, manufacturers of the technology and consumers, respectively, in time t and must be measured over the service life of the technology, T. The sum of this measure is MB_t, where:

$$MB_t = CS_t + FS_t + MS_t \tag{3.1}$$

What needs to be added for the case of most NRM projects is that, in addition to market benefits, NRM research produces positive human health (HH_t), natural resources (NR_t) and environmental benefits (EB_t). Some of these benefits may be internalized by the adopters of the technology, e.g. improved farmer health from reduction of toxic chemicals is part of their willingness to pay for the technology and is, therefore, included in FS_t. However, due to the non-rival character and the non-exclusiveness of some of the NRM outputs (off-site and off-time externalities), additional non-market benefits (NMB_t) and costs have to be accounted for. If we adjust the definition of the health, environmental and resource effects to exclude market benefits, the non-market benefit of an NRM technology is:

$$NMB_t = HH_t + NR_t + EB_t \tag{3.2}$$

Generally, the non-market benefits will be cost-reducing instead of output-increasing, although improvements in HH_t will ultimately enhance productivity. For example, the *Atriplex* or cactus alley cropping (e.g. the ICARDA NRM project in Morocco) has a positive impact on the level of pollution by reducing the level of sedimentation in water bodies caused by soil erosion of the conventional barley-cropping system in the dry areas of the Mashreq/Maghreb region. To quantify non-market benefits, one has to use techniques of monetization such as replacement cost procedures, contingent valuation or hedonic pricing in order to estimate the additional benefits of NRM. The sum of market and non-market benefits at time t is $TB_t = MB_t + NMB_t$, and it has to be compared with the cost of the NRM project.

On the cost side, the full costs (TC_t) of NRM projects are often difficult to measure because NRM technologies draw information from a number of research activities of a Centre that are often not project-specific, e.g. agronomic and varietal trials or soil and socio-economic surveys. Given that there are specific NRM research costs (RC_t) that occur over a defined period of time, there are also the costs of developing the technology further for local adaptation through applied research (DC_t) and the costs of technology diffusion due to additional extension efforts and of organizing farmers, in cases where the NRM technology requires collective action through public or NGO extension services (EC_t). The costs of participatory research and farmer experimentation with the technology, which sometimes may be necessary before it can be adopted in individual farmers' fields, are included in the marginal costs of the output for which the technology is used. Thus, the total cost of innovation at time t is:

$$TC_t = RC_t + DC_t + EC_t \tag{3.3}$$

Considering the time dimension, if r denotes the discount rate, the present value of the net benefits of an NRM research project can be calculated as:

$$NPV = \sum_{t=0}^{t=T}(TB_t/(1 + r)^t - \sum_{t=0}^{t=T}TC_t\,/(1 + r)^t) \tag{3.4}$$

The internal rate of return (IRR) is the discount rate resulting in an NPV of zero:

$$NPV = \sum_{t=0}^{t=T}(TB_t - TC_t)/(1 + IRR)^t = 0 \tag{3.5}$$

If all prices used in the analysis are economic prices and if the NRM technology is an international public good, the IRR reflects the efficiency of the investment in NRMR for world society. The IRR can be compared with the social opportunity costs of capital or the social rate of time preference (Pearce and Turner, 1990).

Apart from the variables included in Eqn (3.1), there are also other factors that affect the IRR, e.g. network externalities, social capital, prior knowledge, institutional arrangements and social, cultural and policy conditions. These factors to some extent may be embedded in the costs and benefits of technology adoption and, therefore, should be reflected in adoption rates, but they rarely are explicitly revealed. However, on the other hand, these factors may be good indicators of the potential benefits of the research provided they can be overcome by policy shifts or in the process of social change. For example, NRM projects usually do not enjoy the benefits of both private and public marketing infrastructures that exist for seeds and effectively help to diffuse new varieties at low cost.[1] In addition, NRM projects sometimes have to overcome existing path dependencies and vested interests as shown, for example, in the case of integrated pest management where adoption can be inhibited in spite of a new technology that is economically attractive (e.g. Cowan and Gunby, 1996). Thus, external factors can introduce some degree of uncertainty to the rate of return, as erstwhile conducive conditions can also turn negative. For example, in the case of soil management, if commodity prices crash, the incentives to maintain soil conservation practices may decline rapidly.

In the rest of the chapter we emphasize modelling of various types of NRM innovations and present basic formulations that may not explicitly present dynamics for rates of return. However, the results above can be used to obtain operational measures of rates of return.

Modelling Micro-level Natural Research Management Innovations and their Adoption

Traditionally, models of production either looked at input as generic, distinguishing mostly between fixed and variable inputs, or concentrated on a small number of key inputs, such as capital, land and labour. However, there is growing recognition that different agricultural inputs vary in their impacts on the environment. For example, chemical pesticides are damage-control agents: their effectiveness depends on the size of the pest population and the build-up of resistance. They may also have negative environmental side-effects, depending on when and where they are applied. Some agricultural inputs, like water, and some outputs of NRM projects, like fish and forest products, are natural resources and agricultural production affects the dynamics of

[1]There are, however, in addition to the efforts of NGOs and civil society organizations, publicly financed agricultural extension systems in most countries, and with them various programmes and policies with subsidies aimed at introducing improved NRM management practices, although the latter are often constrained by competent staff and inadequate resources.

these resources. NRMR projects seek to test and develop management methods that improve the interaction of agricultural systems, natural resources and the environment. Many of these projects are production-oriented, while others emphasize stewardship, although the latter require incentives through compensation. Here we review some modelling of NRM technologies to assess their adoption and impacts. Because of the diversity of NRMR projects, none of these models can capture all possible features, but they can provide a good starting point for our interpretation of the case studies. We sketch the key features of micro NRM innovations affecting crop systems, so a key variable is land that is assumed to vary in several dimensions (water-holding capacity, yield, etc.). We also assume constant returns-to-scale technologies. The technologies of these crop systems are characterized by three types of equation:

- Production functions, where:
  output/land = *f* (technology, variable inputs, stocks, random effects, qualities).
- Pollution-generation functions, where:
  pollution/land = *g* (technology, variable inputs, stocks, random effects, qualities).
- Equations of motion, denoting changes of stocks over time.

These equations are especially important in analysing perennial crops or livestock, as well as cases of stock pollution (soil degradation). Here we emphasize modelling the first two elements.

Production functions may include several crops because several NRM innovations allow increasing the number of crops produced on a parcel of land. The stocks affecting productivity include human capital, natural capital and physical capital. We separate between two sources of variability – heterogeneity (reflecting differences in quality across locations and farms) and randomness (reflecting differences in conditions across time). The same factors that affect the production functions affect the pollution-generating functions. While we introduce here a rather general presentation of production systems, modelling of a particular innovation should concentrate on explicit representation of the elements that are pertinent for this innovation. Below we present some special cases. In each case we use i as a technology indicator, and it assumes the value 0 for the traditional technology and 1 for the modern one.

Innovations introducing multiple cropping

First we consider cases of NRM innovations that allow transition from single to multiple farming activities. We can distinguish between cases where NRM innovations result simultaneously from production of multiple outputs on a field (crop–livestock intercropping, production of grains with hedge crops) and cases where NRM leads to sequential production of multiple outputs in the same season.

To demonstrate some of the modelling and analysis issues of the adoption of NRM technologies, we now present a simple analysis, without explicit time dimensions, comparing outcome before and after new NRM technologies are available. Let y_0 be output and

$$y_0 = f_0(x_0, q) \tag{3.6}$$

be the production function per unit of land with the traditional technology. The variable input per unit of land is x_0 and q is an indicator of heterogeneity (e.g. land quality, human capital, climate condition). The distribution of land with quality q is presented by $h(q)$. Pollution per unit of land and the pollution-generating function is:

$$z_0 = g_0(x_0, q) \tag{3.7}$$

Assume that higher q reflects higher quality and, without loss of generality, is associated with higher output levels. The highest quality is $q = \bar{q}$. There may be situations where there is either positive or negative correlation between pollution and output. We assume negative correlation (so that $\delta f_0(x_0,q)/\delta q \geq 0$, but $\delta g_0(x_0,q)/\delta q \leq 0$). Thus, with the same level of variable input, land with lower q is producing less and polluting more.

For example, lower q may be an indicator of vulnerability to windstorms. Windstorms can reduce output through wind erosion that may also damage neighbouring bodies of water. The indicator q may assume values from 0 to 1, where 1 corresponds to a location with no wind damage. The variable input x may represent intensity of soil tillage, where more effort leads to higher output yet more vulnerability. The variable input may also be interpreted as a chemical (pesticide), and lower q corresponds to reduced input-use efficiency and negative side-effects. For example, spraying in windy locations may result in 50% drift while in more suitable environments q is 0.8, and the input-use efficiency is 80%. For simplicity, assume profit-maximizing producers, the price of output is p and the price of variable input is w. The optimal variable input per unit of land, x_0^*, will be determined where $\delta f_0(x_0^*,q)/\delta x_0 = w/p$, and it can be shown that higher-quality units will produce more output and use more variable inputs. The profits per unit of land with the traditional technology are:

$$\pi_0(q) = pf_0(x_0, q) - wx_0^* \tag{3.8}$$

Furthermore, there is a critical threshold level q_c^0 where profits are equal to zero, so that production occurs only on locations with $q \geq q_c^0$. The aggregate output supply under the traditional technology is:

$$Y_0(p,w) = \int_{q = q_c^0}^{\bar{q}} f_0(x_0^*, q)h(q)dq \tag{3.9}$$

One can similarly define aggregate variable input demand $X_0(p,w)$. Similarly, aggregate pollution supply is denoted by:

$$Z_0(p,w) = \int_{q=q_c^0}^{\bar{q}} g_0(x_0^*,q)h(q)dq \tag{3.10}$$

Let the social cost of the pollution be denoted by $C(Z)$ assuming price-taking behaviour and no regulation of pollution. Under these assumptions, there is overplanting of the traditional variety and social welfare is equal to aggregate profit minus the cost of aggregate pollution.

Simultaneous multiple cropping

Now suppose that an NRM technology of simultaneous multiple cropping is available. In the case of vulnerability to windstorms, it may involve planting, say, a hedge or alley crop so that the effects of windstorms are reduced. The hedge or alley crops occupy a fraction of the field, which produces v_B dollars of value. It reduces the area planted with the main crop, which reduces output, but may increase yield per acre as vulnerability to wind declines. We abstract away from the dynamic costs of planting a hedge crop, which is likely to be a perennial crop, and assume that the annualized cost of the new technology is c. Thus, the net benefit per unit of land is $v = v_B - c$. The production function of the main crop with the new technology is $f_1(x_1,q)$ and the pollution function is $g_1(x_1,q)$, where x_1 is per unit input with the new technology. The new technology reduces pollution $(g_1(x_1,q) < g_0(x_1,q))$ and the reduction of pollution is larger with the lowest qualities $(\delta[g_0(x,q) - g_1(x,q)]/\delta q < 0)$. The new technology reduces the output of the major crops on locations with high q, and thus low vulnerability to storms, and may increase the output on locations with very low q, so that the gap in output between the technologies increases with q $(\delta[f_0(x,q) - f_1(x,q)]/\delta q > 0)$. The optimal variable input per unit of land with the NRM technology (if it is profitable) is x_1^*. The profits per unit of land with the NRM technology are:

$$\pi_1(q) = pf_1(x_1^*,q) - wx_1^* + v \tag{3.11}$$

The same methods as in Caswell *et al.* (1990) can show that under plausible conditions the new technology will be adopted on lands of lower quality. The critical land quality, q_c^1, is the lowest quality where farming will occur and $q_c^1 < q_c^0$. There will also be a switching land quality, q_s, where $\pi_1(q_s) = \pi_0(q_s)$, above which the traditional technology will be adopted. The introduction of the NRM technology expanded the utilized land by the area with land qualities with $q_c^1 < q < q_c^0$. The lands with $q_c^0 \le q \le q_s$ will switch from the traditional to NRM technologies. Higher earning for the hedge crop will increase the gain from adoption and will increase the range of qualities where adoption is optimal. The analysis suggests that adoption is likely to increase the greater is the gain from the second crop (v_B) and the smaller is the cost of adoption (c). The specific properties of the production function and the distribution of q will affect adoption.

The aggregate pollution after the NRM technology is introduced is:

$$Z_1(p,w) = \int_{q=q_c^1}^{q=q_s} g_1(x_1,q)h(q)dq + \int_{q=q_s}^{\bar{q}} g_0(x_0,q)h(q)dq \tag{3.12}$$

The aggregate output of the main crop and the aggregate variable input are determined similarly and are denoted as $Y_1(p,w)$ and $X_1(p,w)$, respectively. The total value generated from the hedge crop is:

$$V = \int_{q=q_c^1}^{q=q_s} vh(q)dq + \int_{q=q_s}^{\bar{q}} vh(q)dq \tag{3.13}$$

Thus, for a competitive industry, the benefit from the new technology at a given period is:

$$TB = p[Y_1(p,w) - Y_0(p,w)] - w[X_1(p,w) - X_0(p,w)] + V + C(Z_0(p,w)) - C(Z_1(p,w)) \tag{3.14}$$

For simplicity, we ignored the time dimension of the benefits of the technology. Computation of the rate of return requires assessing benefits and costs over the life of the technology and solving Eqn (3.5). It is not clear that the new technology will reduce pollution as more land is introduced to production, but these new lands generate extra value for farmers. Furthermore, even without considering the cost of R&D, it is not clear that the NRM technology will improve welfare (i.e. whether $TB > 0$). If the new technology generates extra pollution because of expansion of farming activities, the extra cost of the pollution may exceed the extra benefits. However, if the NRM technology reduces aggregate pollution ($TB > 0$) even if TB is large and the rate of return to R&D is high, the technology by itself cannot attain an efficient outcome, i.e. one that maximizes the sum of the surplus of consumers and producers, minus environmental costs and R&D expense. The optimal policy requires that the farms will take into account the environmental costs of their activities, i.e. optimal input use at each field is at the level where the value of marginal product of the input is equal to the sum of its price and the marginal externality cost of the input:

$$p\delta f_i(x_i,q)/\delta x_i = w + (\delta C/\delta Z)\delta g_i(x_i,q)/\delta x \tag{3.15}$$

This optimal outcome can be achieved by policy intervention through taxes, subsidies or tradable quotas. Introducing such a policy may also change incentives for adoption. It may increase adoption especially if the marginal cost of pollution is high. Thus, when there are externalities, achieving optimality requires combining policy and technology innovations.

The case studies discussed in the next part of the book include two chapters where the NRM innovations introduced simultaneous multiple production of crops. The model presented here is especially appropriate for the ICARDA case studies where alley cropping of *Atriplex* and cactus is used to enhance the productivity of barley and other crops grown in semiarid conditions (Chapter 9). The International Centre for Research in Agroforestry (ICRAF[2]) project has intercropping of grass, legumes, plants and nitrogen 'trees' that allow enhancement of soil productivity in locations, mostly in Africa, where nitrogen fertilizers are underutilized because of credit, price or access constraints (Chapter 8). The legumes or trees mostly enhance productivity of the main crop, but may provide extra benefit (firewood). The quality indicator q in this case may respond to differences in soil nitrate, so adopters will be growers with especially low soil nitrate. Here our model applies quite well, with the externality consideration playing a minor role if the differences among producers reflected differences in human capital. In this case our analysis has to be modified. Then the adopters will have higher qs, new lands will not enter into production and the well-to-do farmers will benefit from the technology.

Sequential multiple cropping

Consider the case where the NRM technology entails adding an activity for the off-season crop. It may either add or subtract resources to produce the traditional crop. The production function of the off-season crop is:

$$y_1^0 = f_1^0(x_1^0, q, y_1) \tag{3.16}$$

where y_1^0 is output and x_1^0 is variable input for the off-season crop. It may also benefit from residues of the traditional crops, whose volume is assumed to depend on y_1 (e.g. crop residues are used as a source of nutrients for the second crop). Assume that the crop grown with the traditional technology continues to be grown, but its productivity is affected by the input use of the off-season crop so that the production function becomes:

$$y_1 = f_1(x_1, q, x_1^o) \qquad ([3.17)$$

The unit price of an off-season crop is p^o, and the introduction of the extra crop results in extra cost c. The introduction of the off-season crop assumes to change the pollution per unit of land to $g^o(x_1, x_1^o, q)$. The optimal x_1 is determined by solving:

$$p\delta f_1/\delta x_1 + p^o \delta f_1^o/\delta y_1.\delta f_1/\delta x_1 = w + \delta C/\delta Z.\delta g^o/dx_1 \tag{3.18}$$

This optimality condition recognizes that, with an off-season crop, the determination of x_1 takes into account the direct benefits and the contribution to the off-season crop. Thus, if this crop reduces the externality, then the optimal level of the variable input in the regular season and output from the first season increase, and there are gains from production in the off-season. The off-season crop increases the productivity in the first season and reduces the pollution, and the main season crop reduces

[2]Now called the World Agroforestry Centre.

the negative side-effects of the off-season. Thus, the multiple cropping of crops that complement each other results in a cycle of virtue. But of course, the introduction of multiple cropping requires extra costs per unit of land, and adoption will occur only when this extra investment will repay itself. Gains from adoption may vary among farmers and locations. The WorldFish Centre project described in this book (Chapter 7) is a case study of multi-product NRM technology. It includes production of aquaculture by small-scale farmers in Malawi who produce vegetables and other food crops. The authors show that location matters, and that gains from adoption vary over space. They also argue that larger producers may gain because of economies of scope. In their case there were extra nutritional and environmental effects that enhanced the social gains from the adoption and the rate of return of the research leading to the technology.

Finally, in some cases, the more advanced multiple crop system may require learning and analytic capacity because one source of heterogeneity is human capital, and individuals who have better allocative ability (sometimes related to education) may have higher adoption probabilities. In other situations location of particular features provides the extra edge and will lead to early adoption.

Pollution-reducing innovations

Many agricultural activities generate negative side-effects, be it chemical residues, noise or odour. Extra cost may reduce the level of pollution associated with certain activities. Let the per unit of land production with the ith technology be $y_1 = f_i(x_i,q)$, where $i = 0$ corresponds to a traditional technology and $i = 1$ to a modern one. Similarly, we define the pollution-generating functions, $z_i = g_i(x_i,q)$ with $i = 0$ or 1. Each technology has a fixed cost per unit of land c_i. We assume for pollution-saving technologies that, for the same level of inputs per unit of land x, $z_1 < z_0$. We also may assume for most cases that $c_1 > c_0$, i.e. the new technology requires more fixed costs.

More detailed specification is needed to compare the performance of various pollution-saving technologies to traditional technologies. There are many situations where the pollution from production is the residue of these situations; and the input-use efficiency, the fraction of the variable inputs actually consumed in the production process, is substantially below unity; thus, a fraction of the applied input is a polluting residue. For example, residues from fertilizers may move to bodies of water, causing salinity and nitrification problems. Excess irrigation water may accumulate to contribute to waterlogging problems. Technologies that increase input-use efficiency (increase the fraction of input consumed in production) frequently serve to reduce environmental damages as well. Khanna and Zilberman (1997) present several examples of such technologies. One obvious example is drip irrigation. While this technology is perceived to be expensive, there is evidence of various low-cost versions of it available for low-means farmers in sub-Saharan Africa. Other examples of conservation technologies that reduce pollution are: (i) new nitrogen management strategies that adjust applications to crop and land status; (ii) enhanced precision of pesticides application, based on better information; and (iii) equipment-rotation grazing that improves the quality of feed and reduces waste in grazing livestock. The input-use efficiency of the *i*th technology is denoted by $\psi_{\mathrm{i}}(q)$ and is also affected by land quality or other indicators of environmental conditions. It is reasonable to assume that there is improved input-use efficiency with the modern conservation technology ($\psi_1(q) \geq \psi_0(q)$) and with higher quality ($\psi_i(q_1) \geq \psi_i(q_0)$) if $q_1 > q_0$. With pollution as a residue, $z_i = (1 - \psi_i(q))x_i$. If farmers use these technologies efficiently, their adoption tends to increase output and reduce pollution per acre, and in most cases save variable inputs, although with such knowledge-intensive and location-specific NRM technologies there is often a higher cost associated with extending and adapting the technologies on the ground. These technologies tend to be adopted on lower-quality lands or assets and expand the land type in production (Caswell *et al.*, 1990). Modern irrigation technologies tend to add lands with lower water-holding capacity into production, and precision application technologies that will efficiently increase application of fertilizers will lead to planting the crop on marginal lands. These impacts on the extensive margin may actually lead to a reduction of average output per unit of land if the area of the new land is large. The International Centre for Tropical Agriculture (CIAT) project outlined later in the book (Chapter 6) actually presents a wide variety of soil management technologies that enhance the land capacity to hold inputs (by various means such as hedge crops and various cultural practices), and thus increase input-use efficiency and reduce pollution. Note that soils are renewable resources, and sometimes projects that enhance their productivity should be viewed within a dynamic perspective. That suggests another category of NRM projects, which is discussed below.

Health-improving innovations

Agricultural inputs, such as pesticides and other chemicals, may endanger workers' health and the environment. The damage to health may not be an externality, as farmers may be aware that a technology is endangering their health, but its use is preferable to the alternative of lower productivity and income. Technologies or management practices that will reduce health risks, by reducing application of or exposure to chemicals, replacing chemicals with less dangerous ones or using safer cultural practices, can be modelled in a manner similar to the modelling of pollution-reducing technology. Let $y_i = f_i(x_i,q)$ be the production function per unit of land where $i = 0$ and $i = 1$ correspond to the traditional technology and a modern technology, respectively. Following Lichtenberg and

Zilberman (1988), let $r_i = \gamma_i(x_i,b_i,q)$ be the risk function denoting the probability of a bad outcome (mortality or morbidity) per unit of land utilized with the ith technology given the variable input and care effort per unit of land denoted by x_i and b_i, respectively. The traditional technology may not allocate effort for care, $b_0 = 0$, while the new technology will emphasize care and protection. The damage may be affected by an environmental quality indicator denoted by q. The risk function may be obtained from risk assessment studies that assess factors that affect probabilities of mishaps and diseases as functions of decision variables. The two technologies require fixed input, and care and protection efforts are costly. At the same time the bad outcome is costly as well, and adoption decisions will compare the cost savings of the traditional technology with the value of the health risk reduction associated with the modern technology. Antle *et al.* (1998) document the health effects of pesticide use in potato production in Ecuador. Antle and Pingali (1994) show how practices restricting pesticides use in the Philippines can improve health, and that contributes to productivity gains. In a recent study from southern India, Mancini and Wesseler (2007) show how improved knowledge and information through Farmer Field Schools can reduce the risks from pesticide intoxication, although the costs of this approach remain a widely debated issue.

None of the NRM case studies in this book has reported health-improving effects through reduction of exposure to risk, although the WorldFish Centre project for example has contributed to health through improved nutrition.

Renewable resource-conserving innovations

Agricultural production is a dynamic process, and management practices affect the evolution of stock variables that affect productivity. Stock of prime soil is one obvious example. Exposure to pesticides is another stock variable that affects productivity and is affected by choice of input. When dynamics is important, variables are assigned to capture the time dimension, and let t be a time indication (year). The stock variable associated with technology i at this time is S_{it}, which for example can be a measure of the stock of soil at a given field. The production function of the ith technology is:

$$y_{it} = f_i(x_{it},S_{it},q) \tag{3.19}$$

In our specification, the output depends on both the stock and the variable input levels. It is increasing and concave in both. The rate of change in the stock is given by its equation of motion. This equation may be quite complex, but we simplify it for our presentation and make the change in stock depend on the variable input, the quality and the stock. In particular,

$$\dot{S}_{it} = \frac{\delta S_{it}}{\delta t} = \phi_i(S,q) + \gamma_i(x_{it},q) \tag{3.20}$$

We interpret the first element in the hypothetical equation of motion as the erosion element, which is negative, $\phi(S,q) \le 0$, and the second, $\gamma_i(x_{it},q) \ge 0$, is the build-up element that increases with the input level. The renewable resource-conserving technology will reduce the erosion elements so that $\phi_0(S,q) \le \phi_1(S,q) \le 0$. Altogether we will assume that, for a given input and quality, the current technology is more erosive. The new technology may not increase productivity with the same input and stock, but its contribution to productivity may be through the reduction of stock erosion. Let r be the discount rate and the NPV of profits from use of technology i at asset quality q from time t be denoted by $\Pi_i(q,.t)$:

$$\Pi_i(q,.t) = \int_0^\infty e^{-r\tau} \left\{ \text{Max} pf_i(x_{it},S_{it}q) - wx_{it} \right\} d\tau$$
$$\text{s.t. } \dot{S}_{it} = \frac{\delta S_{it}}{\delta t} = \varphi_i(S,q) + \gamma_i(x_{it},q) \text{ for all } t \text{ given } S_t \tag{3.21}$$

We will not provide a solution to Eqn (3.19), but the growing body of literature on dynamics solves similar problems (for examples, see McConnell, 1983; Barbier, 1998). Assuming adoption of the resource-conserving technology ($i = 1$) at time t requires fixed investment per unit of land denoted by k, the technology is adopted at a location with quality q at time t if:

$$\Pi_1(q,.t) - \Pi_0(q,.t) - k > 0 \tag{3.22}$$

Heterogeneity among locations and farmers will lead to heterogeneity at the time of adoption. The analysis can be expanded to account for changes in the price of technology over time, uncertainty about its impacts, and thus learning and similar factors affecting the extent and timing of adoption (see Sunding and Zilberman, 2001). Technologies that conserve renewable resources in agriculture may also control pollution, as the pollution and externality problems may be associated with the erosion of the resource. In these cases the pollution-generating functions of the two technologies may be denoted by:

$$z_{it} = g_i\ (x_{it},S_{it},q),\ i = 0 \text{ or } 1 \tag{3.23}$$

Assuming that the conservation technology reduces pollution, the impact of the adoption should be considered in assessing the social return of the conservation technology. If policies provide incentives for adoption, they will be included in the private calculus of profitability and added to Eqn (3.21).

In many cases NRM involves restoring degraded stocks that reduce agricultural productivity. Gebremedhin and Swinton (2001) argue that soil fertility restoration programmes are important mechanisms to address severe poverty problems. These programmes require precise design of incentives to target villages and individuals for participation. Their analysis identifies factors that contribute to participation in restoration programmes in Ethiopia. Knowler (2004) provides evidence of several valuable soil management strategies that yielded positive returns by increasing productivity and reducing pollution residues. The International Maize and Wheat Improvement Centre (CIMMYT) project (Chapter 5) introduces low-tillage technologies to rice–wheat systems in India and other countries. The low-tillage technologies, as well as some of the technologies introduced by CIAT for cassava in South-east Asia, are NRM innovations that conserve soil and thus also reduce pollution.

Damage control innovations

Agriculture suffers greatly from pests and pesticides remain the major method of control. There has been much concern about the side-effects of chemical pesticides, and the development of effective and environmentally friendly pest control has become a major element of NRM programmes. The damage-control function approach was introduced to analyse and quantify the benefits of various pest control strategies (Lichtenberg and Zilberman, 1986). This approach models production of per unit of land of ith technology as:

$$y_i = f^P(x_i^o)(1 - d^G(n_i)) \tag{3.24}$$

where $f^P(x_i^o)$ is potential output that occurs without pest damage. It is the function of inputs other than pesticides used in production. The term $d^G(n_i)$ is the damage from the pest, and it is a function of n_i, the pest population after treatment with the ith technology. The specification of the technology is presented in the 'kill' function that relates the number of pests after treatment to the original infestation. For example, let n_0 be the initial pest population, and x_i^C and x_i^{NC} be the levels of the chemical and non-chemical pest control inputs used with the ith technology. Then the level of input after treatment is:

$$n_i = f_i^T(n_0, x_i^C, x_i^{NC}, q) \tag{3.25}$$

The initial technology may involve no treatment, mechanical treatment or pure chemical treatment of a pest problem. NRM projects may introduce alternatives, be it improved cultural practices, biological control or integrated pest management. The initial vulnerability to pests is one source of heterogeneity among locations. Climatic and location parameters that affect the performance of pest control strategies in various locations should also be incorporated. Each pest control strategy has a certain fixed cost per unit of land, c_i^P. Let the prices of the output and inputs be p, w_i^o, w_i^C and w_i^{NC}, respectively, and the profit per unit of land of the ith technology is:

$$\begin{aligned}\pi_i^P = \underset{x_i^O, x_i^C, x_i^{NC}}{\text{Max}}\ & p[f^P(x_i^O)(1 - d^G(f_i^T(n_0, x_i^C, x_i^{NC}, q)))] - \\ & w_i^O x_i^O - w_i^C x_i^C - w_i^{NC} x_i^{NC} - c_i^P\end{aligned} \tag{3.26}$$

Profit maximization will lead to the adoption of the technology with the highest π_i^P. Heterogeneity of vulnerability to pests (reflected by n_0) or other reasons (reflected by q) will lead to differences in where and when various pest control technologies are adopted. Note that the pest management may result in negative environmental effects, and we can introduce a pollution-generating function $g_i(x_i^O, x_i^C, x_i^{NC}, q)$ for all i values. Analysis of the impacts from the adoption of NRM pest control policies should consider impacts on the environment. When environmental side effects of pesticides policy are regulated, it will affect adoption of technologies, and Eqn (3.24) should be modified accordingly. The modelling of pest population and control technology has been expanded to consider some of the complexities of real life, including predator–prey relationship and resistance build-up (Carlson and Wetzstein, 1993). There has been much emphasis on strategies to control resistance build-up. Fleischer and Waibel (2003) calculated the cost of herbicide resistance in maize production for different groups of farmers in Germany, which ranged between 1% and 8% of the land value depending on the discount rate used and whether or not option values were included.

The importance of public sector research in the provision of NRM technologies to control pest damage has been demonstrated in the case of the cassava mealybug (see Box 3.1). The biological control of the cassava mealybug is a special case of an NRM technology with common property resource properties. It has spread very fast, in part because there was hardly any pesticide use among cassava farmers in Africa.

Box 3.1. The case of the cassava mealybug in Africa.

In the early 1970s a problem with two pests emerged: the cassava green mite and the cassava mealybug. Both pests were introduced accidentally and illegally with planting materials. The cassava mealybug spread quickly over most of the cassava belt in Africa, reportedly causing significant economic loss. Research by the International Institute of Tropical Agriculture (IITA) has led to the identification of its natural enemy – a parasitic wasp (*Apoanagyrus lopezi*). The parasite was subsequently reared and mass-released by IITA. In 1981 the first release of the parasite took place, and 1 year later it was distributed to the mealybug-infested African countries. By 1992, the mass-rearing and release operations for *A. lopezi* were terminated. In most of Africa the pest is now controlled, and it has lost its pest status as the ecological balance has been restored. The return on this investment has been analysed in two economic studies (Norgaard, 1988; Zeddies *et al.*, 2001). Both came to the same conclusion: even when using the most conservative assumptions, the benefit–cost ratio is well over 100%.

Innovations to design appropriate technologies

Evenson and Kislev (1976) have shown that the development of new technologies is an exercise in the selection among many alternatives that vary in outcomes and impacts. The marketing literature emphasizes that buyers or adopters of technologies are concerned about the extent to which a technology fits their needs and is appropriate for their circumstances. Companies offer product demonstration and return options to reduce the fit risk faced by buyers (Heiman *et al.*, 2001). They spend on focus groups, consumer surveys and other forms of market research as they design the specifications of new products. A similar approach is useful in conducting research that aims to introduce new technologies and management practices. Effective interaction between technology developers and users is likely to result in the development of more appropriate and valuable technologies. To illustrate this point, suppose that there are two technical solutions to a particular problem (alternative crops for hedgerows, alternative monitoring and control strategies of pests, etc.). These two solutions apply to many locations encountering specific natural resource problems, but varying in specific socioeconomic and physical circumstances. The first solution is superior and appropriate with probability q, and the second is appropriate with probability $1 - q$. The extra benefit from the introduction of the appropriate technology (resulting from extra adoption and higher benefits per adopter) at a given location is Δb. Without study of the particular circumstances, scientists will recommend to introduce first a technology if the probability that it is appropriate is greater than 50% ($q > 0.5$). The expected gain from the introduction of the technology will be Δbq. Suppose that a research effort that will identify the second technology to be appropriate for a given location costs c dollars. The expected gain from this research is equal to $\Delta b(1 - q) - c$. This suggests that research aimed to pinpoint the appropriate technology for a given location is more valuable the higher is the gain from the appropriate technology, the lower are the costs of the research and the lower is the probability of fit of the dominant technology.

The above theoretical analysis is appropriate for assessing the impact of participatory research that emphasizes collaboration between scientists and potential adopters to identify appropriate solutions. In reality, a specification is necessary for specifying the role of the local, regional, national and international scientists at CGIAR Centres. In addition, participatory research may go beyond adopting existing solutions to specific situations. It may lead to the evolution of new solutions. These situations can be modelled by assuming that there is a production function for the new technological solution that is affected by both the stock of knowledge of the farming population (denoted by S_0^C) and the scientists (S_0^S) as well as the effort of these groups, measured in monetary terms and denoted by e^C and e^S, respectively. Let $E(\Delta b)$ be the expected net benefit from a new appropriate technology, $E(\Delta b) = g(S_0^S, S_0^C, e^S, e^C)$. The benefits are likely to increase with higher levels of initial stocks as well as by efforts by the two groups. The net benefits of a research project that entails research levels of e^C and e^S is $g(S_0^S, S_0^C, e^S, e^C) - e^S - e^C$.

These modelling frameworks suggest that, with good quantitative estimates of expected benefit functions, it may be possible to optimize private and public efforts that are incorporated in collaborative research efforts to develop new NRM technologies.

However, one side-effect of participatory research that involves the community is the build-up of skills and knowledge that enhance productivity in the future. Creating human capital for productivity increase has long been recognized as a driving force for economic development (Romer, 1990). Human capital is built by acquisition of knowledge (Schultz, 1975) and is crucial for adoption of innovations (Feder and Slade, 1984). While formal education has long been recognized as an important factor in farmers' abilities to acquire and process information, research in the past has highlighted the role of agricultural extension services in fostering the adoption of, for example, Green Revolution technologies in Asia (Hiebert, 1974; Jamison and Lau, 1982). In addition, 'learning by doing' and 'learning from neighbours' have also been acknowledged as sources of human capital accumulation and technical change in agriculture (Foster and Rosenzweig, 1995).

In addition to the immediate benefit of participatory research, the exposure and experience accumulating with collaboration with scientists are likely to enhance the human capital of the participating farmers, which will lead to increased economic gains in the future. Of course this does imply significantly higher researcher costs, however. Thus, the stock of human capital in a future period, S_1^c, is evolving according to $S_1^c = S_0{}^c + \psi^c(e^c)$, where $\psi^c(e^c)$ is a human capital gain associated with research efforts by the community. The expected value of the extra gain in human capital is $v_1(S_1{}^c - S_0{}^c)$ and thus, within a two-period model, the expected benefits of participatory research are:

$$E(\Delta b) + \psi^c = g(S_0^S, S_0^C, e^S, e^C) - e^S - e^C + v_1(S_1^c - S_0^c)/(1 + r) \qquad (3.27)$$

where r is a discount rate. If the participation in the research also enhances the human capital of the scientists, the value of this extra gain in human capital also has to be taken into account in assessing the net benefits of the project. Measurement of the value of gain in knowledge because of participation in research is challenging. One approach is the use of a classic difference in difference model (e.g. Beaudry and Green, 2003) to test whether participants have improved economic performance compared with non-participants.

Participatory research was an integral element of several of our projects. In the case of the CIAT project, household knowledge is treated as a stock resource in the utility function and manifested by participation in on-farm experimentation, albeit household knowledge was not empirically measured in the model. The WorldFish Centre project measures the increase in technical efficiency of adopters of integrated aquaculture–agriculture technologies by technological modifications they introduce.

Risk-reducing innovations

Thus far, the modelling assumes that natural resource systems are deterministic. The reality is that they are exposed to much variability. For example, farmers may be exposed to droughts and floods, pest infestations and windstorms that are stochastic in nature. Therefore, many NRM strategies aim to cope with randomness and risks. For example, farmers may develop various storage activities or adopt conservation technologies to address the risk of drought. Pest infestations are also random. Farmers may engage in various pest control activities including weeding, pest monitoring, use of buffers to slow pest movements, and the use of various pesticide strategies that affect the distribution of, and especially reduce the risk of, pest infestation.

There is a significant body of literature on modelling and estimating the stochastic aspect of agricultural production systems. Many rely on the Just and Pope (1978) production function, where $y_i = \phi_i(x_i) + \psi_i(x_i)\varepsilon$ is output produced with technology i with input x_i. $\phi_i(x_i)$ is the deterministic aspect of the production function, as a function of the input, and $\psi_i(x_i)\varepsilon$ is a stochastic element where ε is a random variable with mean 0. With this specification, the expected output is $\phi_i(x_i)$ and the variance of the output is $(\psi_i(x_i))^2\sigma^2$, where $\sigma^2 = E(\varepsilon^2)$. Comparing various technologies, $i = 0$ corresponds to traditional technology and $i = 1$ corresponds to a more modern technology. They may rank differently with regard to their impact on average yield and the variability thereof. For example, modern irrigation technologies may both increase yield and reduce risk simultaneously. Alternatively, enhanced fertilization practices may increase both yield and risk. The features of the various available technologies combined with economic conditions will determine each technology's relative attractiveness. Similar to the modelling of production risk, one can develop a model for the environmental side-effects of production that are also dependent on random variables, such as wind, temperature, rainfall, etc.

While we emphasize production risk, farmers may also face price risk, including prices of both inputs and outputs. Analysis of the impact of technologies, therefore, must necessarily include all sources of risk and consider policy and institutional solutions such as insurance.

The consideration of risk is especially important when farmers are not risk-neutral. Risk-averse behaviour is likely to lead to diversification among alternatives, including partial adoption of various technologies. Arrow (1971) argued that smaller producers have higher levels of absolute risk aversion and innovations, both technical and institutional, and that reduced exposure to risk may sometimes be very valuable to smaller growers. The survey by Feder *et al.* (1985) and studies including Antle (1987) and Rosenzweig and Binswanger (1993) documented empirically the importance of risk consideration in the choice of resource management strategies by farmers of different wealth levels in developing countries. We present here a simple framework to assess risk-reducing technologies. Let us assume that the farmer has a negative exponential utility function with constant absolute risk aversion r, and suppose they face risks where profits are distributed normally with mean μ_0 and variance σ_0^2. Now suppose that a new technology is introduced, resulting in a mean profit of μ_1 and variance σ_1^2. Assume that the risks after using technologies are not correlated with risks before using technologies. Once the technology is adopted, the certainty equivalent of the gross gain from adoption is $\mu_1 - \mu_0 - r(\sigma_0^2 - \sigma_1^2)$. Assuming that the technologies cost I dollars to the farmers, the net gain to each farmer is $\mu_1 - \mu_0 - r(\sigma_0^2 - \sigma_1^2) - I$. With risk aversion, the risk-reducing technology may reduce mean profit, but it will increase net benefit if the variance and risk aversion are sufficiently large. Now, if N farmers adopt the new technologies, and the research costs are equal to R, then the aggregate surplus is $\sum_{i=1}^{N}[\mu_{1i} - \mu_{0i} - r(W,g)(\sigma_{0\,i}^{2} - \sigma_{1\,i}^{2}) - I_i] - R$, where $r(W_i,g)$ is the risk aversion of the ith person, which is a function of wealth and other factors. The gains from risk-reducing technologies are larger for individuals who are more risk-averse, or who face more risk. The analysis here is relatively simple using a mean-variance model, and applications may use more sophisticated models (see the recent book by Just and Pope, 2002).

Much of the work on risk investigated adoption of crop varieties and choices in plant production. Fafchamps *et al.* (1998) analyse the role of raising livestock as part of a drought management strategy in West Africa. Almost all the NRM strategies considered in this book have a potentially strong risk management component. However, these risk aspects have been underemphasized in the impact analysis. In some cases, that may lead to underestimation of the benefits of a particular NRM strategy. For example, in the ICRAF case, given the fluctuation of energy prices and resulting fertilizer costs, the value of this fertilizer tree technology includes a risk-reducing effect. The ICARDA cases analyse alley-cropping technologies, which provide significant value by reducing vulnerability to sandstorms in desert conditions. The soil management strategies introduced by the CIMMYT and CIAT case studies are valuable in reducing soil erosion.

Expansion of Micro-modelling

This chapter emphasizes the modelling of various categories of NRM technologies analysed mostly in the context of profit-maximizing behaviour. Space limits giving more attention to more complex decision criteria and the constraints that may affect adoption and utilization of NRM. The household model has been used effectively to analyse joint consumption and production choices by peasants (Strauss and Thomas, 1995). De Janvry *et al.* (1991) emphasized that peasants' household choices are being taken when markets are missing and malfunctioning. Alderman *et al.* (1994) suggested that realistic analysis of household behaviour has to take into account the issues of gender and custom in various societies. Furthermore, farmers' choices and their interaction with the environment are heavily affected by constraints on the availability of physical, natural and financial assets. Reardon and Vosti (1995) present a general framework linking NRM, asset availability and poverty that begs empirical application. Carter and Barrett (2006) suggest the existence of multiple equilibria of resource-poor farmers. While some are stuck in poverty traps, others may be capable of taking advantage of new technologies. The report by Barrett (2005) cites the case of the parasitic weed *Striga hermonthica* that demonstrates the constraints that may prevent adoption of valuable NRM technologies. Nutrient-depleted soils in sub-Saharan Africa have become infested with the weed resulting in high yield losses. *Striga* is difficult to eradicate because of its potential to colonize large areas in a short period of time. Effective eradication requires coordinated measures because the effectiveness of an individual farmer's effort is linked to the actions of neighbouring farmers' efforts at weed control. Coordination can be constrained by heterogeneity in knowledge between recent immigrants and long-time residents, inter-clan frictions and other social phenomena (Barrett, 2005).

The management of *Striga* as well as other pests requires coordination among farmers and suggests the value of projects that attempt to modify behaviour at an aggregate level. These are macro-level solutions that are discussed below.

Macro-level Natural Resource Management Projects

The traditional justifications for government intervention in the economy relate to inefficiency problems of externalities, non-competitive behaviour, public goods and information. Equity considerations may also be used to justify government intervention. Support for public research, in most cases, is justified because it provides a public good. Most NRMR projects are micro-level that seek to improve technologies and to provide public goods that produce knowledge that would not otherwise be provided by the private sector. However, some NRMR projects address larger issues of inadequate policy and failure in governance that result in excessive harvesting of natural resources. Macro-level NRMR projects provide public goods in the form of information that can improve public policy decisions and consumer choices regarding products derived from natural resources. We first examine the impacts of projects that provide information to producers and consumers, and then later the impact of projects that provide policy information.

Management standards for certification programmes

Often, management of natural resources is constrained by some unique informational problems that can be remedied by global collective action.

In particular, because of the size and geographic spread of natural resources like trees and wildlife, and because of shortcomings in many governments in developing countries, a large portion of these natural resources are harvested in an excessive, unregulated and suboptimal manner (Naim, 2005). This environmentally damaging harvesting of natural resources in developing countries is done sometimes in an unregulated manner to meet market demand from the developed world. Naim (2005) presents evidence that many of the buyers of these natural resource products would think twice before purchasing if they knew the nature of the source. However, there is an issue of asymmetric information. For example, consumers cannot distinguish between lumber harvested in a sustainable manner from that which was not. One needs a mechanism that will solve this problem of asymmetric information. A key ingredient of policies that curb exploitation of natural resources in developing countries is certification as a means of providing information to the final buyer that the product conforms to sound environmental standards.

A simple model illustrates this point. Let the demand for a natural resource (timber, water) be denoted by $X = D(p)$, where p is price and X is quantity. The per unit costs of harvesting with the cheapest technology are assumed to be constant for simplicity and are denoted by c_H. Harvesting results in environmental damage, and the per-unit environmental cost is equal to c_E. An environmentally sound technology has per-unit cost of $c_G > c_H$, but $c_G < c_H + c_E$ and this technology does not produce negative externalities. Suppose that initially only the cheap technology is available; then the equilibrium will be at A in Fig. 3.1, where the price will be equal to c_H. There is overproduction in point A, since the externality cost is not taken into account. Without the use of the clean technology, if production generates positive welfare, the optimal output with the cheap technology should be at point B. The welfare loss of being at unregulated output A is equal to BGA. This, however, ignores the potential downside effects of less employment of poor labourers involved in this activity.

Suppose that a research project identified a new, cleaner technology, and established standards to its application so users can be certified. With the cleaner technology, the optimal outcome should be at point C, and welfare gain from having the cleaner technology compared with point A is equal to NBGACM. Comparing point C with point B, the welfare gain will be NBCM.

If the natural resource is produced in a developing country and exported elsewhere and the developing country is not sufficiently strong to impose a tax or a direct control that results in a cleaner technology, then the initial outcome will be at a point such as A and result in overproduction and inefficiency. Suppose that a certification programme is introduced and all the output produced with the clean technology is labelled. In this case we will reach the optimal solution if the importing countries ban unlabelled products, or if the consumers are aware of the environmental problem and internalize the externality cost, thus buying only

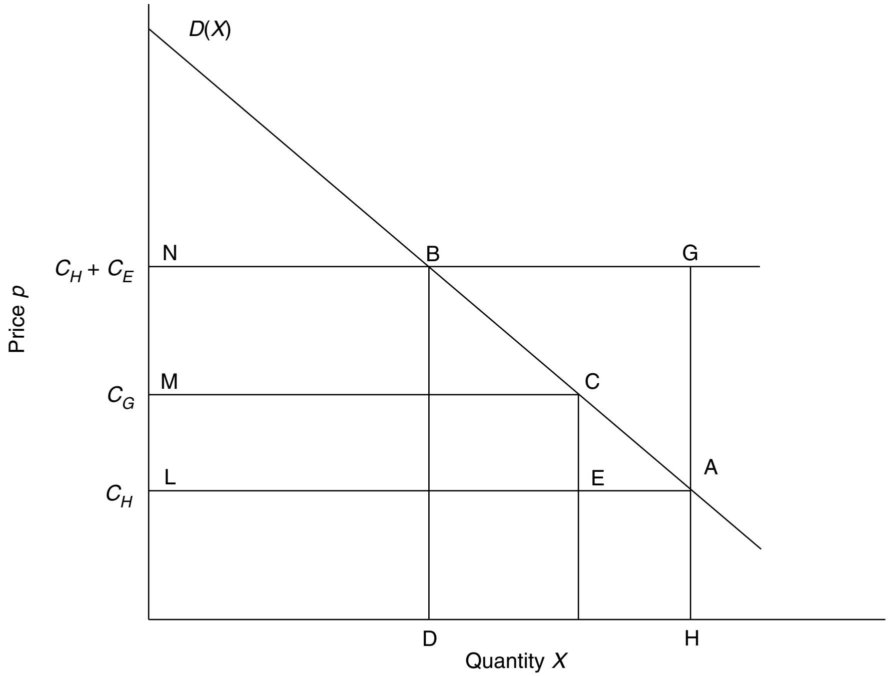

Fig. 3.1. The welfare effects of certification in natural resource management.

outputs produced with a clean technology. In this case the certification programme leads to the welfare gain associated with the transition from A to C, which is denoted by G_C. This gain is equal to the area of NBGACM. It consists of the reduction in environmental damage of the output NGAL minus the loss of consumer surplus by moving from A to C (MCAL).

This simple model suggests that establishing production standards for certification policies may lead to full adoption of the cleaner technology. Indeed, there may be examples of bans on uncertified products made from natural resources which may lead to socially optimal outcomes. In many cases, however, boycotting of uncertified products is voluntary, and if consumers are heterogeneous, only part of the population will boycott uncertified products. In these cases, the certification will not result in optimal outcome but will still provide social benefits (Hamilton and Zilberman, 2007).

If the cost of research leading to a certification programme is C_R and the cost of the programme is C_C, the net gain from the programme is equal to the certification programme, and the gain net benefits of the certification programme is $N_C = C_G - C_R - C_C$. Development of standards that will support effective certification programmes is challenging; it must incorporate sound understanding of biological and environmental impact, as well as understanding of economic and cost considerations. Furthermore, the organization that establishes these standards must have a reputation for objectivity and competence. Thus, research conducted in the CGIAR

Centres can provide the basic knowledge that may either result in effective standards or be crucial in evaluating performance standards established by other organizations. Two good examples are in the case studies presented in this book; namely, the case of forest certification programmes based on research done by the Centre for International Forestry Research (CIFOR) (Chapter 11), and the case of a zero-tillage technology in India where CIMMYT played the role of an informal technology certifier (see Chapter 5).

Considering development standards as a source of efficiency may sound strange, since economists generally are averse to command-and-control and best-management practices. Therefore, if these standards can provide the foundation for certification problems leading to sustainable harvesting of natural resources then the standards are indeed very valuable. Furthermore, the design of these standards can be flexible enough to allow firms and individuals to exploit their unique knowledge, while at the same time assuring that the resources are managed in a socially responsible way. The CIFOR project can be viewed in this light. It provides the foundation for sound harvesting practices that can be adopted by certification programmes. It is important to assess the extent to which these standards are being adopted, as it is important to identify what percentage of the global lumber is being produced by individuals who follow these standards. When the standards and the certification project that they support are successful, then the real measure of their effectiveness is the amount of resources that have been saved from unscrupulous exploitation, the evaluation of which is very challenging indeed.

The CIMMYT case study provides information to farmers who are ‘users’ of technology, which contributes to the adoption of zero tillage. Contrary to classic research activities, e.g. in plant genetic improvement, in the case of zero tillage CIMMYT’s role was not to develop a fundamentally new technology or discover new scientific principles. Rather, CIMMYT’s role in the development and promotion of the zero tillage technology in India was to facilitate technology introduction by helping the NARS to design experiments for technology testing, local adaptation, identify constraints and to demonstrate the technical feasibility and economic efficiency of the technology to the user. Hence, CIMMYT’s contribution was to make the diffusion process faster and more efficient. The main research input was CIMMYT’s expertise for designing and implementing on-farm experiments and to provide its status as an independent international organization that can effectively facilitate negotiations with the private sector and government decision makers involved in setting the institutional frame conditions for the technology (‘honest broker’).

Policy design and implementation projects

While much of the empirical literature on innovation emphasizes technological innovation, Ruttan (1984) has recognized the importance of institutional innovation. The Grameen Bank (awarded the Nobel peace prize in 2006) is a notion of micro-credit that reflects how institutional innovations can provide immense improvements in welfare, as well as a model of doing business that can be applied, after some adaptation, in other locations. However, there are a lot of details involved in the design of an effective micro-credit scheme; therefore, transferring the knowledge and starting the adoption process require effort in identifying the basic principles that will make micro-credit and best-management practices for different situations work. Similarly, the economics of natural resources has, in many cases, recognized that market activities have to be augmented by government policies and, in other cases, market mechanisms have to be introduced. However, the design of implementation of policies is quite tricky; it requires attention to many details and development of a sound legal system and methods of finance, monitoring and enforcement. As several chapters in Pardey and Smith (2004) suggest, bad design has caused many failed attempts to introduce policies that are, in principle, superior to the initial situation. Therefore, systematic research on policy design and implementation in management of natural resources is of significant value, providing an international public good and thus meeting the criteria that the CGIAR has set for its NRM projects.

The simple model below values the gains from policy research. The benefits from policy reform in country i, where $1 \le i \le I$, is measured in monetary units and is the sum of changes in producer and consumer surplus resulting from the policy. These benefits are denoted by the function $B_i(E_i,K)$, where E_i denotes efforts measured in monetary units and K is stock of knowledge. Let us assume that effort is determined to maximize net benefits $B_i(E_i,K) - E_i$, $B_i(K_0,\Delta K),K_0,\Delta K) - E_i$, so the optimal level at country i is where the marginal benefit of effort is equal to its marginal cost, $\delta B_i/\delta E_i = 1$. The optimal effort is $E_i^*(K)$ and is dependent on the stock of policy knowledge, which is a public good. Let the initial policy knowledge without policy research in the relevant Centre be denoted by K_0, and the public policy research adds ΔK, so that $K = K_0 + \Delta K$.

The gain from policy research in country i is:

$$\begin{aligned} G(\Delta K) = {} & B_i\big(E_i^*(K_0 + \Delta K),K_0 + \Delta K\big) \\ & - B_i\big(E_i^*(K_0),K_0\big) - \big(E_i^*(K_0 + \Delta K) - \big(E_i^*(K_0)\big) \end{aligned} \tag{3.28}$$

This gain from extra knowledge in country i can be decomposed from the extra knowledge and the savings in effort in cases where knowledge and effort are substitutes. If knowledge and effort are complements, then the gain from the extra knowledge will be decomposed from the extra benefits minus extra cost of effort. Since knowledge is a public good, if the cost from extra knowledge is $C(\Delta K)$, the aggregate benefits from policy research are:

$$\sum_{i=1}^{I} G_i(\Delta K) - C(\Delta K) \tag{3.29}$$

This result suggests that the gain from policy research increases the greater the number of countries that rely on it. The analysis can be expanded by incorporating extension costs that have to be subtracted from the net gain benefit formula in Eqn. (3.28). Furthermore, the analysis can be expanded to include dynamic consideration. In this case knowledge can affect not only the gain from reform and the effort needed, but also the timing of reform. Since reform is costly, sometimes delay is worthwhile as it allows extra learning and delay costs.

Research leading to improved policy design may be interdisciplinary and integrate theoretical and empirical analyses. The conceptual analysis will identify features of new institutions that meet policy objectives, and the empirical analysis will involve collecting data and investigating case studies to see what works in practice. For example, economists have long recommended the practice of trading in water rights as a mechanism to improve both the economic and environmental benefits from water use. However, these recommendations have not been widely accepted. Research is needed to determine the right conditions to introduce water markets and the best design to improve performance, based on both sound theory and past experience. It will allow the development of insight regarding the design of the specific trading mechanisms that would be of the highest value under particular conditions. The CGIAR has Centres, such as the International Food Policy Research Institute, CIFOR and the International Water Management Institute (IWMI), which emphasize policy research. Part of the work pertains to design of policy prescriptions for specific situations, and part focuses on the establishment of a foundation to provide the blueprint for successful institutions for resource allocation and management of natural resources.

The IWMI macro NRM project reported in this book (Chapter 10) is one example of such a research project. It aims to provide principles in designing effective water institutions adjusted to specific situations. This type of project can provide some general principles, but it may require detailed adaptation for the specific situation. Especially at the early stages of institutional design, the researcher may need to be involved with implementing the policy proposal. If we consider the policy research as a refinement of institutional innovation (be it a water market or a water users' association), then evaluation of a project such as the IWMI must consider improvements in proposed design, the specifications affecting adoption of new institutional design and reform, and the gains from introducing the institutional reforms.

Policy introduction issues

The introduction of new policies is the result of political–economic processes that result from power distribution among groups and political structure. Krueger (1997) has argued that rent-seeking behaviour is ubiquitous in the making and implementation of trade and other policies, and that it should apply to natural resource polices as well. A generic approach to modelling outcomes of political–economic systems was introduced by McFadden (1976) and Zusman (1976). They view policy making as the outcome of cooperative games where there are a certain number of interest groups, and each of them has a certain weight that may vary over time. Suppose that there are I groups, each indexed by i, where i assumes values from 0 to I, where $i = 0$ is frequently used to denote the policy-making organization in charge of policy making or implementation. For example, in deciding the fate of a water system affecting farmers, consumers and the environment, $i = 0$ denotes the interests of the water resources administrator that will run the system. The policy making has to determine the value of parameter (or vector of parameters) x, which is constrained by the economic reality reflected by the set $s(x)$. The net benefits of group i from the policy is presented by the function $NB_i(x)$, and the weight of group i in policy making is $w_i(x)$. Then the policy is determined by:

$$\max_x \sum_{i=0}^{I} w_i NB_i(x) \tag{3.30}$$

subject to $x \in s(x)$. It is possible that policy makers may over- or underestimate their benefits, so that instead of using the true net benefit function $N\hat{B}_i(x)$, they use $NB_i(x_i) = f\big(B_i(x_i), \varepsilon_i(x)\big)$, where $\varepsilon_i(x)$ is an error term. Hence the optimization problem determining policy change is:

$$\max_x \sum_{i=0}^{I} w_i N\hat{B}_i(x), \text{ subject to } x \in s(x) \tag{3.31}$$

Sometimes the above adoption models of policy research recommendations assume that politicians do not pursue personal interests, i.e. there is absence of nepotism and corruption. This assumption, however, may not hold for many developing countries. In countries where democratic institutions are still underdeveloped and the policy formulation process is often lacking transparency, in explaining the adoption of policy information generated by research a political–economy model (e.g. Shleifer and Vishny, 1998) may be useful. Here we assume that the adoption policy research recommendations by politicians will depend on the benefits that the politician making the policy decision can expect from the policy changes. These benefits will largely depend on the beneficiary groups of a policy change, and on the opportunities of the politician to take a stake in the profits of these groups. Such a stake can be voter favour, certain donations or other preferential treatments. The explicit introduction of a group of policy makers with $i = 0$ and the unequal weight given to various groups is intended to reflect the self-interest of policy makers associated with policy design.

One criterion to assess policy change is whether it leads to a Pareto improvement. In terms of our model, a policy is Pareto improving if $NB_i(x) \geq 0$ for $i = 1,\ldots,I$, i.e. some of the groups in society are better off while none is worse off. This criterion is rather strict and benefit–cost analysis considers a project to be desirable if $\sum_{i=1}^{I} NB_i(x) > 0$, i.e. the net benefits are possible (reflecting a potential for Pareto improvement if compensatory transfers between gainers and losers are made). If the policy outcomes are arrived by processes that are akin to solving Eqn (3.31), they may lead to outcomes that will not improve net aggregate benefits so that $\sum_{i=0}^{I} N\hat{B}_i(x) \geq 0$, while $\sum_{i=1}^{I} NB_i(x) < 0$.

Policy research can influence w by providing information on potential beneficiaries, and informing policy makers about the potential benefits of good policy change and the costs of bad status quo. Except for the 'win–win' policies of Eqn (3.30), educating policy makers in NRM policy options can be even more important for inducing policy change than creating brilliant policy ideas. The best policy proposal in terms of society's gains may not be accepted if the marginal benefits to politicians are small and the costs of resistance to policy change are high. Hence, there is a particularly important role for CGIAR Centres in NRM policy to synthesize and complement existing knowledge and play the role of 'honest brokers', and guide national governments and international organizations to plan and implement policy change.

As mentioned above, one of the benefits of policy research is to reduce the errors in policy assessment of different groups. Thus, instead of using the true benefit functions a_j and a_k (see above), $\hat{a}_j = f(a_j,\varepsilon_j)$ and $\hat{a}_k = f(a_k,\varepsilon_k)$ are used where ε_j and ε_k are errors. In this case the optimization problem of policy makers can be written as:

$$\max NB_p^{ex} = \mathrm{q}\cdot\sum_{j=1}^{J} \hat{a}_j - m\cdot\sum_{k=1}^{(1-J)} \hat{a}_k \qquad (3.32)$$

Policy research can reduce the assessment error of the different groups and supply a more accurate estimation of benefits of new policies or prevent policy change. Note, however, that different groups may have varying capacities to access and utilize policy research results. This is especially true for marginalized groups: groups with high transaction costs and low per capita benefits from a policy change as opposed to groups who have high capacity to do their own analysis. Such differences are particularly relevant in NRM in developing countries, for example, if an NRM policy change (e.g. removal of input subsidies) will reduce the rents of powerful groups including manufacturers and dealers. Since policy research benefits various groups differently, it is important that researchers study policies with the aim to develop outreach programmes that make their results accessible to many groups. Otherwise, they may tilt outcome in favour of the groups that are able to utilize their research.

Summary

This chapter has shown that in analysing the performance of agricultural sectors and markets, environmental and NRM considerations can be incorporated by means of an expanded set of economic models. The tools introduced in this chapter can be useful in establishing frameworks to analyse NRM research activities. Such frameworks go beyond the traditional tools that were used in the past for analysing the impacts of germplasm improvement research. In particular, the issues of innovation and adoption of NRM technologies require in-depth analyses of the underlying processes, the status of natural resource stocks and externalities as well as economic and political conditions.

It has been shown in this chapter that there exists a variety of NRMR project types that we have broadly grouped into micro and macro NRMR projects. The vast majority of NRMR is in the category of micro innovations. Hence the chapter has devoted considerable attention to models that can describe and capture the consequences of multiples and sequential cropping as well as crop–livestock integration (including fish). Damage control and pollution reduction innovations, which are important features of NRMR, can draw on a set of well-tested models. The incorporation of risk into the analysis has been stressed and attempts have been made to provide a framework to capture the effects of participation, knowledge and learning, which are core elements of many NRMR projects.

Recognizing the growing importance of policy research related to natural resources policies, a set of guiding principles has been developed for macro NRM projects. It has been made clear that, while providing policy makers with new research information, this alone is insufficient to foster adoption of such recommendations by politicians. Hence the analysis has been expanded to include aspects of political economic modelling.

The frameworks provided have been used to varying degrees by the researchers who conducted the NRMR impact assessment studies and reported in Part II of this book. Clearly the following studies document and evaluate only a small sample of case studies but they highlight many of the issues that have been introduced in this chapter. The next chapter introduces these case studies by providing an overview and by posing a number of opening questions that can guide the reader.

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4 Natural Resource Management Case Studies: Overview and Summary

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This chapter summarizes and compares the main features of the seven case studies on natural resource management research (NRMR) impact assessment. Its aim is to introduce the cases and prepare the ground for identifying the lessons that have emerged from them and for providing some recommendations to improve NRMR impact assessment in the future.

The first section of the chapter introduces the different types of NRMR projects that were included in the Consultative Group on International Agricultural Research (CGIAR) Science Council's Standing Panel on Impact Assessment (SPIA) project. In the second section, the methodologies used by the seven studies are described briefly. Thereafter, the main results of the studies are compared on the basis of economic and other indicators that demonstrate extent and magnitude of impact. Finally, some important features of these studies are pointed out which are then discussed in more detail in the succeeding chapters that present the different cases.

Description of the Research Projects

An important point that needs to be mentioned beforehand is that the case studies, which are introduced in more detail in the following seven chapters, are not necessarily representative of NRMR in the CGIAR. The aim of the SPIA initiative (see Chapter 1) was to generate evidence from a variety of NRMR types commonly undertaken by the CGIAR. The cases were selected on the basis of the quality of the proposals submitted. Furthermore, some conditions had to be fulfilled for the NRMR project to be selected; for example, sufficient time elapsed since the research had been completed and initial evidence of adoption was established. While only modest support was provided by SPIA for implementation, all Centres were encouraged to make submissions. Two more Centres volunteered cases for inclusion in the overall exercise, with the agreement that they would go through the same rigorous peer review process as the original five. It should be noted that the proposed case studies are not necessarily those research projects that had the highest impact, as some impacts may be more difficult to measure and hence remain hidden or problematic to document.

The following seven case studies and Centres were included in the project:

- International Centre for Tropical Agriculture (CIAT): Integrating Germplasm, Natural Resources and Institutional Innovations to Enhance Impact: Cassava-Based Cropping Systems Research in Asia.
- Centre for International Forestry Research (CIFOR): Criteria and Indicators for Sustainable Forest Management.
- International Maize and Wheat Improvement Centre (CIMMYT): the Case of Zero Tillage Technology in India.
- International Centre for Agricultural Research in the Dry Areas (ICARDA): Natural Resource Management Technologies in Crop–Livestock Production Systems in Arid and Semiarid Areas of Morocco and Tunisia.
- International Water Management Institute (IWMI): Assessing the Outcomes of Research and Interventions on Irrigation Management Transfer
- World Agroforestry Centre: Fertilizer Trees, Their Development, Socioeconomic and Ecological Impacts in Southern Africa.
- WorldFish Centre: Development and Dissemination of Integrated Aquaculture–Agriculture Technologies in Malawi.

Various types of NRMR projects with different indicators of impact are reflected in the titles of the studies. It is shown in Table 4.1 that the selected projects represent a blend of NRMR areas and cover a range of geographical regions. Two projects focus on research in sub-Saharan Africa, namely those of the World Agroforestry and the WorldFish Centres. The ICARDA project addresses problems of dryland agriculture in North Africa. The projects of CIMMYT, CIAT and IWMI concentrate on Asia, and the CIFOR project has a global coverage. No project was selected that addresses NRM problems in Latin America because no adequate case was proposed.

Regarding types of research and their related research output, the projects can be grouped into macro- and micro-level projects (see Chapter 1). The former type includes projects that address research questions on policy and institutional aspects of natural resource management (NRM), while the latter comprises research on commodity-oriented and farm level-based NRM technology.

Table 4.1. Overview of natural resource management projects.

Centre	Project type and research product	Countries	Period of research	Investment (million US$)[a]
CIAT	Cassava productivity enhancement and soil conservation technologies and farmer participatory research	Thailand, Vietnam	1993–2004	4.0
CIFOR	Criteria and indicators of sustainable forest management	Global	1994–1999	3.3
CIMMYT	Zero tillage in rice–wheat systems	India	1990–ongoing	3.5
ICARDA	Alley cropping with cactus/*Atriplex*	Morocco, Tunisia	1995–2002	<1.0 for both countries
IWMI	Irrigation management transfer	Mainly South and Central Asia	1992–ongoing	Not specified
World Agroforestry	Tree fallows in maize	Zambia	1986–2002	~3.5
WorldFish	Integrated agriculture–aquaculture	Malawi	1986–mid-1990s	1.5

[a]Nominal values.

Two projects fall into the policy research category (macro projects), namely the CIFOR project on ‘criteria and indicators of sustainable forest management’ and the IWMI research on ‘irrigation management transfer’. In both cases, the research product is market or policy information, provided as an international public good, which can be used to improve policy decision making in NRM. The remaining five research projects included in the SPIA initiative were of the classic NRM type, i.e. projects dealing with technologies related to management of natural resources at the farm level. Three of these projects, namely CIMMYT’s research on zero tillage technology in rice–wheat systems, World Agroforestry’s tree fallows in Zambia and ICARDA’s research on introducing spineless cactus and *Atriplex* in wheat cropping in the Mashreq/Maghreb area, are concerned with soil as major natural resource stock.

As explained earlier, the output of field-level NRMR is often not embodied technology but rather it is management rules and procedures. Contrary to policy projects the field-level NRMR generates information for farmers on how to manage crops and crop–livestock systems. In some cases the management information is coupled with embodied technology such as machines or crops. In other cases, farm-level management information and information for other agricultural decision makers is produced. For example, in the CIMMYT case, the research product was clarification of the technical and socio-economic questions related to the zero and reduced tillage technology. The technology was already there but was not adopted. Apart from conducting technical research, much of CIMMYT's contribution was through its role as an 'honest broker' that helped to build confidence among local authorities and the agribusiness industry with the use of the technology in India. Similarly, the products of the World Agroforestry and ICARDA projects on agronomic and socio-economic research were to generate knowledge that was tied to specific technologies, i.e. leguminous trees in the case of the former and fodder crops in the form of *Atriplex* and spineless cactus in the latter case.

CIAT's project on cassava productivity enhancement, soil conservation technologies and farmer participatory research and the WorldFish Centre's project on integrated agriculture–aquaculture in Malawi applied a more comprehensive approach. Again, the research that generated soil, crop and fish management knowledge was coupled with embodied technologies, like improved cassava varieties in the former case and fishponds in the latter.

These two projects could also be labelled as what has been called integrated natural resource management (INRM) research. They explicitly incorporated farmer participation in the research design, which is one of the features of INRM research (see Chapter 2).

All seven research projects commenced in the mid-1980s or early 1990s. A period of 5 to 10 years had transpired between the research phase and the diffusion of the resulting technology. Hence, in theory, a sufficient time period was available allowing for an *ex post* impact analysis. However, the nature of NRMR implies the continuous updating of new knowledge instead of a one-time provision of a new embodied technology like seeds or machines, which eventually become replaced by new products. Therefore, many of the case studies faced difficulties in defining the start of the research exactly and, in addition, in making a clear distinction between research and extension.

Research investment per project ranged between US$1 and 4 million. However, it was generally rather difficult to quantify the costs of investments in NRMR for these projects because NRMR activities were often so closely interlinked with other research at the Centres. A good example of this problem was IWMI. Here the research activity on irrigation management transfer was strongly interwoven with IWMI's overall research programme. Many of IWMI's researchers were involved in analysing and synthesizing experiences on the privatization of irrigation systems worldwide. As a result of the difficulties encountered by the impact assessment teams in exactly specifying and quantifying the costs of the research activities that led to the NRM innovation, the figures in Table 4.1 are merely estimates based on available records of the Centre and of the national agricultural research system (NARS) and derived from expert judgements. In several cases, the term 'research investment' also includes some costs that fall into the category of extension investment. In some cases (e.g. ICARDA) Centres had engaged in dissemination and extension efforts in order to introduce and spread the NRM technology when national research and extension organizations had inadequate capacity.

Further complicating the cost side, all the projects showed significant involvement by NARSs and other partners. This feature of NRMR projects has implications for the attribution of the research products to the respective actors.

Another important aspect of the seven NRMR projects relates to the respective CGIAR Centres' comparative advantage in carrying out this research. For research by the international agricultural research centres the question must always be asked whether Centres can conduct this research more efficiently than other public or private research organizations at the national or international level. It is important to raise this issue at the beginning because this will facilitate comparisons with other CGIAR investments of the past and in the future. This question, however, can be answered rather clearly in the case of the two macro projects. Here, the independence and trustworthiness of the Centres had particularly qualified them to respond to the respective research demand.

For the micro projects this question is generally more difficult to answer, especially if the knowledge package or the technology is produced for the situation of one country. To some extent this is the case, for example, for the WorldFish Centre's project in Malawi. On the other hand, most NRMR for developing countries is of a basic research type whose benefits are often also enjoyed by the private sector. Also, NARSs tend to underfund NRMR, as most agricultural ministries in developing countries will give priority to short-term productivity enhancement research. For example, as demonstrated by the WorldFish case study in Malawi, the government had long been trying to introduce aquaculture to small-scale farmers but was not successful because the specific NRM knowledge and institutional 'buy-in' was missing.

The specification and the definition of CGIAR's NRMR and the assessment of its impacts are more challenging than corresponding studies in the field of germplasm improvement (GPI) research (e.g. Evenson and Gollin, 2003). Whereas in the latter the research activities and the research products are relatively easily identifiable, NRMR combines diverse methodological and disciplinary approaches, leading to difficulties in the tracking of effort and monitoring of expenses. The definition of outputs, outcomes and especially impacts and their specific attribution to the contribution of the different actors in the research process are more difficult to perform and therefore likely to be more uncertain than in the case of GPI research. The limited capacity of the Centres' accounting systems to allocate costs by research activity makes it difficult to produce exact cost figures for the highly integrated research activities of NRM.

Overview of Methodologies Applied in Impact Assessment

The different conceptual frameworks and analytical approaches for impact assessment in the selected NRMR projects are presented in Table 4.2. The approach of impact assessment generally differed between the

Table 4.2. Conceptual framework and methodologies.

Centre	Conceptual framework	Major methodologies used
CIAT	Household Production and Welfare Theory	Simultaneous equations of productivity change, consumer and producer surplus, rate of return
CIFOR	Institutional Economics and Information Theory	Impact pathway and client analysis
CIMMYT	Production and Welfare Theory	Statistical and descriptive analysis, partial budgets, consumer and producer surplus, rate of return, amount of resources saved
ICARDA	Production and Welfare Theory	Mathematical programming, ecological modelling, adoption and production functions, stochastic simulation, environmental impacts
IWMI	Institutional Economics and Information Theory	Bibliometric and webmetric analysis, client surveys
World Agroforestry	Production and Welfare Theory	Literature analysis on adoption, partial budget, rate of return
WorldFish	Household Production and Welfare Theory	Adoption functions, total factor productivity, stochastic production frontiers and technical efficiency analysis, descriptive statistics for income and profit, consumer and producer surplus, rate of return

macro and micro projects. The micro studies mostly used a neoclassical economics framework similar to the studies on research for crop GPI.

Table 4.2 indicates the approaches used in the NRMR impact case studies. Typically they started out with a description of the Centre's research output followed by an adoption study and proceeded to investigate the productivity and income effects of the technology by a production function or household model. To estimate technology adoption, the ICARDA and the WorldFish projects used an econometric adoption model. Probably the most advanced model was developed in the WorldFish case study, which applied a two-stage estimation procedure to model the adoption process. In the first stage, a Logit model was used to determine the factors that explain adoption of the technology and in the second stage a model was developed for adopters to determine intensity of adoption. The remaining micro projects used adoption proxies (CIMMYT),[1] compared project and non-project villages (CIAT), or made empirical estimates based on key informants (World Agroforestry).

[1]Adoption was estimated via the number of zero-till seeders sold.

Information about technology adoption is crucial in impact assessment. Credible evidence of adoption generally requires a good model that can adequately describe the technology diffusion process over scale and time. Proper identification of adopters and non-adopters is important to avoid the use of misguided counterfactuals in impact assessment; e.g. if selection biases are not being accounted for, the estimated impacts can be wrong. It must be pointed out that in none of the case studies was there baseline information available, which therefore has prevented the application of a classic difference in difference model (e.g. Wooldridge, 2000).

As typical for micro NRM projects, the scale of project coverage was either small or it was difficult to assess quantitatively. For example, in the CIAT case, technology adoption was largely concentrated on project villages, while in the ICARDA study technology diffusion was tied to the amount of government subsidy for promoting the resource-conserving technology. Ideally, conducting these two studies some 5–10 years later would have permitted a more comprehensive *ex post* analysis. On the other hand, the CIMMYT project was able to establish an effective public–private sector partnership that allowed them to make the assumption of large-scale diffusion. It must be pointed out, however, that in most of the projects the final scale of technology diffusion had to be predicted. Therefore, all analyses that computed rates of return had an element of *ex ante*, i.e. expected or projected rates of return.

Defining adoption was more problematic in the case of the two macro projects because of the difficulty in identifying to what degree the policy information had affected the policy decision-making process and the role that the use of the information had played in this. In the case of the CIFOR project, impact pathway and client analysis was applied. The IWMI project used bibliometric and webmetric analysis, and in addition a client survey, to measure uptake of information – the first step in the process of documenting impacts from such research initiatives.

To measure impact, all of the case studies of micro NRMR projects applied a welfare economics framework that enabled them to estimate supply shifts and thus calculate a financial or an economic rate of return on the R&D investment. As a basis to estimate shifts in supply resulting from technology adoption, the CIAT and the WorldFish case study chose econometric methods and had estimated production functions. The ICARDA study used a bio-economic simulation model, while both ICRAF and CIMMYT applied simple partial budgeting approaches. Risk analytical procedures applying stochastic simulation for the calculation of rates of return were used by the ICARDA project.

All five studies that assessed the impact of micro NRMR projects calculated a rate of return. In the case of CIMMYT shadow prices were used and hence this could be defined as an economic rate of return. Some of the projects included the distribution of the project benefits among producers and consumers in the analysis.

The effects of NRMR on poverty impacts were not included in the analyses. In spite of increasing demand by donor agencies for poverty impacts of agricultural research, this question could not be included because adequate research procedures to do so (e.g. sample size, benchmarks) would have exceeded the resources allocated to these impact studies.

In principle, the same can be said for the environmental impact of the NRMR projects. Measurement of the basic data in physical units (e.g. amount of water saved) was carried out only by some projects, as well. For example, the CIMMYT project demonstrated the energy effects of the zero tillage technology. The World Agroforestry study provided quantitative estimates on carbon sequestration. Other impacts that would require evaluation frameworks beyond neoclassic economics (e.g. social capital, empowerment, health, gender) were not addressed in the analytical procedure of the case studies. These were beyond the limited scope of the original research studies.

For the impact assessment of the macro projects, the methodology that was followed in the micro projects was not applicable. Also, no policy adoption model described in the recent literature (Pardey and Smith, 2004; see also Chapter 3) was used. The CIFOR studies were unable to identify the economic benefits of certification and the IWMI case did not succeed in generating information on the avenues and extent of adoption of the policy recommendations in privatization of irrigation.

As mentioned above, for research products that are 'just' published policy information in the form of guidelines or a specific set of recommendations, it is difficult to establish the link between use of that information by policy makers and the respective policy decision. In these cases it was therefore not possible to clearly identify what would have happened if the research products were not available. Both research projects had heterogeneous impact pathways. Attribution was complicated because of the difficulty in separating out the contributions of others. The case study analyses therefore concentrated on providing a thorough description and quantification of the demand for the information for which the research was undertaken, through application of interviews, a user survey and through bibliometric techniques and webmetric searches. The CIFOR study took this a bit further, by including interviews with key stakeholders.

Overview of Results

Table 4.3 summarizes and compares the main impact assessment results of the projects. More details are provided in the case study chapters that follow. The overview provided in the present chapter aims to put the individual project results into a broader perspective. At the same time some distinct and common features of these projects are highlighted and key results discussed.

As shown in Table 4.3, the area where the NRMR results were applied varies a lot and often cannot be defined with certainty although, in

Table 4.3. Impact results of natural resource management projects.

Centre	Scale (ha or no. of users), actual (A)[a] and predicted (P)[b]	Consumer (C) and producer (P) surplus (%)	Internal rate of return (%)	Other impacts documented
CIAT	Eight villages; additional 2800 t of cassava per village and year (A)	P: 100	~40	Knowledge and institutional learning
CIFOR	45 million ha of forest under certification (P)	n.c.	n.c.	Cost savings for certifiers
CIMMYT	0.82 million ha (A); 3.4 million ha (P)	C: 65 P: 35	57	Conservation of water and energy resources
ICARDA	Tunisia: 470 ha (A); 96,000 ha (P) Morocco: 1650 ha (A); 350,000 ha (P)	n.c.	Tunisia: 16 Morocco: 48	Reduction of soil erosion; net environmental benefit: US$131 per ha
IWMI	50,000 downloads in 5 years (A); 7500 copies of IMT guidelines (A)	n.c.	n.c.	Demand for policy advice
World Agroforestry	About 77,000 farmers (A)	n.c.	15 (25-year time horizon)	Carbon sequestration, risk reduction, reduced soil erosion
WorldFish	About 1000 t of fish per year (A); about 15,000 t per year (P)[c]	C: 60 P: 40	12	Household nutrition

[a]A refers to *ex post* evidence of adoption by the end of the data collection of the study, i.e. around 2002/2003.
[b]P refers to the predicted adoption on national level outside the project intervention area.
[c]Calculated on the basis of the observed annual growth rate up to 2016.
n.c., not calculated.

theory, recommendation domains should be conceived at the time of the research project planning. As explained at the beginning of the chapter, uncertainty varies by project. For example, the CIAT project promoted a participatory research approach in well-defined project villages, which has limited its coverage to these areas and to some extent to their surroundings. Furthermore, in not all cases could adoption be measured in terms of agricultural area. Sometimes only the number of farmers or the physical commodity output was given. For the macro projects the unit is the number of policy documents distributed and the number of users of these documents.

The internal rates of return (IRRs) that were estimated by the five micro-level case studies ranged from 12% (WorldFish) to 57% (CIMMYT). Thus the IRRs were of the same order of magnitude as found in many other R&D projects in agriculture (Alston *et al.*, 2000), although they may not reach the high levels found for GPI research (Evenson and Gollin, 2003). Compared with the overall IRR of aggregate CGIAR investment, Raitzer (2003) calculated an IRR of 15% if only those research projects are included where *ex post* impact was empirically attributable to the research. Evenson (2001) in a review of rates of return for agricultural research in Africa found 37% on average. However, this figure can be judged too optimistic as the studies underlying this study tended to underestimate the research costs. Also it must be pointed out that the IRRs of the NRMR projects in the current study were calculated using conservative assumptions, e.g. without spillover effects and environmental benefits being included. But on the other hand, some assumptions can be considered uncertain as they were based on projected future levels of adoption.

In two (CIMMYT, WorldFish) of the three cases that calculated economic surplus, it was found that NRMR projects benefit consumers relatively more than producers. Thus NRMR is in line with most other research investment in agriculture. Of course results depend on the elasticity of supply and demand. In the CIMMYT and the WorldFish case studies the elasticity of demand of the commodities involved was found to be low, thus leading to high price effects of the research. Conversely, the CIAT and World Agroforestry cases did not consider price effects and thus had only calculated producer benefits, which may underestimate the true benefits.

The quantification of environmental, health and other benefits was mostly only described rather than quantified by the case studies (see Table 4.3). There were some exceptions, however. The ICARDA case study using an ecological model of soil degradation was able to quantify and value the effects on natural resources and came up with an environmental benefit of US$131 per hectare.

Emerging Issues

This short introduction of the case studies points out some issues that can be highlighted prior to a detailed account of the selected NRMR projects. These may draw the attention of the reader to the next seven chapters that discuss the case studies. Also, some guiding questions that the reader of the case studies may find useful to keep in mind when going through the case study chapters are listed in Box 4.1.

Regarding the emerging issues first, the studies demonstrate that, at least in cases where benefits can be quantified, CGIAR investment in these specific NRMR projects has paid off, even though the IRR may not reach the level achieved for specific successful examples of crop GPI research. However NRMR has additional environmental benefits that were documented but not quantified and monetized. The case studies had clearly identified these but in most cases these have not been quantified.

Box 4.1. Emerging issues of the natural resource management research impact assessment case studies.

- Are the internal rates of return of these specific natural resource management research (NRMR) projects sufficient to justify the investment, as these are not at the upper end of the spectrum of rates of return associated with agricultural research e.g. for crop germplasm improvement?
- Would rates of return be higher if environmental benefits were included?
- Will more effort to quantify and value environmental benefits make a better case for NRMR?
- Was the impact pathway well conceived (from conception), i.e. a problem framework in place; what could be done to better estimate adoption and costs of adoption (farmer time, learning) of natural resource management (NRM) technologies?
- How well defined is the Centres' role and the research output as well as the timeframe for the research (versus extension)?
- Were there other players in the process who have contributed to the technology?
- Did the case study use an adequate counterfactual scenario?
- Will the conduct of baseline data collection help to overcome the counterfactual and attribution problem?
- Does the scale of micro NRMR necessarily have to be small?
- Are comparative studies across regions and countries on NRMR sufficient to produce generalizable knowledge on NRMR?
- What possibilities exist for the quantification of benefits for macro NRMR projects?
- What could be done to help institutionalize impact assessment for NRMR in the Centres?

This is an important point that will be given more attention in the synthesis chapter (Chapter 12).

The second issue that emerges from the cases is that NRMR often includes a significant component of extension. This question reveals that in NRMR the Centres perceived the need to be innovative in achieving technology adoption. Usually delivery systems in poor countries are largely dysfunctional or even absent. NRMR rarely has the champions and the willing extenders that one finds in the case of GPI, where the technology is embodied in seeds and there are actors both in the private and public sectors who understand the purpose of the research and stand ready and eager to extend the results of research. Given the lack of an NRMR delivery system so crucial for its successful implementation, a serious issue to consider is whether there is sufficient justification for conducting NRMR by the CGIAR at all. The detailed results of the impact assessment case studies may give some answers to this question.

A third issue that needs to be pointed out before the studies are introduced in detail is the quantity and quality of data. The Centres when doing NRMR often do not plan projects using explicit *ex ante* impact projections, and none of the cases had a baseline survey. This limits the use of analytical models that could help to overcome the counterfactual and attribution problems.

None of the NRM case studies formally incorporated contingent valuation or contingent choice models into the research process. Perhaps this is because of limited data availability for developing countries. However, the question needs to be addressed of whether it will be necessary to pay more attention to such issues in order to reach meaningful conclusions on the impacts of some types of NRMR.

Without drawing further conclusions at this stage, the overview of the case studies in this chapter has shown that there is evidence of positive impact from the NRMR in the CGIAR. At the same time, the following chapters will raise a set of interesting new questions and issues that will be addressed in more depth in the synthesis chapter.

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5 CIMMYT. Assessing the Impact of Natural Resource Management Research: the Case of Zero Tillage in India's Rice–Wheat Systems

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Rice–wheat systems provide the staple grain supply for about 8% of the world's population, making these systems critically important for global food security (Timisina and Connor, 2001; Ladha *et al*., 2003b). In South Asia rice–wheat systems produce more than 30% of the rice and 42% of the wheat consumed (RWC-CIMMYT, 2003, p. 24) and cover about 14 million ha of cultivated land – with most of the area located in India and the Indo-Gangetic Plains (IGP) (Timisina and Connor, 2001).

Recent studies indicate a slowdown in productivity growth in the rice–wheat systems of India (Kumar *et al*., 2002). Evidence from long-term experiments shows that crop yields are stagnating and sometimes declining (Duxbury *et al*., 2000; Ladha *et al*., 2003a). Current crop cultivation practices in rice–wheat systems degrade soil and water resources and thereby threaten the sustainability of the system (Byerlee and Siddiq, 1994; Duxbury *et al*., 1994; Fujisaka *et al*., 1994; Hobbs and Morris, 1996; Ali and Byerlee, 2000; Kumar and Yadav, 2001; Gupta *et al*., 2003; Ladha *et al*., 2003a). The prevailing policy environment has encouraged inappropriate land and input use (Pingali and Shah, 1999) and crop system constraints have encouraged unsuitable responses.

If the supply of food is to keep pace with rapidly growing demand, rice–wheat farmers will have to produce more food from fewer resources while sustaining environmental quality. This will require rapid technological change towards technologies that are both more productive and less resource-degrading. The Rice–Wheat Consortium of the Indo-Gangetic Plains (RWC: www.rwc.cgiar.org) is a consortium involving international agricultural research centres and national agricultural research systems (NARSs) from Bangladesh, India, Nepal and Pakistan. Over the past 10 years it has developed and promoted a number of resource-conserving technologies that increase farm-level productivity, conserve natural resources and are less polluting.

To date, the resource-conserving technology that has been most widely adopted in the IGP is zero-till (ZT) wheat after rice, particularly in India. The present chapter reviews and synthesizes the experience with zero tillage (ZT) in the irrigated IGP of India so as to better understand and document the impact of this technology and related research. In the next section we introduce the ZT technology in the context of India's rice–wheat systems, including a brief historic overview of the related R&D. In the four following sections we present the methodology of the study, look into ZT adoption, review the farm-level impacts of ZT and estimate the welfare impacts and review the environmental impacts. A final section concludes.

The Zero Tillage Technology

Zero tillage implies planting crops in previously unprepared soil by opening a hole, narrow slot, trench or band of the smallest width and depth needed to obtain proper coverage of the seed.[1] Zero till is also known as no till and direct planting. It is a practice adopted by farmers since ancient times and it continues to be followed by farmers in developing countries to date. The modern concept of ZT tends to imply seeding a crop mechanically in undisturbed soil covered with plant residues. 'Though the name refers to only one practice, no till actually is a farm management system that involves many agricultural practices, including planting, residue management, weed and pest control, harvesting, and rotation' (Ekboir, 2002).

The prevailing ZT technology in the rice–wheat systems uses a tractor-drawn zero-till seed drill to establish wheat in the rice stubble. Often, use is made of a zero-till seed-cum-fertilizer drill: a conventional seed drill fitted with sharp-edged modified furrow openers, a calibrated engraved disc and a cup mechanism for placing fertilizer. The machine opens a number (six to 11) of narrow slits for placement of seed and fertilizer at the depth of 7.5–10 cm into the soil (Mehla *et al.*, 2000). The ZT drills are made domestically and cost around US$400 (Parwez *et al.*, 2004). Within the context of conservation agriculture, ZT implies the retention of crop residues as mulch on the soil surface and its year-round application to all crops in the cropping cycle. In the Indian context farmers still typically apply ZT to the wheat crop only and maintaining adequate residue levels for an effective mulch has proved problematic – both in terms of prevailing crop residue management practices (Timisina

[1]Reduced tillage refers to the practice of less frequent tillage as compared with conventional farming practices. In this study no distinction is made between zero and reduced till.

and Connor, 2001) and sowing wheat in the presence of significant loose rice residues with the current ZT drills (Pandey *et al.*, 2003).

In the IGP wheat is grown in the cold and dry weather during November to March and rice is grown during the warm humid/semi-humid season during June to October (Timisina and Connor, 2001). ZT of wheat is particularly appropriate for these systems and addresses four important constraints.

First, rice–wheat systems are characterized by late planting of wheat, which significantly reduces wheat productivity. The delay in planting the wheat crop is mainly due to the late harvest of the previous crop and/or a long turnaround time. The late harvest of the previous rice crop can be linked to both the late rice establishment and the duration of the rice crop. For instance, in some parts of the IGP farmers grow fine-quality rice (especially basmati), which takes a longer time to mature. The long turnaround time often reflects intensive tillage operations, soil moisture problems (too wet or too dry), the unavailability of draught and mechanical power for ploughing and the urgency of storing the rice crop before preparing the land for wheat cultivation. Farmers perceive the need for intensive tillage due to the difference in soil management practices for rice and wheat – the former being grown under anaerobic conditions and the latter under aerobic conditions. ZT greatly reduces the turnaround time, allowing wheat establishment in a single pass almost immediately after the rice harvest.

Second, continuous rice–wheat cultivation has led to a build-up of biotic stresses. The major weed affecting wheat in the IGP is *Phalaris minor*, which shows emerging resistance to isoproturon herbicide after repeated and widespread use. By reducing soil movement ZT serves as an effective control measure of *P. minor* (Malik *et al.*, 2002c).

Third, rice–wheat systems have led to land degradation. Excessive groundwater pumping has led to lowering of the water table in some of the rice–wheat areas (Kataki *et al.*, 2001; Malik *et al.*, 2002a) and irrigation-induced degradation in other areas (e.g. water-logging, salinity). ZT potentially reduces irrigation water use and thereby alleviates pressure on aquifers and soils.

Fourth, rice–wheat systems need to enhance their cost competitiveness in the context of trade liberalization. ZT potentially includes savings in energy, water, labour and other inputs. ZT drastically reduces machinery use and the cost of the tillage operation – a major cost of crop production in the IGP. Compared with broadcasting, the ZT drill saves seed and fertilizer, placing them at the desired depth and vicinity and in the right quantities.

The advantages of ZT technology are thus manifold. On the one hand, this practice generates higher yields at lower production costs; on the other, it is an environmental friendly practice that saves water and soil (Hobbs *et al.*, 1997).

A Brief History of Zero Tillage in India

Research on ZT for wheat in India started almost three decades ago with the following key events:

- 1970: start of ZT research but lack of adequate planting equipment and weed control difficulties.
- 1991: first prototype of the Indian ZT seed drill (Pantnagar drill).
- 1997: improved ZT drill by private manufacturer.

In 1997 the private manufacturers supplied over 150 improved ZT drill machines to state agricultural universities (SAUs) and the Indian Council of Agricultural Research (ICAR) institutions located at Haryana, Punjab, Uttar Pradesh and Bihar. The manufacturers spent a lot of time in the fields with farmers and scientists to better understand the problems in machine operation, which led to rapid improvement of subsequent models. The manufacturers, scientists and farmers shared their experiences with senior staff and officials to seek their support in promoting ZT. All were encouraged by the better results of ZT. The combined efforts of NARSs, SAUs, private manufacturers, RWC and the International Maize and Wheat Improvement Centre (CIMMYT) resulted in widespread adoption of ZT after the turn of the millennium.

In India rapid and widespread adoption of ZT started in Haryana State. Two drivers behind the success are the adequacy of the technology in meeting farmers' needs and the favourable institutional context. In Haryana many farmers grow late-maturing, fine-grained rice varieties (e.g. basmati) causing late sowing of wheat. The incidence of the weed *P. minor* was widespread in this area. ZT was helpful not only in reducing the cost of tillage but also in increasing the wheat yield. Several actors played a key and complementary role in spreading the ZT technology, including Haryana Agricultural University, the Directorate of Wheat Research (ICAR) and the State Agricultural Department aided by the various sponsored R&D projects from the RWC, CIMMYT, ICAR and the Australian Centre for International Agricultural Research. The state government also supported ZT in the form of a subsidy of Rs3000 per new ZT drill on a unit gross price of Rs13,000, which has enhanced farmers' access to the machine (Ekboir, 2002). Other than these the drivers of the success were timely congruence of technology interventions, liberalization and the participatory operational approaches provided by the RWC.

Seth *et al.* (2003, p. 67) list the main reasons for the rapid success of ZT in India as:

- The initiative was responding to a strong farmer demand where the private sector could see substantial market opportunities for their products.
- RWC played a crucial catalytic role in promoting the public–private partnership, nurtured it through its formative stages and facilitated

technology transfer from international and national sources. In addition, RWC established a small revolving fund to facilitate delivery of machines at district points.
- Close linkages of scientists and farmers with private manufacturers, including placement of machines in villages for farmer experimentation, allowed rapid feedback and refinement of implements.
- Involvement of several manufacturers ensured competitive prices, good quality and easy access to drills by farmers along with guarantees for repairs and servicing.
- Strong support from state and local government officials helped with dissemination.

The RWC played an innovative role as information provider, capacity builder and technology clearing house. As a research-for-development network, the RWC works closely together with international organizations, government organizations, the private sector and farmers. In doing so it facilitates their collaboration, strengthens inter-linkages, encourages information sharing and feedback, circumvents institutional blockages and mobilizes resources.

Method

The present study comprised three components: a review, focus group discussions and modelling. For the first component we compiled and reviewed information on ZT wheat in India's rice–wheat systems in the IGP, including published literature, grey literature and unpublished data sets. The available information tends to report primarily on the technical aspects of ZT at the plot level. To a lesser extent economic and environmental aspects are covered. The available information was primarily derived from trial data (on-station and on-farm). Only occasionally did it include survey data. There was significant variation in the scientific rigor behind the various information sources, often lacking measures of variability or statistical analysis.

For the second component we conducted village-level focus group discussions in Punjab, Haryana and eastern Uttar Pradesh (UP). The exercise included both adopters and non-adopters in six villages (two in each state). The group was divided into rich and poor farmers on the basis of landholding, and discussions were carried out for males and females separately. The focus groups were conducted to analyse the socio-economic impact of ZT wheat first-hand and for validating the secondary data.

For the third component we modelled the economic impact of ZT wheat R&D in India's IGP. The aggregate welfare impact of ZT was estimated using the economic surplus approach in a closed economy framework with linear supply and demand functions and a parallel research-induced supply shift (Alston *et al.*, 1998). These welfare impacts were used to estimate the *ex ante* rate of return on investment in ZT

Table 5.1. Comparison between 'with' and 'without' cases.

	'With' case (with RWC & CIMMYT investments)	'Without' case (without RWC & CIMMYT investments)
ZT/RT adoption	Extrapolation from observed diffusion curve to date to 33% in 2009	5-year lag (of current rate and extrapolation)
CIMMYT cost	US$600,000 over 12 years	0
RWC cost	US$2,900,000 over 19 years	0
NARS cost	US$3,900,000 over 23 years	US$4,100,000 with 5-year lag
Extension cost	US$4,100,000 over 26 years	US$4,200,000 with 5-year lag

RWC, Rice Wheat Consortium of the Indo-Gangetic Plains; CIMMYT, International Maize and Wheat Improvement Centre; ZT, zero tillage; RT, reduced tillage; NARS, national agricultural research system.

wheat R&D. Table 5.1 presents the main contrasts between the 'with' case (with RWC and CIMMYT investments) and 'without' case used to estimate the rate of return. The economic impact of R&D was calculated for two 'with' case scenarios to test for sensitivity of the findings. Table 5.2 presents the main parameters used and the differences between the conservative and optimistic scenarios.

It is important to stress here that the economic impact thus estimated reflects only the ZT-induced downward supply shift for wheat. Data lim-

Table 5.2. Selected parameters for impact calculations.

Indicator	Conservative scenario	Optimistic scenario
Elasticity of demand	0.22	id.
Elasticity of supply	0.40	id.
Social discount rate	5%	id.
Ceiling level of ZT/RT adoption	33%	id.
Yield advantage	6%	10%
Change of cost in per ha cost of cultivation	5%	10%
Produce prices	Social (FHP/NPC)	id.
Timeframe	1990 base year + 30 years	id.
Benefits:		
– Zero till (ZT)	100% (27% of ZT & RT area)	
– Reduced till (RT)	50% (73% of ZT & RT area)	id.
Extension component	100% NARS	id.

FHP: Farm harvest price; NPC: Nominal Protection Coefficient – explorable basis. Sources: elasticity – Pal *et al.*, 2003; NPC – Gulati *et al.*, 2003 as cited in World Bank, 2005; id. = identical.

itations preclude us from including and valuing environmental and social impacts of ZT at this stage (e.g. externalities, intangibles, long-term effects and distributional effects). Reliable estimates of these effects are typically still scanty. Compounding the issue, the extent and durability of the ZT wheat environmental gains are debatable with current farmers' practices for the subsequent rice crop and crop residue management. Overall though, ZT typically implies positive environmental impacts, so that our economic impact estimates can be seen as a conservative estimate that underestimates the true social value of the technology and the social rate of return.

We can make only a reasonable assumption about the counterfactual in the absence of efforts by RWC and CIMMYT. It can thus be assumed that CIMMYT's role and persistence were key factors in getting the technology adaptation process through its slow and difficult start. In this process CIMMYT has assumed the role of an 'honest broker' in building up confidence of the applied research and testing process. The RWC as a network could not have functioned on a stand-alone basis, but its presence and perseverance have generated synergies and momentum that otherwise were unlikely to be achieved. Indeed, success tends to generate an upward spiral of interest and additional resources. The RWC has been crucial in achieving and building on the initial gains for ZT in the Indian IGP – through fostering prototype ZT equipment, farmer experimentation and information sharing. Attribution remains difficult, though, and the RWC thereby takes shared credit for the successful spread of ZT. For instance, in neighbouring Pakistan institutional rivalry has slowed the significant spread of ZT so far. In recognition of the processes described above we thus assume that, in the absence of RWC and CIMMYT's efforts in India, widespread ZT adoption may have lagged behind by at least 5 years but it could well also be up to 10 years.

Adoption of Zero and Reduced Tillage

In India's rice–wheat systems, adoption of ZT is primarily in the wheat crop and concentrated in the north-western IGP. On an annual basis, the RWC compiles estimates of the scale of adoption of various resource-conserving technologies (Gupta, 2004; RWC, 2004, www.rwc.cgiar.org). These estimates are primarily expert estimates at the state level using a range of indicators. In these estimates it is problematic to reliably separate ZT from reduced tillage (RT) – so that these two technologies are typically lumped together.

These estimates also primarily reflect tillage level and the use of ZT drill for individual crops, without explicit consideration of crop residue management. In 2003/04 the total estimated wheat area under zero and reduced tillage combined was approximately 820,000 ha in the Indian IGP (Table 5.3). Most of the adoption was concentrated in Haryana (46% of 2003/04 ZT/RT area), Punjab (26%) and western UP (21%). These areas

Table 5.3. Geographic distribution of rice–wheat system and estimated zero and reduced till area in the Indo-Gangetic Plains of India. (From Pal *et al.*, 2003; RWC, 2004.)

State	Area under rice–wheat rotation (1998–2001) ('000 ha)	Area with zero/reduced tillage wheat ('000 ha)		
		2001/02	2002/03	2003/04
Punjab	910	20	50	215
Haryana	2,190	97	275	350
Uttar Pradesh, Uttaranchal & Himalachal Pradesh	5,130	12.6	45	235
Bihar	1,830	0.4	1	18
West Bengal	330	0	0	0
Total area	10,400	130	371	818

are characterized by high agricultural productivity. The ZT/RT adoption has started to pick up in the eastern part of UP and Bihar, where agricultural productivity is lower. So far ZT has spread more widely in the better endowed areas.

In 2004/05 the total estimated area under zero and reduced tillage combined was approximately 1.6 million ha in the Indian IGP (Shoran, 2005). The 2004/05 estimate for the first time disaggregated the estimated ZT and RT areas, with ZT comprising 27% and RT 73%.

The aggregate ZT/RT adoption estimates can be triangulated against other available adoption indicators. A recent random survey of 400 farm households in Haryana's rice–wheat belt included 34% ZT users in 2003/04 (Erenstein *et al.*, 2007). A random survey of 759 farm households in Punjab included 12% ZT users and 5% RT users in 2003/04 (Singh, J., personal communication). These studies provide further support for the significant levels of ZT adoption in Haryana and Punjab. Although the focus groups conducted within the context of this study do not provide a representative sample (six villages from adoption areas), they did highlight the significant extent and speed of ZT adoption in each village.

The adoption estimates can also be contrasted with the reported sales of ZT drill machines. A recent study in Haryana and Punjab, where most adoption is concentrated, has compiled the number of ZT manufacturers and the number of ZT drills sold annually over the last 10 years (Parwez *et al.*, 2004). Both indicators show a significant increase in recent years (Fig. 5.1). These data highlight that, by the end of the year 2003, a cumulative total of 15,700 ZT drill machines had been sold in the two states.[2]

[2]Adoption of ZT technology moved from Haryana to Punjab, but manufacturers were initially located in Punjab and machines were transported from there in the early years of adoption.

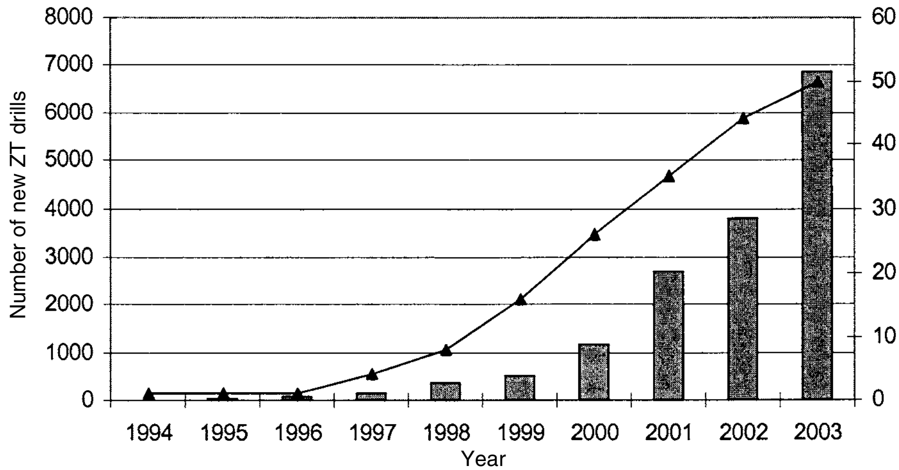

Fig. 5.1. Number of zero till (ZT) drills sold per year (bars) and numbers of ZT manufacturers (▲) in Haryana and Punjab, India, 1994–2003. (From Parwez *et al.*, 2004.)

If we assume all machines to be operational, and unreported sales to cancel out against eventual exported machines to other states, then the reported 565,000 ha of ZT/RT in the two states in 2003/04 (Table 5.3) implies an average of 36 ha planted per ZT drill. This compares well with the results of a survey of 153 ZT drill-owning farmers in Haryana, which showed that on average each ZT machine had planted 42 ha of wheat in 2001/02 (Malik *et al.*, 2002a).

The ZT technology is currently in the mass adoption phase in the Indian IGP. The ZT technology cannot be realistically extended to the entire IGP area due to a range of agroclimatic and socio-economic factors that limit its applicability. Similar to Pal *et al.* (2003), we estimate the adoption ceiling for ZT/RT to be 33% of the wheat area in the IGP's rice–wheat systems – a potential ZT/RT area of 3.43 million ha.

Figure 5.2 (leftmost line, 'with' case) depicts a logistic curve fitted to the reported ZT/RT adoption estimates and the 33% ceiling – thereby highlighting the acceleration of the diffusion of ZT/RT over recent years. In the same figure we have also included the same curve with a 5-year lag which corresponds with our counterfactual – the shaded area thereby highlighting the differential adoption attributable to the RWC and CIMMYT's contribution.

The current stage of mass adoption calls for ongoing analysis of the experiences of adopters and making the necessary modifications in the technology and diffusion process to suit the local needs, and enable even wider adoption and adaptation. Understanding farmers' perceptions and practices and the drivers and modifiers behind these is instrumental. Some farmers use the ZT drill, but maintain a limited degree of tillage – i.e. RT (or partial adoption). Some adopters continue to use ZT alongside conventional tillage (CT) on the same farm (Pandey *et al.*, 2003). Ten per

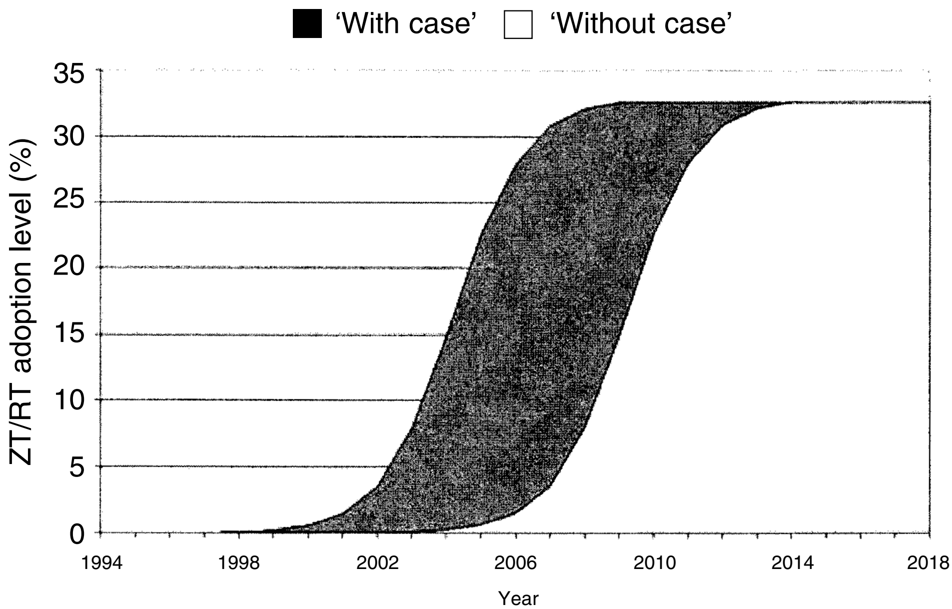

Fig. 5.2. Expected adoption pattern of zero tillage/reduced tillage in the Indian Indo-Gangetic Plains in the 'with' and 'without' case (see text for explanation).

cent of 400 randomly surveyed farm households in Haryana's rice–wheat belt had disadopted ZT in the survey year (Erenstein *et al.*, 2007) – including 'temporary' disadoption, whereby farmers had reverted to RT for various reasons (e.g. to control a rainfall-induced flush of weeds). The focus groups also found some farmers who discontinued ZT due to problems, including the perceived need for occasional tillage, formation of hardpan and weed control.

The ZT technology is dependent on affordable and timely access to ZT drills and their correct operation – an issue particularly in the early stages of adoption. Custom hiring services have thereby been a key ingredient for the rapid diffusion of ZT. A survey of ZT drill-owning farmers has highlighted that 69% of the wheat area planted with each drill was under custom hiring (Malik *et al.*, 2002a). Surveyed disadopters in Haryana mentioned the non-availability of ZT machinery as the main reason for disadoption (Malik *et al.*, 2002a). The focus groups in eastern UP also included cases that had discontinued ZT due to untimely availability of ZT drills, reflecting the inability of a few ZT service providers to meet the demand during wheat establishment time. Availability of machinery is still likely to restrain adoption in the eastern plains in the near future.

Farm-level Impact of Zero Tillage

The present section reviews the farm-level impacts of ZT wheat in rice–wheat systems in the Indian IGP based on the available literature and contrasts it with the focus group findings.

Effects on land preparation and crop establishment

Conventional tillage practices for wheat are very intensive in India's rice–wheat systems. Due to the adoption of ZT technology, the number of field operations for wheat crop establishment (including tillage) has decreased from an average of seven to only one (Malik *et al.*, 2002a). Owing to this, tractor operational time of about 8–12 h/ha is reportedly saved (80–88% saving; Malik *et al.*, 2002a, 2004). The corresponding seasonal saving in diesel for land preparation is reported to be in the range of 15–60 l/ha, representing a 60–90% saving (Malik *et al.*, 2002b, 2004; Hobbs and Gupta, 2003; Laxmi *et al.*, 2003). In view of the prevailing mechanization levels in the Indian IGP, ZT primarily implies a saving of tractor time and labour use savings are relatively limited in land preparation and crop establishment (Malik *et al.*, 2002a; Laxmi *et al.*, 2003). The reduced turnaround time allowed wheat planting to be advanced by 7–10 days in Haryana and by 8–25 days in Bihar (Malik *et al.*, 2002a).

The focus group meetings revealed similar savings in tractor operational time for land preparation (13, 7 and 6 h/ha in Punjab, Haryana and eastern UP, respectively) and corresponding diesel use (27, 35 and 14 l/ha, respectively). The lesser quantity of diesel saving in UP is due to the lower level of mechanization in this area. In UP people reported advancement of wheat sowing by 10 days.

Effects on water use

Zero tillage is reported to save irrigation water in the range of 20–35% for the wheat crop. It thereby reduces water usage by about 10 cm/ha, or approximately 1 million l/ha (Mehla *et al.*, 2000). The savings arise because with ZT it is possible to sow wheat just after the rice harvest, making use of residual moisture for wheat germination. Moreover, irrigation water advances more quickly in untilled soil than in tilled soil. The saving is generally reported for the first irrigation (e.g. 8–10 h with ZT and 13–17 h with CT; Hobbs *et al.*, 1997). The problem of waterlogging and yellowing of the wheat plants after the first irrigation is thereby reduced (RWC-CIMMYT, 2003, p. 95). ZT can also imply a saving of one irrigation (Hobbs *et al.*, 1997; Mehla *et al.*, 2000; Malik *et al.*, 2002a,b; Laxmi *et al.*, 2003). The irrigation savings tend to translate into immediate cost savings whenever farmers rely on lift irrigation, like in the case of electrically or diesel-operated wells.

The focus groups reported similar water savings – be it in terms of one irrigation saving or reduced duration of primarily the first irrigation.

Effects on soils, weeds, pests and diseases

Zero tillage typically improves soil quality in various dimensions, including soil structure, soil fertility and soil biological properties. Rice–wheat systems typically have low soil organic carbon (Duxbury *et al*., 2000). ZT soils reportedly have higher organic carbon contents than CT soils, but also a lower pH (due to nitrification; Malik *et al*., 2002a). The same study reported that the higher stability of soil aggregates under ZT (due to accumulation of organic matter) results in reduced soil erosion from wind and rain. Studies have also reported that the upper soil surface for ZT was comparatively soft, had higher moisture content, and there was no significant difference in bulk density under both tillage systems (Malik *et al*., 2002a). However, such gains during the wheat crop will only present seasonal gains as long as the subsequent rice crop remains intensively cultivated and anaerobic. For structural soil quality enhancement the whole cropping system would need to shift to aerobic and ZT conditions with adequate residue management.

Zero tillage typically reduces the incidence of weeds in the wheat crop (Malik *et al*., 1998, 2002a, 2004) – primarily due to the early emergence of wheat and lesser soil disturbance. Both long-term trials and farmer surveys suggest a change in the weed spectrum in ZT wheat fields, particularly a decrease in *P. minor* and an increase in the population of broad-leaved weeds (Malik *et al*., 1998, 2002a; Laxmi *et al*., 2003).

Zero tillage also alters the dynamics of selected pests and diseases (Malik *et al*., 2002a; Laxmi *et al*., 2003). ZT has reportedly no harmful effect on the population density of insect pests in general and of the yellow stem borer of rice in particular (Malik *et al*., 2002a). In fact, ZT reduced the nematode population and enhanced both the earthworm population and predator diversity and density in wheat (Malik *et al*., 2002a).

The focus group meetings also reported a perceived increase in soil quality, a decrease in *P. minor* and an increase in broad-leaved weeds. Rodent damage was occasionally reported, is seemingly associated with residue retention and calls for closer monitoring.

Yield effects

The generally positive yield effects of ZT on wheat are mostly due to: (i) timely sowing; and (ii) increased input-use efficiency and weed control (Mehla *et al*., 2000). Terminal heat implies that wheat yield potential reduces by 1.0–1.5% per day if planting occurs after 20 November (Randhaw *et al*., 1981; Ortiz-Monasterio *et al*., 1994; Hobbs and Gupta, 2003). Approximately 30% of wheat cultivation is under late sowing in the Indian IGP, and ZT allows for timelier establishment.

On average, an increase of 11% (400 kg/ha) in wheat yield was reported with ZT in each year (2000/01 and 2001/02) across six research Centres in the IGP (Dhiman *et al.*, 2003) – ranging from a marginal 1% (50 kg/ha) decrease in the Punjab to a maximum of 26% (600 kg/ha) increase in eastern UP. On-farm trials across the IGP have also highlighted the higher yields with ZT, with increases ranging from 1–15% in the north-west to 9–36% in the east (Malik *et al.*, 2002a, 2004). On average, a 280 kg/ha increase in wheat yield was reported in 112 farm trials (46 in 2000/01 and 66 in 2001/02) across five states in the IGP (Dhiman *et al.*, 2003) – average increases ranging from 110 kg/ha in the Punjab to 490 kg/ha in Bihar. Both on-station and on-farm trials thereby highlight significant yield gains with ZT, with the gains increasing from Punjab towards the middle IGP reflecting the increasing importance of timeliness. Long-term monitoring of six sets of farmer fields over 8 years in Haryana has shown that ZT consistently had yields higher than or similar to CT (Malik *et al.*, 2005, p. 16).

As yet, few farm surveys are available to document yield effects of ZT adoption in the IGP. One survey of approximately 400 farmers in 2003 contrasted ZT adopters with non-adopters in Haryana and Bihar (Laxmi *et al.*, 2003). In Bihar, ZT significantly out-yielded CT by 9% (220 kg/ha, 2.7 versus 2.5 t/ha). In Haryana, the difference in yields was not statistically significant (ZT 5.2 versus CT 4.9 t/ha). In another adoption survey of 34 farmers in Uttaranchal, ZT adopters significantly out-yielded conventional tillers by 5% (200 kg/ha, 4.4 versus 4.2 t/ha; Pandey *et al.*, 2003).

The focus group meetings confirmed the positive yield effect of ZT. The discussions reported a ZT yield gain of 500 kg/ha in the Punjab and Haryana and 325 kg/ha in eastern UP – a yield gain of approximately 10% in each site.

Cost savings and profitability

Most of the available studies concur in highlighting the profitability of ZT wheat production over conventional practice. Two factors contribute to the overall profitability of ZT: the value of the yield increase and the production cost savings – particularly savings in land preparation and crop establishment. Savings in irrigation pumping and inputs may add to this. Comparison of the various studies is somewhat complicated by their site specificity and methodological differences, including the source of the data and costs included. Most calculations typically use the local cost of hiring ZT services as the opportunity cost of the ZT drill (e.g. Rs 715/ha; Malik *et al.*, 2002a).

A number of profitability estimates have been derived from on-station and on-farm trial data. These typically comprise savings derived from partial budgeting and the value of the yield increase. On-station cost savings for ZT have been reported to range from Rs 1700 to 2300/ha (Malik *et al.*, 2002a; Dhiman *et al.*, 2003). For on-farm trials in Bihar and Haryana, slightly lower savings of Rs 1400/ha have been reported, which together with the value of the additional yield (Rs 3000/ha) provided an overall net profit of Rs 4400/ha for ZT (Malik *et al.*, 2002a). In the Haryana trials the savings amounted to 6% of total cost (ZT Rs 22,800 versus CT Rs 24,200/ha; Malik *et al.*, 2002a). For on-farm trials in western UP, savings ranged from Rs 2300 to 2800/ha, which together with the value of the additional yield (Rs 900–2500/ha) provided an overall net profit of Rs 3400–4800/ha for ZT (Malik *et al.*, 2004). For eastern UP higher costs savings were reported (Rs 3500–4900/ha for ZT; Malik *et al.*, 2004).

The limited farm surveys also report significant cost savings. Compared with conventional tillers, ZT adopters saved Rs 1700 and 2200/ha in Haryana and Bihar, respectively (Laxmi *et al.*, 2003). ZT adopters in Uttaranchal reportedly saved Rs 3900/ha (24%), which together with the value of the additional yield (Rs 500/ha) provided an overall net profit of Rs 4400/ha (43%; Pandey *et al.*, 2003).

The focus group meetings in Punjab and Haryana reported cost savings of Rs 2000–2500/ha and an overall net profit of Rs 4400–5000/ha for ZT. In eastern UP, reported cost savings were significantly higher at Rs 7500/ha, with an overall net profit of Rs 9500/ha for ZT. These last estimates seem somewhat high compared with the other estimates, but in general the focus groups confirmed the significant cost savings and increase in profitability attributable to ZT. The similarity of reported savings and profits attributable to ZT are striking though, providing support to the relatively wide applicability of this technology.

Socio-economic and system impacts

Both large and small landholders adopt ZT (Laxmi *et al.*, 2003; Malik *et al.*, 2004). This is facilitated by the ability of smallholders to contract ZT drill services – just as they do for their tillage services in general. Malik *et al.* (2004) have highlighted the benefits of ZT to be relatively scale-neutral: smallholders achieving similar gains in net returns (ZT 7700 versus CT 6000 Rs/ha) to large-size farms (ZT 9000 versus CT 7100 Rs/ha). In terms of the yield gains and cost savings reviewed above, the areas with less intensified agriculture conceivably gain more from ZT than the highly intensified agriculture areas, thereby potentially reducing regional inequality. For now though, the technology has spread far more significantly and thereby primarily benefited the better-endowed areas. In much the same way, the early adopters of ZT tend to be better endowed (e.g. larger landholdings, better educated; Pandey *et al.*, 2003; Erenstein, 2007).

The use of ZT in wheat opens the scope for new technologies, including application of ZT to other crops (e.g. pulses and cereals) and permanent beds and the diffusion of new varieties. Most varieties in use in farmers' fields have been selected under CT conditions, and variety–ZT interactions have been reported (Mehla *et al.*, 2000). Conceivably, varieties selected under ZT conditions are likely to enhance the benefits of ZT. Zero tillage also has the potential of increasing cropping intensity and diversity in selected areas of the IGP (e.g. moving towards double cropping in rice–fallow systems; introducing triple cropping in rice–wheat systems). The benefits of ZT wheat would also be significantly enhanced if the subsequent rice crop were to be cultivated under aerobic and ZT conditions – as well as opening the scope for further diversification.

Beyond the farm level, ZT opens a new service industry – be it for machinery manufacturers or custom hiring services. The potential multipliers associated with these changes, particularly intensification, diversification and service industries, are likely to more than compensate the relatively limited direct ZT-induced labour displacement, particularly in view of the prevailing mechanization levels. However, time, monitoring and further studies are needed to substantiate such potential impacts.

The focus group discussions also showed that both large and small landholders had adopted ZT. The large landholders benefited due to less risks of delays in wheat establishment. The smallholders reported that they could also reap the advantages of ZT wheat if they were able to get the machine in time on custom hiring. Although the authors perceive the labour-saving nature of ZT wheat to be relatively limited, landless labourers, both men and women, reported to have been adversely affected, some commenting they lost their seasonal wage employment. Migrant and landless labourers raised concerns about the possible adoption of ZT in paddy, as they fear the more significant loss of earnings during paddy transplantation. The time and resource savings were variously used by the adopters. Both males and females reported having more time to undertake other income-generating/saving activities (such as raising livestock, carpentry, electrical work, tailoring, etc.) as well as leisure (e.g. social ceremonies).

Women generally appreciated ZT. They acknowledged that after the adoption of ZT in wheat there is less tension, which normally prevailed because of the hectic schedule of field operation under CT, and this has resulted in more peace at home. Women also reported that with ZT their drudgery is reduced, and their male counterparts are helping them in animal care and children's education. In the low-productivity areas women were less informed about ZT than the women in high-productivity areas. ZT as such has not played any role in school enrolment or dropout rates of children – especially girls.

Economic and Environmental Impact of Zero Tillage/Reduced Tillage

Welfare impacts

The significant farm-level impacts of ZT in terms of yield increase and cost savings translate into a downward shift of the supply curve. The aggregate welfare effect of this shift was estimated through the economic surplus approach and used to estimate a rate of return for the 'with' case (with RWC and CIMMYT investments), using various assumptions and parameters as outlined in the Method section (Tables 5.1 and 5.2). A fundamental assumption is that the observed adoption levels – and expenditures of the national agricultural research and extension system (NARES) – would have lagged behind by 5 years in the 'without' case (Fig. 5.2). We attribute the differential benefit stream (primarily consumer and producer surplus and some saving of NARES cost) to the investments made by RWC and CIMMYT. The estimates of the benefits are conservative in the sense that they include only the welfare effects attributable to the tangible direct benefits. The positive environmental impacts addressed in the next section would only add to the social value of the technology.

For the conservative scenario we assume ZT-induced yield gains of 6% and cost savings of 5%, and half these values for RT. The results show that even with these relatively conservative values, the ZT/RT research programme is highly beneficial with a benefit:cost ratio (BCR) of 39 and a net present value (NPV) of US$94 million. The internal rate of return (IRR) was 57% (Table 5.4). The discounted economic surplus (US$96 million) indeed dwarfs the discounted cost of the 'with' case (US$2.5 million). The economic surplus primarily benefited consumers (65%) compared with producers (35%). For the more optimistic scenario we assume ZT induces 10% yield gains and 10% cost savings (and half these values for RT). In this case the estimated NPV is US$164 million with a BCR of 68 and an IRR of 66% (Table 5.4).

Results of sensitivity analysis of the conservative scenario to changes in various key indicators are presented in Table 5.5. For each indicator, two alternative values were imputed, *ceteris paribus*. For the discount rate, a 10% and 0% value were imputed. But even under a discount rate of 10% the returns to ZT/RT R&D remained highly beneficial – albeit that

Table 5.4. Conservative and optimistic zero tillage/reduced tillage impact scenarios.

	Conservative scenario	Optimistic scenario
Net present value (million US$, 1990)	94	164
Benefit:cost ratio	39	68
Internal rate of return (%)	57	66

Exchange rate: 1 US$ = 17.9 Rs (1990); 1 US$ = 43.7 Rs (2005).

Table 5.5. Sensitivity analysis to variations of the conservative zero tillage/reduced tillage impact scenario.

	Discount rate (0 versus 10%)	Yield gain (0 versus 3%)	Cost reduction (0 versus 2.5%)	RT contribution (0 versus 25%)	Lag (1 versus 3 years)
Net present value (million US$, 1990)	214 versus 43	22 versus 58	71 versus 82	39 versus 66	18 versus 57
Benefit:cost ratio	69 versus 26	10 versus 24	30 versus 34	17 versus 28	10 versus 26
Internal rate of return (%)	57 versus 57	37 versus 51	53 versus 56	45 versus 53	45 versus 55

RT, reduced tillage.

NPV was halved. Four other indicators altered are the yield gain, the cost saving, the contribution of RT and the assumed time lag. For these indicators scenarios were typically computed without and with only half the original values. The calculations are most sensitive to variations in the assumed yield. Without any yield increase NPV is reduced by 77%, but even so the 'with' case still proves beneficial with a BCR of 10 and an IRR of 37%. The results are relatively less sensitive to the assumed cost savings – without any costs savings NPV is reduced by 25%. The assumed contribution of RT (estimated at 50% of ZT values) also proves influential, mainly as a result of the significant area share under RT relative to ZT. Without any contribution from RT, NPV is reduced by 59% but the investments remain favourable. Finally, the results are also relatively sensitive to the assumed time lag. In the case of only a 1-year lag, NPV would be reduced by 81% but BCR and IRR again remain favourable.

ZT/RT thus generated high welfare gains from a relatively small investment by the RWC and CIMMYT. These gains are relatively robust and persist even under more stringent assumptions. The investment was relatively small in view of the positive spillovers and sunk costs of previous research both in the region and elsewhere. This drastically reduced technology development time and cost towards relatively cheap adaptive research and allowed for rapid institutional learning.

Environmental impacts

ZT/RT wheat has several environmental benefits. Foremost amongst these are savings in fossil fuel and reduced greenhouse gas emissions (Malik *et al.*, 2002a; Grace *et al.*, 2003; Hobbs and Gupta, 2003). Using a conversion factor of 2.6 kg CO_2 emission per litre of diesel (Grace *et al.*, 2003) and a relatively conservative estimate of 35 l of diesel saved per hectare, we estimate ZT annually saving 91 kg of CO_2 emission per hectare. Adoption of ZT on a potential area of 3.43 million ha of wheat would annually reduce emissions by 0.31 million t of CO_2 and save 120 million l of diesel. At the current price of diesel (or crude oil equivalents) this implies US$50 million of benefits annually. Other greenhouse gas emissions, including methane and nitrous oxides, have an even greater effect on global warming. Grace *et al.* (2003) have highlighted that ZT with residue retention and 50% of the recommended application of nitrogen/phosphorus/potassium fertilizer could effectively halve the total carbon-equivalent emissions to 14 t CO_2/ha per year compared with a high-input CT cropping system with residue burning and organic amendments, due to improved nutrient use and environmental efficiency.

In the north-west IGP crop residues are often burned, creating severe seasonal air pollution/smog and human health hazards in the area. ZT is being further adapted so as to maintain crop residues as mulch without burning or incorporation. The burning of crop residues is not considered a CO_2 source to the atmosphere by the Intergovernmental Panel on Climate Change, as on an annual basis there will be no change in carbon stock. ZT does reduce CO_2 emissions by slowing oxidation of the carbon soil stock due to reduced soil disturbance (Grace *et al.*, 2003; Hobbs and Gupta, 2003).

Water is becoming an increasingly important constraint to agriculture in the IGP as competition for domestic and industrial use increases and water-use efficiency is poor (Hobbs and Gupta, 2003). ZT wheat enhances water use efficiency, reduces irrigation requirements and thereby helps save irrigation water. This benefit is especially important for the north-west where water shortage is already acute, leading to inter-state political conflicts. In Haryana and Punjab, irrigation through tube wells meets around 60–65% of the total irrigation requirement. Due to excessive exploitation, groundwater resources are depleting at an alarming rate. In Punjab 59% of blocks are critical and in Haryana 69% of districts have declining water tables (Minas and Bajwa, 2001). ZT farming on 0.25 million ha in the IGP reportedly saved 75 million m^3 of water in the year 2002/03 (Malik *et al.*, 2004). Adoption of ZT on a potential area of 3.43 million ha of wheat would save an estimated 1029 million m^3 of water each year. Empirical measurement and modelling are needed to better quantify these savings scientifically and estimate the value of those water savings.

Zero tillage thus primarily has positive environmental impacts and this would enhance the social returns to the R&D investment. However, further research, some of it already initiated, is needed to substantiate these impacts more rigorously. At the same time the current use of ZT for only wheat limits the extent of some of the potential environmental gains. More significant environmental gains are likely when the whole rice–wheat system converts to year-round conservation agriculture.

Lessons Learned

To keep pace with rapidly growing demand South Asia's farmers will have to produce more food from fewer resources while sustaining environmental quality. ZT is one technology that fits this need and is being rapidly adopted in the Indian IGP in wheat after rice. The successful diffusion of ZT is due to the concerted efforts of the NARES (including SAUs) and the private sector. CIMMYT and the RWC have played a pivotal and innovative role as facilitator and information provider, technology clearing house and capacity builder. ZT of wheat after rice generates significant benefits at the farm level, both in terms of significant yield gains (6–10%, particularly due to more timely planting of wheat) and cost savings (5–10%, particularly tillage savings). These benefits explain the widespread farmers' interest and the rapidity of the diffusion across the Indian IGP, further aided by the wide applicability of this mechanical innovation. Small-scale machine manufacturers have played a key role in meeting and creating an increasing demand. Service providers have enhanced technology access by making it divisible and are key promoters, having the expertise and personal interest to successfully spread the technology. It has all required the timely congruence of a profitable opportunity and the willingness to adapt by several key champions.

A conservative *ex ante* assessment of supply-shift gains alone (excluding other social and environmental gains) shows that the investment in ZT/RT R&D by RWC and CIMMYT was highly beneficial, with a BCR of 39, an NPV of US$94 million and an IRR of 57%. Sensitivity analysis highlights the influential role of the yield gain, the contribution of reduced tillage (i.e. partial adoption) and the assumed time lag. Significant positive spillovers of sunk ZT R&D costs – both previous and from elsewhere – have also contributed to the high returns. The case thereby highlights the potential gains from successful technology transfer and adaptation in natural resource management (NRM).

The present study has valued impact based on private gains alone, with environmental and social gains as added non-valued benefit. To a large extent this was dictated by data limitations. Still, the approach has merits. Private gains correspond more closely with farmers' and private sector interest and therefore with potential and rapid adoption. The challenge for NRM research thereby is to generate technologies that are privately attractive in their own right with environmental gains as added benefit. The present case also highlights the potential of a phased approach, building on the easy wins to subsequently use the momentum to address second-generation problems. In some instances, such an approach may be more successful than tackling NRM issues head on.

Zero tillage primarily has a positive environmental impact (fossil fuel savings, reduced greenhouse gas emissions, water savings) and this would enhance the social returns to the R&D investment. The water savings in the wheat crop are particularly interesting in view of excessive groundwater exploitation in intensive rice–wheat-growing areas. Further research to substantiate and value the environmental impacts is needed. There is also significant scope for enhancing the environmental impact of ZT in rice–wheat systems. Two areas that merit particular attention in this respect are crop residue management and a shift towards direct-seeded aerobic rice. Leaving more crop residues as mulch, however, has implications for both ZT drill functioning and potential trade-offs between residue use for livestock feed and conservation agriculture.

Zero tillage tends to be adopted first by the better-endowed farmers. ZT rental services have, however, made the technology relatively scale-neutral and divisible. Time and resources saved through ZT are variously used by the adopting farm households – including productive, social and leisure purposes. Thus, adoption of ZT enhances farmers' livelihoods. ZT so far has spread more widely in the better-endowed areas. The challenge remains to extend these gains to the less-endowed areas of the IGP, where it has significant potential and can contribute to poverty alleviation.

The present case study has reviewed a wealth of information in relation to ZT and rice–wheat systems in the Indian IGP, supplemented by village-level focus group discussions. Although the various sources differed in rigour and detail, the same consistent messages come through, validated by focus groups and farmer adoption. The combined yield increase with cost saving implies that returns to ZT adoption are pretty robust, thereby significantly reducing the risk of adoption. Still, significant knowledge gaps exist. Most studies focus on either the plot level or the macro level. Gaining a better understanding of the intermediate levels and potential interactions is needed to assess the degree to which the gains are actually realized on the ground and the scope for scaling up from plot-level impacts. Available information on the cost of ZT R&D and attribution also proved problematic. Most studies report on the technical and private financial gains of ZT at plot level – with limited documentation of socio-economic, livelihood and environmental impacts. Addressing these knowledge gaps would significantly strengthen future impact assessment endeavours.

Zero tillage therefore offers high potential economic, environmental and social gains in the Indian IGP. None the less, significant challenges remain, not least in terms of actually realizing these potential gains on the ground. This implies moving beyond mere production cost savings to natural resource savings and using ZT as a stepping stone to conservation agriculture. ZT is also no panacea – and complementary resource-conserving technologies that are privately and socially attractive are needed. Technological intervention also needs to be complemented with policy reform to create an enabling environment for sustainable agriculture. This could easily prove even more significant, but implies addressing some of the more thorny policy issues such as the subsidy and taxation schemes that currently undermine the sustainability of rice–wheat systems.

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6 CIAT. Impact of Participatory Natural Resource Management Research in Cassava-based Cropping Systems in Vietnam and Thailand

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In South-east Asia, many of the poorest farmers live in areas with limited potential for crop production. Cassava (*Manihot esculenta* Crantz) is an important crop on these soils, because it is easy to grow, requires few external inputs and its roots and leaves can be used as human or animal feed. Cassava is also planted as an industrial crop for the production of animal feed and starch where market conditions are developed. The wide variety of end uses makes it a popular crop and an effective vehicle for improving the livelihood of poor upland farmers.

Cassava has an ability to thrive on soils which are inherently infertile, in areas where other crops have depleted soils of nutrients and under conditions of moisture stress. Thus cassava is often planted in erosion-prone hillsides, in soils of low nutrient status and regions of uncertain rainfall. Environmental concerns are often associated with cassava grown on steep slopes. The crop's slow initial growth and wide plant spacing do not provide adequate protection of the soil from the direct impact of rainfall, thereby generating runoff and erosion. At the farm level, soil erosion can cause crop yield losses reducing agricultural incomes. At the national level, soil erosion produces sediment and silt that can clog irrigation channels and lower the water storage capacity of dams, and load nutrients.

Farmers may or may not be aware of the extent of the soil loss or nutrient depletion or do not have resources to replenish the soils (Hershey *et al.*, 2001). Many soil conservation and soil fertility management technologies are 'preventive innovations' because they avoid unwanted future events such as loss of productive soils. Preventive innovations typically have a low rate of adoption because it is hard to demonstrate their advantages, since benefits may occur only at some future, unknown time (Rogers, 1983). Also, if the benefits associated with the use of a soil conservation technology accrue primarily beyond the farm, producers may not include those benefits in their decision to adopt the technology. Low adoption rates may also be attributed to how these technologies were developed through a centralized research and extension system. The practices may not be widely adopted because farmers do not consider conventional 'pipeline' products practical or appropriate.

To address these problems, the Regional Cassava Office for Asia of the International Centre for Tropical Agriculture (CIAT), in collaboration with national agricultural research partners in Thailand, Vietnam, Indonesia and China, implemented a Nippon Foundation-funded project entitled 'Improving the Sustainability of Cassava-based Cropping Systems in Asia' between 1994 and 2003. The goal of the project was to increase the living standards of small farmers and to improve agricultural sustainability in less-favoured areas of Asia by improving the productivity and stability of farming systems where cassava is an important crop. Although prior research had identified many potential soil conservation and fertility management options for use in these cassava systems, they were not adopted by farmers. Therefore, the CIAT project was designed with a dual focus on developing technologies and increasing their adoption and effective use. This was to be accomplished by using a farmer participatory research (FPR) approach in which farmers themselves were involved in identifying, testing and promoting promising technologies.

The objective of this chapter is to assess the impact of the CIAT project. This involves assessing both the adoption and impacts of the project technologies as well as the contribution of the participatory research approach. Few studies attempt to distinguish between these two different types of impact. A growing share of scarce R&D resources is being allocated to participatory methods; however, it appears that the use of such methods is often based on personal experience and conviction rather than on solid evidence of their relative contribution to impact. This case study is part of a growing effort to document and measure the impact of participatory methods in natural resource management (NRM) research (Sanginga *et al.*, 2001, 2002; Johnson *et al.*, 2003, 2004).

The chapter is organized as follows. The next section discusses some conceptual issues related to assessing the *ex post* impacts of farmer participatory cropping systems and NRM research (NRMR). The third section describes trends in cassava production in Asia and explains the main features and outcomes of the CIAT project, and the fourth section presents the farm-level impacts of participation and adoption of new technologies. The final section suggests some conclusions.

Conceptual Issues in Assessing the *Ex Post* Impact of Farmer Participation in Cropping Systems Research

Cropping systems research is concerned with improving the productivity and sustainability of agricultural systems. It examines not only crop improvement but also soil and water management, pest control, crop rotations or other activities related to resource use in agriculture. Improving cropping systems generally involves a combination of improved crop varieties, crop husbandry and NRM practices.

Agronomically, cropping systems are assessed in terms of both yield and other parameters such as loss of soil or soil nutrients or changes in pest or weed pressure. Economically, the sustainability of cropping systems can be assessed at the farm level by looking at net income over time, amenity gains, increased positive externalities such as greenhouse gas sequestration, or mitigating negative externalities such as soil erosion or nutrient loading.

Few rigorous *ex post* studies documenting the benefits of cropping systems research exist. One reason is that adoption of the soil and water management technologies forming a key part of improved cropping systems management has generally been low. Even when they do work agronomically and are targeted to priority problems faced by upland farmers, soil management technologies are often complex, highly site-specific, costly to implement and slow to yield monetary benefits, making them unattractive to many farmers (Fujisaka, 1994).

FPR has emerged as a potential solution to the problem of limited adoption of cropping systems and NRM technologies by farmers (Ashby, 2003), and there is a growing body of empirical evidence in support of its effectiveness (e.g. Hinchcliffe *et al.*, 1999; van de Fliert *et al.*, 2001; Johnson *et al.*, 2003). One explanation for why FPR methods might increase adoption is that incorporating farmers into the process of designing and developing technologies increases the probability that the technologies will be relevant and appropriate. This type of FPR is often referred to as ‘functional’ because its purpose is to improve the efficiency of a conventional research process (Pretty, 1994; Ashby, 1996).

Another approach to participatory research seeks not just to improve the final product (the technology), but also to improve the knowledge and capacity for innovation of those who participate in the process (Okali *et al.*, 1994). This type of FPR, known as ‘empowering’, views the research process as an interactive learning experience for both farmers and researchers. This approach is particularly promoted among practitioners in the area of NRM, where technologies are often complex and require adaptation to specific agrarian situations. Each farmer has to understand the technology and how to adapt it to his or her own farming system. An inventory of participatory NRMR projects found that 54% of projects reported specific skills development and 69% reported strengthening overall analytical capacity and empowerment among their project outcomes (Johnson *et al.*, 2004).

Empowering participation does have significant implications for how impacts are generated and measured. As with conventional technologies, benefits can still be quantified in terms of increased agricultural productivity or reduced environmental damage; however, the sources of the benefits are of two types. Part of any observed increase in productivity can be attributed directly to the superiority of the new technology or practice. These are often referred to as 'embodied' effects since they are part of the technology itself. The second source of improved productivity is the increased knowledge or capacity that the farmer obtained by participating in the research process. These are often referred to as 'disembodied' effects because they are not part of the technology (Chambers, 1988). These two types of impact are not independent, since a more knowledgeable farmer can make better use of a new technology. Therefore it is important to be able to separate the embodied and disembodied effects in order to accurately evaluate the impact of both the participatory research process and the technology.

Project Context

Cassava production trends in Asia

World cassava production in 2004 was about 196 million tonnes, 53% of which was produced in Africa, 30% in Asia, and 17% in Latin America and the Caribbean (LAC). In the 1990s Africa increased cassava production by an average annual rate of 2.9%, while the production growth in Asia and LAC was stagnant. However, in the last 5 years Asia has experienced 2.9% average annual production growth, compared with 1.3% in Africa and 1.4% in Latin America. Vietnam and Thailand had negative growth rates in the 1990s but, in the past 5 years, Thailand has had 1.4% average annual production growth and Vietnam has had nearly 20% average annual growth of cassava production (FAO, 2005). Land degradation patterns are similar in Thailand and Vietnam: about half of the total land in Vietnam and Thailand is considered to be very severely degraded, nearly 30% severely degraded and about 20% moderately degraded.

Much of the production gains in Asia are related to increases in yield. In the last 5 years, the cassava yield in Thailand has increased by 2.8% annually while the cassava area harvested has declined. In Vietnam, the production gains are related to both area expansion and yield increases. In the past 5 years, the average annual growth of the cassava-harvested area in Vietnam was nearly 9% while yields increased at an average annual rate of 11% (Table 6.1). Regional derived demand for cassava is expected to increase for livestock feed as demand for meat grows with Asian incomes (Fuglie, 2004).

Table 6.1. Average annual growth rate of yield and cassava area harvested (%). (Authors' calculations based on FAO, 2005.)

	1970–1979		1980–1989		1990–1999		2000–2004	
Region	Δ Yield	Δ Area	Δ Yield	Δ Area	Δ Yield	Δ Area	Δ Yield	Δ Area
World	0.60	1.35	0.88	1.20	0.33	0.88	0.65	1.15
Africa	1.17	0.60	1.17	1.97	0.72	2.19	–0.12	1.45
LAC	–1.79	0.59	0.59	0.01	0.42	–1.26	0.26	1.18
Asia	1.82	3.76	1.30	0.50	0.70	–1.04	2.74	0.16
Thailand	–0.92	12.66	0.32	3.51	1.07	–3.34	2.84	–1.48
Vietnam	0.28	12.59	1.91	–4.42	–1.04	–1.30	11.01	8.89

LAC, Latin America and the Caribbean.

Cassava research in Asia

Research shows that nutrient depletion and erosion can be serious problems when cassava is grown as a monocrop on infertile soils and on sloping land. Judicious application of manure or chemical fertilizers will permit continuous cassava production at high levels of yield without nutrient depletion (Howeler, 1996). Similarly, soil and crop management practices have been developed that will minimize erosion when cassava is grown on slopes (Howeler, 1987, 1994, 1995, 1998a,b). These practices include minimal land preparation, contour ridging, fertilizer application, mulches, intercropping and vegetative contour barriers to reduce runoff and enhance deposition of suspended soil behind these barriers.

CIAT holds the world's largest collection of cassava germplasm, forming the basis for a comprehensive breeding programme. New varieties with higher yield potential, higher starch content, improved plant type and greater resistance to pests and diseases have been developed. Since 1983, the CIAT Cassava Programme in Asia has worked with national cassava breeding programmes, selecting from material transferred from CIAT and breeding for local adaptation. Thirty-eight cassava varieties containing genetic material from CIAT have now been released in Asia. These are grown on about 1,506,000 ha (43% of total cassava area). Similarly, there has been an active and collaborative research programme on the crop's nutrient, fertilization and soil management requirements.

The CIAT project

The main objective of this project was to develop better cassava production practices that would enhance the sustainability of production by helping farmers increase their income and by protecting the soil resource base from degradation as a result of nutrient depletion and erosion. Both the first (1994–1998) and second (1999–2003) phases aimed at enhancing the adoption of more sustainable production practices by involving farmers directly in the development of site-specific, best-bet practices through farmer participatory methods. The first phase of the project developed and tested mainly an FPR methodology, while the second phase used this methodology, implemented in a simplified version in many more sites, and used various farmer participatory extension (FPE) methods in order to disseminate the farmer-selected practices to as many other farmers as possible.

The FPR methodology developed included selection of suitable villages that might benefit from the project, a discussion and planning phase regarding implementation with officials at different levels, and a rapid rural appraisal with farmers in the village to obtain basic information and assess their interest in participating. After analysing the results, the villages were selected based also on the willingness of local leaders to collaborate.

Once a village was selected, interested farmers from the village sites were taken on a field trip to visit demonstration plots, or visit another village where farmers had already conducted FPR trials or had adopted some selected practices. At the demonstration plots, farmers evaluated and scored all the varietal trials and soil fertility management options (treatments) and selected a few of the most interesting to try out in FPR trials on their own fields (see Table 6.2 for technologies selected in the first phase).

Researchers and extension workers worked with farmers to develop and select appropriate trials, stake out plots and establish the selected treatments. Typical FPR trials had four to six treatments, including the

Table 6.2. Technological components selected by participating farmers from their farmer participatory research trials conducted from 1994 to 1998. (From Howeler, 2004.)

Technology	Thailand	Vietnam
Varieties	Kasetsart 50	KM60
	Rayong 5	KM94
	Rayong 90	KM95-3
		SM1717-12
Fertilizer practices	15–15–15	FYM 10 t/ha (TP) + 80 N + 40
	156 kg/ha	P_2O_5 + 80 K_2O
Intercropping	Monoculture (TP)	Monoculture (TP)
	C + pumpkin	C + taro (TP)
	C + mungbean	C + groundnut
Soil conservation	Vetiver barrier	*Tephrosia* barrier
	Sugarcane barrier	Vetiver barrier
		Pineapple barrier

TP, traditional practice; C, cassava; FYM, farmyard manure.

farmer's traditional practice, without replication. Although the emphasis was on FPR erosion control trials, farmers could also test other technology components such as new varieties, fertilization practices, intercropping, weed control and even pig feeding with cassava roots and leaves. At the time of harvest, a field day was organized to let other farmers from the village and surrounding villages evaluate and discuss the results of the various treatments. From these results and discussions farmers then selected the best treatments for either further testing or for adoption in their production fields.

Technologies developed

After 2–3 years of testing in FPR trials, farmers decided on the most suitable practices. To enhance the further dissemination of those selected practices, the project used several participatory and conventional extension methods such as organizing cross-visits of farmers from one village to another, field days during either the crop cycle or at harvest, and FPR training courses for farmers and local extension workers. During the first phase of the project, 244 farmers and extension workers attended the FPR training in Thailand, and 292 were trained in Vietnam. In Thailand, the project also set up community-based self-help groups called 'Cassava Development Villages'. In the second phase of the project, a total of 338 FPR trials was conducted in Thailand, and 584 trials were conducted in Vietnam.

Tables 6.3 and 6.4 show the average effects of various soil conservation practices, tested in numerous experiments and FPR trials, on relative cassava yield and soil loss in Vietnam and Thailand, respectively.

In summary, the project developed best-bet technologies, using farmer knowledge and participation, through the FPR process. Next, the successful elements of the FPR methodology were identified and disseminated to partner organizations using FPE. As a result, specific soil fertility management technology options were diffused to additional non-project farmers. In addition, the human capital of the participating farmers is assumed to be increased because they engaged in the technology development process with the researchers. This hypothesis, among others, is tested in the following section.

Conceptual Framework

To evaluate hypotheses that the FPR methodology increased the adoption of soil fertility management and conservation technologies while simultaneously increasing human capital, a farm-level decision model is formulated. Farm production is multifunctional and produces two generic products: a commodity output (in this case cassava) and a non-commod-

Table 6.3. Technologies tested and developed in Vietnam, 1993–2003[a]. (From Howeler, 2004.)

Soil conservation practice[b]	Relative cassava yield (%) C monoculture	Relative cassava yield (%) C + groundnut	Relative dry soil loss (%) C monoculture	Relative dry soil loss (%) C + groundnut
1. With fertilizers; no hedgerows (check)	100	–	100	–
2. With fertilizers; vetiver grass hedgerows**	113 (17)	115 (23)	48 (16)	51 (23)
3. With fertilizers; *Tephrosia candida* hedgerows**	110 (17)	105 (23)	49 (16)	64 (23)
4. With fertilizers; *Flemingia macrophylla* hedgerows*	103 (3)	109 (4)	51 (3)	62 (3)
5. With fertilizers; *Paspalum atratum* hedgerows**	112 (17)	–	50 (17)	–
6. With fertilizers; *Leucaena leucocephala* hedgerows*	110 (11)	–	69 (11)	–
7. With fertilizers; *Gliricidia sepium* hedgerows*	107 (11)	–	71 (11)	–
8. With fertilizers; pineapple hedgerows*	100 (8)	103 (9)	48 (8)	44 (9)
9. With fertilizers; vetiver + *Tephrosia* hedgerows	–	102 (7)	–	62 (7)
10. With fertilizers; contour ridging, no hedgerows*	106 (7)	–	70 (7)	–
11. With fertilizers; closer spacing, no hedgerows	122 (5)	–	103 (5)	–
12. With fertilizers; groundnut intercrop, no hedgerows*	106 (11)	100	81 (11)	100
13. With fertilizers; maize intercrop, no hedgerows	69 (3)	–	21 (3)	–
14. No fertilizers; no hedgerows	32 (4)	921 (5)	137 (4)	202 (12)

[a]Effect of various soil conservation practices on the average relative cassava yield and dry soil loss due to erosion as determined from soil erosion control experiments, farmer participatory (FPR) demonstration plots and FPR trials. Figures in parentheses indicate the number of experiments/trials from which the average values were calculated. C, cassava.
[b]Most promising soil conservation practices indicated by **; promising soil conservation practices indicated by *.

ity environmental output. The multifunctional and multi-product farm production function constraint is defined as:

$$0 = (Y, Y^{NM}, L, A, B, P_t \mid \delta_t, \theta_t) \tag{6.1}$$

Multi-product output – commodity (Y) and non-commodity (Y^{NM}) – is a function of labour (L), land (A) and biochemical inputs (B), and current prices (P_t) that control for policy or induced innovation effects, and is conditioned upon the effective production technology (δ_t), made available by current (R_t) and past research (R_{t-1}) and current (E_t) and past extension delivery (E_{t-1}). In this model we can include the FPR input as part of current and past research activities.

‘Knowledge’, represented by θ, or alternatively thought of as a cumulative information management function accrued informally or through formal information delivery systems in the current production period t or previous ones ($t - 1$), is modelled as an approximation to the individual’s stock of human capital. Knowledge growth can be modelled as a stock accumulation balance:

$$\theta_t = \theta_{t-1} - D_t + IA_t \tag{6.2}$$

where D_t represents the depreciation of useless information and IA_t represents knowledge acquisition. Information acquisition takes place through active learning processes, like participatory research, or through passive mediums such as mass media or conventional extension field

Table 6.4. Technologies tested and developed in Thailand, 1994–2003[a]. (From Howeler, 2004.)

Soil conservation practice[b]	Relative cassava yield (%)	Relative dry soil loss (%)
1. With fertilizers; no hedgerows, no ridging, no intercrop (check)	100	100
2. With fertilizers; vetiver grass hedgerows, no ridging, no intercrop**	90 (25)	58 (25)
3. With fertilizers; lemongrass hedgerows, no ridging, no intercrop**	110 (14)	67 (15)
4. With fertilizers; sugarcane for chewing hedgerows, no intercrop	99 (12)	111 (14)
5. With fertilizers; *Paspalum atratum* hedgerows, no intercrop**	88 (7)	53 (7)
6. With fertilizers; *Panicum maximum* hedgerows, no intercrop	73 (3)	107 (4)
7. With fertilizers; *Brachiaria brizantha* hedgerows, no intercrop*	68 (3)	78 (2)
8. With fertilizers; *Brachiaria ruziziensis* hedgerows, no intercrop*	80 (2)	56 (2)
9. With fertilizers; elephant grass hedgerows, no intercrop	36 (2)	81 (2)
10. With fertilizers; *Leucaena leucocephala* hedgerows, no intercrop*	66 (2)	56 (2)
11. With fertilizers; *Gliricidia sepium* hedgerows, no intercrop*	65 (2)	48 (2)
12. With fertilizers; *Crotalaria juncea* hedgerows, no intercrop	75 (2)	89 (2)
13. With fertilizers; pigeon pea hedgerows, no intercrop	75 (2)	90 (2)
14. With fertilizers; contour ridging, no hedgerows, no intercrop**	108 (17)	69 (17)
15. With fertilizers; up-and-down ridging, no hedgerows, no intercrop	104 (20)	124 (20)
16. With fertilizers; closer spacing, no hedgerows, no intercrop**	116 (10)	88 (11)
17. With fertilizers; C + groundnut intercrop	72 (11)	102 (12)
18. With fertilizers; C + pumpkin or squash intercrop	90 (13)	109 (15)
19. With fertilizers; C + sweetcorn intercrop	97 (11)	110 (14)
20. With fertilizers; C + mungbean intercrop*	74 (4)	41 (4)
21. No fertilizers; no hedgerows, no or up-and-down ridging	96 (9)	240 (10)

[a]Effect of various soil conservation practices on the average relative cassava yield and dry soil loss due to erosion as determined from soil erosion control experiments, farmer participatory research (FPR) demonstration plots and FPR trials. Figures in parentheses indicate the number of experiments/trials from which the average values were calculated. C, cassava.
[b]Most promising soil conservation practices indicated by **; promising soil conservation practices indicated by *.

days. The time constraint accounts for the opportunity cost of investing in human capital and is written as:

$$l + L(\theta) + IA = T \tag{6.3}$$

where IA is the time allocated to education or information acquisition. θ, therefore, represents the impact of the information acquisition activity. It affects the productivity of farm labour and the amount of time available for leisure (l). The farm income constraint is defined as:

$$P^M C^M + w(l + IA) = P^H(Y - C^H) + P^{NM} Y^{NM} - c(r,v,\phi,I,Y,Y^{NM}) + NF \tag{6.4}$$

where P^M and P^H are the explicit prices of market and household products, w is the wage rate for labour and wl and wIA are the opportunity cost of leisure and education. On the right-hand side is the farm profit equation plus non-farm income (NF). The prices for land, labour and biochemical inputs are defined as r, v and ϕ, respectively, and I represents annualized investment costs associated with the production of Y^{NM}; P^{NM} represents a virtual or market price for the environmental good produced by the farm. Household utility is maximized over the consumption of market, household and non-market (public good or abated environmental externalities) goods and leisure subject to a vector of exogenous characteristics controlling for market, physical and research infrastructure capital Z:

$$U = U(C^M, C^H, Y^{NM}, l; \mathrm{Z}) \tag{6.5}$$

Assuming an interior solution to the maximization of (6.5) with respect to (6.3) and (6.4) (or alternatively (6.2), (6.3) and (6.4) with a multi-period discounted utility version of (6.5)), the resulting objective function may be rewritten in reduced form as an indirect function where utility is defined as a function of wages, an implicit wage ($\tilde{w}$) conditioned upon managerial knowledge and S_j is the share of non-market products relative to commodity outputs. V_j is the indirect utility of the level (or intensity) of information acquisition choice j where $j = 1,\ldots,m$:

$$V_j = V(w, \tilde{w}(\theta), T, S_j(Y^{NM} / Y \mid \delta_t), IA_j, Z) \tag{6.6}$$

Based upon Eqns (6.1)–(6.6), there are several descriptive queries and testable hypotheses to be evaluated. First, we are interested in the motivation to become involved with traditional versus participatory research and extension activities on crop and resource management. Very little of this is observable to the researcher so we need to rely upon choice decisions to participate, which may demonstrate the expected return to the education component and the implicit wage impact since this is derived from the calculus of costs and realized benefits.

Second, we hypothesize that those individuals who are involved in participatory research and extension activities produce greater non-market products, primarily in the form of abated soil-related externalities such as erosion, downstream siltation, nutrient mining or soil structure degradation. This is proxied through observation on the adoption and usage of soil fertility and soil conservation interventions.

In order to derive insight into the implicit wage impacts, productivity differences between those who participate and those who do not must be identified. Since we cannot observe these implicit wage impacts directly, we define proxies for their effects in terms of behavioural and productivity changes before and after project intervention. In order to evaluate the net impact upon production, several additional hypotheses are formulated.

Productivity changes are measured in terms of changes in per-hectare yields (converted from local measures) before and after project intervention. We hypothesize that participation positively impacts productivity differences through two mechanisms. The first mechanism is embodied in the adoption of soil fertility management and conservation technologies. The second mechanism is not embodied in any technology per se but related to human capital accumulation through greater information acquisition, as described in Eqn (6.2). This impact is observed by controlling for the treatment effects of the participation decision in the behavioural and productivity impact equations.

Estimating Adoption and Impact at the Farm Level

Data and methods

To assess the impact of the FPR project, data were collected on over 800 farm households in 16 communities in Thailand and Vietnam in 2003 (Agrifood Consulting International, 2004). Complete and usable survey formats were obtained from 767 households. Data collection was carried out in eight villages per country, half of which were villages in which the project worked and half of which were neighbouring villages in which the project did not work. All project villages were characterized on the basis of the year the research site was established (newer sites were excluded), slope of the land, presence and extent of government support (Vietnam only), existence of a starch factory (Vietnam only), importance of cassava in the cropping system and status as 'Cassava Development Village' (Thailand only), and a sample of eight villages was drawn to ensure maximum variability. In addition, eight non-project villages were selected which were similar to and were located near (within 10 km) the selected project villages.

Focus group discussions were conducted in each site, and during the meeting the survey form was distributed to each focus group participant. Focus group participants filled out the forms for their respective households. The survey form asked for information that would have been easily known by participants, such as household membership, the construction of their house, significant property owned by the household and details of the cassava production systems.

Survey forms were completed by the focus group participants, and therefore do not constitute a proportional stratified or random sample. Non-proportional sampling does not negate valid inferences about the village as a whole, since population figures are known from official statistics and in the majority of cases the number of households surveyed comprised a significant proportion of the total households in the village. About 30% of the total number of households was surveyed (Agrifood Consulting International, 2004).[1]

Characteristics of survey villages and households

Selected demographic and other characteristics of sample households are presented in Table 6.5. Fifty-four per cent of households in the sample were from Thailand and 46% from Vietnam. Eighty per cent of households were headed by males, and this did not vary significantly between

[1]Stratifications of households in terms of participation, gender, wealth and poverty in the context of this participatory rapid rural appraisal study are exogenous stratifications, rather than endogenous stratifications, and so valid parameter estimates are still obtained (Maddala, 1986).

Table 6.5. Selected characteristics of farm households in Thailand and Vietnam.

	Total			Thailand		Vietnam		Total	
	Thailand (*n* = 417)	Vietnam (*n* = 350)	Total (*n* = 767)	Participants (*n* = 109)	Non-participants (*n* = 308)	Participants (*n* = 126)	Non-participants (*n* = 224)	Participants (*n* = 235)	Non-participants (*n* = 532)
Household composition									
% Female headed	20	21	20	19	20	15*	24*	17	21
Household size (no. of persons)	4.2	4.6	4.4***	4.3	4.1	4.8	4.5	4.6	4.3*
No. of adults	2.8	2.8	2.8	2.9	2.8	3.0	2.8	2.9	2.8
No. of children	1.4	1.8	1.0***	1.1	1.0	1.8	1.8	1.7	1.5*
Poverty status									
% Poor	8.4	20.3	13.8***	6.4	9.1	24.6	17.9	16.2	12.8
% Average	84.2	67.1	76.4***	82.6	84.7	66.7	67.4	74.0	77.4
% Better off	7.4	12.6	9.8***	11.0	6.2	8.7	14.7	9.8	9.8
Agricultural activities and assets									
Pre-project land area (ha)	4.5	0.95	2.9***	5.9	4.0***	1.1	0.9	3.3	2.7**
Post-project land area (ha)	4.8	0.97	3.0***	6.2	4.2***	1.1	.9	3.5	2.8**
Pre-project cassava area (ha)	2.7	0.48	1.7***	3.8	2.3***	0.5	0.4	2.1	1.5**
Post-project cassava area (ha)	2.9	0.56	1.9***	4.2	2.5***	0.6	0.5*	2.3	1.7***
Cassava yield, pre-project (t/ha)	16.5	14.1	15.4***	19.4	15.5***	13.7	14.3	16.4	15.0**
Cassava yield, post-project (t/ha)	27.8	25.4	23.4***	25.8	20.3***	28.2	23.9***	27.1	21.8***
Slope of land (0 = flat, 1 = rolling, 2 = hilly)	1.4	1.7	1.5***	1.6	1.3***	1.7	1.7	1.6	1.5***
Livestock units owned (no.)	1.9	3.0	2.4***	1.5	2.1***	3.4	2.8*	2.5	2.4
% with fishpond	33	47	40***	50	28***	48	47	49	36***

*$P \le 0.10$; **$P \le 0.05$; ***$P \le 0.01$.

countries. Household composition did vary significantly; households in Vietnam had significantly more children than households in Thailand.

To get an idea of the wealth level, households were asked to rate themselves as ‘poor’, ‘average’ or ‘better off’ as compared with the rest of their community. The results suggest that the distribution of households in terms of relative wealth varies significantly by country. The Vietnam sample contained many more ‘poor’ and ‘better off’ households, while the Thailand sample had more ‘average’ households.

There were also significant differences between countries in terms of agricultural assets and activities. Households in Thailand had much larger average landholdings than their counterparts in Vietnam, 4.5 ha versus just less than 1 ha, respectively. This is consistent with the national statistics on available arable land per capita. Thai farmers’ land was also significantly less hilly; farmers in Thailand reported having only flat or rolling land while in Vietnam some farmers reported having hilly land. Thai farmers planted around 60% of their land to cassava, and this did not change over the course of the project. The national statistics confirm that, in recent years, there has not been significant cassava area expansion in Thailand as compared with rapid expansion in Vietnam. Before the project, Vietnamese farmers were planting about 50% of their land to cassava; however, after the project this had risen to 57%. Cassava yields were significantly higher in Thailand than in Vietnam, although the difference declined from 17% to 9% during the course of the project. Farmers in both countries experienced large yield increases over the period, on average 68% in Thailand and 80% in Vietnam.

Participation in the farmer participatory research project

Overall, 31% of households in the sample participated in the FPR project, 26% in Thailand and 36% in Vietnam. A ‘participant’ was defined as someone who had conducted an FPR trial and/or participated in an FPR training course. A ‘non-participant’ had done neither of these things, but may have participated in a field day organized by the project. In terms of the types of participation described above, we are only looking at empowering participation, since it is the only type assumed to have direct impacts on farmers.

Project versus non-project villages

While the idea was to select project villages that were similar to non-project villages, the data show that project and non-project villages differed significantly in terms of agricultural assets and activities. This is especially the case in Thailand, where project villages had significantly higher initial land area, cassava area and cassava yields compared with non-project villages.[2] Project villages also had, on average, flatter land.

[2]Data on project/non-project village comparison are not presented.

Households in project villages also had significantly more livestock, and were significantly more likely to have fishponds. In Vietnam, there were no differences between project and non-project villages in terms of initial land holdings; however, project villages had, on average, higher initial yields, flatter land and more livestock and fish.[3]

Participant versus non-participant farmers

In Thailand, participant and non-participant households did not differ in terms of composition (Table 6.5). In Vietnam, female-headed households were significantly less likely to have participated than male-headed households.

There were no significant differences between participants and non-participants in terms of their distribution across wealth categories, but there were some significant differences in terms of agricultural activities and assets. In Thailand, participant households had significantly higher landholdings and cassava yields, both before and after the project, than non-participants. Participants had much hillier land than non-participants, which might explain their interest in a project aimed at soil conservation. They also had fewer livestock than non-participants, which may also reflect a greater orientation towards crop agriculture.

In Vietnam the only differences between participants and non-participants in terms of agricultural assets and activities were that participants planted more area to cassava and obtained higher yields after the project. There were no differences in initial landholdings or yields. If we look only at project villages, the results change quite significantly. Participant households had higher initial land area and cassava area, and lower initial yields. There are no significant differences in post-project yields. Participants had significantly steeper land, and were less likely to have fishponds.

Adoption of project technologies

Project versus non-project villages

Again, before looking at differences between participants and non-participants, we look briefly at differences between project and non-project villages. Once more there are significant differences between the two types of village. In Thailand, project villages had significantly higher levels of adoption of all technologies. In Vietnam, only chemical fertilizer use was the same between project and non-project villages.

Participants versus non-participants

Adoption of the technologies promoted by the project varied by technology and country (Table 6.6). Adoption of improved varieties was

[3]These differences between project and non-project villages do not prevent us from making inferences based on the results of the analysis of the sample. It does imply that extrapolation of impacts observed in project villages to non-project villages must be done with caution.

Table 6.6. Extent of adoption (percentage of households) of new technologies by participating and non-participating farmers in the cassava project in Thailand and Vietnam in 2003 (*n*=767).

Technologies adopted	Thailand Participants (n = 109)	Thailand Non-participants (n = 308)	Thailand Total (n = 417)	Vietnam Participants (n = 126)	Vietnam Non-participants (n = 224)	Vietnam Total (n = 350)	Full Sample Participants (n = 235)	Full Sample Non-Participants (n = 235)	Full Sample Total (n = 532)
Varieties (% of area in improved)									
100%	100	88.0	91.1	50.0	38.8	42.9	73.2	67.3	69.1
75%	0	11.7	8.6	5.6	6.7	6.3	3.0	9.6	7.6
50%	0	0.3	0.2	26.2	18.3	21.1	14.0	7.9	9.8
25%	0	0	0	4.0	5.4	4.9	2.1	2.3	2.2
None	0	0	0	14.3	30.8	24.9	7.7	13.0	11.3
Soil conservation practices (% adopting)[a]									
Contour ridging	52	22	30***	35	31	33	43	26	31***
Hedgerows	60	10	23***	50	12	25***	54	11	24***
No soil conservation	21	72	59***	23	58	45***	22	67	53***
Intercropping	28	8	13***	79	49	59***	55	25	34***
Fertilization (% adopting)[a]									
Chemical fertilizers	98	86	89***	85	86	86	91	86	87**
Farmyard or green manure	55	25	33***	74	60	65**	65	40	48***
No fertilizer	0	13	9***	12	8	9	6	11	9*

[a]Percentages may total more than 100% as households can adopt more than one type of technology simultaneously.
*$P \leq 0.10$; **$P \leq 0.05$; ***$P \leq 0.01$.

relatively high in both countries. In Thailand, all households planted improved varieties on at least 50% of their cassava area, and 91% planted only improved varieties. In Vietnam, 75% of households planted improved varieties, and 43% planted them exclusively. In both countries and in the pooled sample, adoption levels were significantly higher among participants than non-participants. If we look only at the project villages, however, we do not see significant differences in the level of adoption of new varieties between participants and non-participants in Vietnam, only in Thailand.

Just under half of the households in the survey adopted one or more soil conservation practices. Thirty-one percent adopted contour ridging and 24% adopted hedgerows. Adoption levels did not vary significantly between countries, but they did vary between participants and non-participants. In Thailand, participants were much more likely to have adopted contour ridging and hedgerows than non-participants. In Vietnam, half of participants adopted hedgerows compared with only 12% of non-participants. Overall, there is a positive and significant correlation between the adoption of contour ridging and hedgerows and participation.

Just over a third of all households in the sample adopted intercropping: 59% in Vietnam and 13% in Thailand. In the full sample, participants were more likely than non-participants to adopt. When looking at only project villages, only in Thailand were participants significantly more likely to intercrop than non-participants. We found limited evidence of a positive relationship between intercropping and participation.

Fertilizer use was relatively high across all households in the sample, with 87% of households using chemical fertilizers and 48% using farmyard manure. Only 9% of households used neither organic nor inorganic fertilizer. In Vietnam, only farmyard manure use was significantly higher among participants compared with non-participants. As a whole there is a positive correlation between adoption of farmyard manure and participation but no relationship exists for chemical fertilizer.

Impact

To assess the impact that these new technologies had on productivity, and the extent to which the project contributed to both adoption and impact, we need to analyse the determinants and outcomes of a series of decisions that farmers made. Figure 6.1 presents a schematic of these decisions involved in an FPR project. Assuming that his or her village is chosen by the project, each farmer in the village chooses whether to participate in the project activities or not. This decision is likely to be determined by a variety of factors such as the importance of cassava in the individual's farming system or the availability of time or land to dedicate to the project. Personal characteristics are also likely to matter, for example his or her interest in experimentation, or connections to

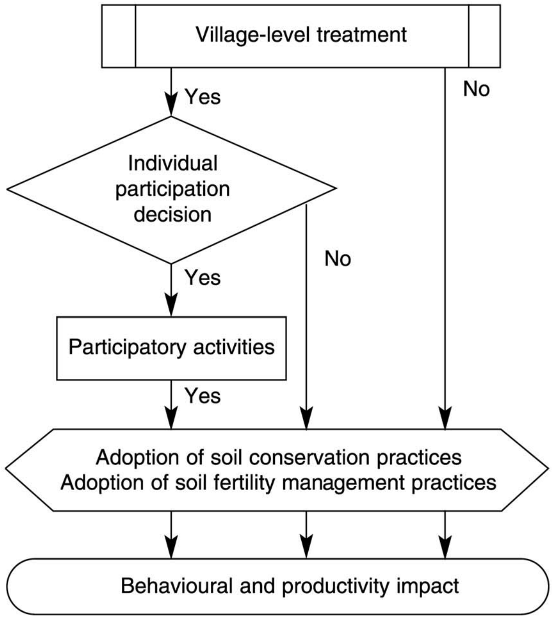

Fig. 6.1. Treatment effects, adoption decisions, behavioural and productivity impact.

community and existing social networks that would allow access to new information without active participation in the project activities.

When the project is finished and the results of the trials are available, all farmers, both participants and non-participants, face the decision of whether or not to adopt them. This decision is separate from the decision to participate, since participants can choose not to adopt and non-participants can choose to adopt. However, the decisions are not independent in the sense that some of the same factors that influence the decision to participate are likely also to influence the decision to adopt (Greene, 1998).

Finally, we need to look at the outcomes of participation and adoption. We look at two types of outcomes: behavioural and productivity. The behavioural outcomes are changes in total area planted and area planted to cassava. Given the availability of new technologies, farmers may change their land allocations, reallocating across crops or changing total area planted. This is of particular interest in this project since expansion of area planted, which occurred over the course of the project, might imply moving into more fragile and erosion-prone areas. The productivity outcome of interest is the change in cassava yield. Since some of the same farm and farmer characteristics that affect participation and adoption will also likely influence land allocation and production, we must estimate these equations as a system.

This analysis was done via estimations of sets of simultaneous equations, and the results indicate that project activities had a significant impact on adoption of soil management technologies, in particular

Table 6.7. Land allocation and productivity impacts controlling for treatment effects.

	Δ Cropped area		Δ Cassava area		Δ Cassava yield	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
INTERCEPT	–0.834**	0.363	–1.383*	0.268	–10.121*	2.484
GENDER	–0.181***	0.098	–0.024	0.074	–0.530	0.677
NUMADULT	0.003	0.033	0.008	0.025	0.247	0.228
NUMCHILD	0.022	0.038	–0.007	0.028	0.002	0.262
POVERTY	0.117	0.086	0.063	0.064	0.963	0.592
LAND1	–0.055*	0.013	–0.002	0.009	–0.175**	0.087
FISH	–0.007	0.090	0.036	0.067	–1.162***	0.617
TLU	0.028*	0.008	0.028*	0.006	–0.008	0.052
COUNTRY	–0.579*	0.153	–0.187	0.114	13.322*	1.049
SLOPE	0.506	0.108	0.500*	0.080	–0.807	0.741
FACTORY	–0.094	0.193	–0.015	0.143	8.576*	1.327
TIME	0.015	0.031	0.005	0.023	–0.302	0.213
SPILL	0.057	0.217	0.256	0.158	2.679***	1.472
VARIETY	0.141	0.176	0.257**	0.130	6.637*	1.201
P(INTER)	0.069	0.264	0.082	0.191	–0.524	1.789
P(HEDGE)	0.228	0.165	0.143	0.121	3.403*	1.126
P(CONT)	–0.301***	0.155	–0.219***	0.113	0.301	1.055
P(FYM)	0.149	0.184	–0.005	0.133	–0.824	1.247
P(CHEM)	–0.085	0.249	0.006	0.181	0.018	1.692
Participation	–0.283	0.433	–0.259	0.316	8.334*	2.948
Selectivity (λ)	0.256	0.285	0.318	0.207	–2.429	1.933
F(20,746)	4.05*		4.91*		23.51*	

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

contour ridging, hedgerows and the usage of farmyard manure. Both project technologies and participation in the project influenced behavioural and productivity outcomes (see Table A1 for variable definitions and descriptive statistics and Table 6.7 for regression results).[4]

In terms of behavioural outcomes, the results indicate that adoption of contour ridging was negative and significantly related to the expansion of total cropped area and cassava area. In addition, the adoption of improved cassava varieties was also significantly related to area expansion of cassava. Slope was also positive and significantly related to area expansion, suggesting that production is moving to more environmentally sensitive areas. However, it appears that farmers are using contour ridging to expand into these areas in a sustainable manner. We find that participation was not significantly related to area expansion, indicating that FPR did not contribute to area expansion of cropping activities.

[4]Full specification of the regression is available in Dalton *et al.* (2005a,b). These are not included due to space limitations. Additional regressions not presented include a binary Probit selection model and five bivariate Probit soil fertility and conservation adoption decisions with treatment effects following Greene (1998).

Farmers with larger initial landholdings expanded relatively less than those with smaller holdings, and female-headed households were more likely to expand their total cropped area than male-headed households. In terms of productivity, adoption of improved varieties and hedgerows contributed significantly to increased cassava yields. Other technologies appeared to have no significant effect. This is somewhat surprising in the case of, for example, fertilizer. One explanation could be that fertilizer use was widespread, and that we did not collect data on quantity or composition of fertilizers used, just on use or non-use. Yield gains were relatively larger in Vietnam than in Thailand. Another exogenous factor associated with increased yields was the proximity to a starch factory. Participation in the project had a positive and significant impact on yield change, a finding that confirms the importance of the 'disembodied' effects associated with FPR. This impact is in addition to the yield gain associated with hedgerow adoption. Since participation is measured as a dummy variable, we cannot say exactly how participation leads to a yield increase independent of the embodied treatment effects. Our hypothesis is that it is related to the enhanced knowledge, experience and managerial capacity gained via participation and experimentation. In addition to the impact on participants, the village-level spillover effect was positive and significant, indicating diffusion of techniques to non-participants located in FPR villages.

Rate of return on the research investment

To calculate the rate of return to the investment in this project, we compare the costs of the project with the benefits it generated.

Project costs

Costs associated with this analysis accrue from three sources: Nippon Foundation costs that financed the overall project, costs associated with the adoption of soil conservation technologies and the opportunity cost of time invested in FPR/FPE activities. Project costs of the Nippon Foundation and local partners are estimated at US$3.96 million over the two phases of the project (Table 6.8).

Second, using partial budgets, the incremental costs associated with adopting the soil conservation and fertility management technologies were estimated (Agrifood Consulting International, 2004). Farm-level costs associated with the adoption of these technologies include the opportunity cost of participation, and direct components such as materials required to establish the conservation interventions and acquisition of new cassava plantings. The total costs associated with the project include both the project costs and the farm-level adoption costs. Many of the farm-level costs, for example new cuttings or conservation materials, are treated as investment costs and are depreciated over an intermediate term of 8 years.

Table 6.8. Project implementation costs (US$ nominal).

Year	Nippon[a]	Local – Vietnam	Local – Thailand	Total
1994	290,943	22,222	116,667	429,832
1995	274,303	22,222	116,667	413,192
1996	274,303	22,222	116,667	413,192
1997	274,303	22,222	116,667	413,192
1998	274,303	22,222	116,667	413,192
1999	224,001	22,222	116,667	362,890
2000	229,057	22,222	116,667	367,946
2001	241,360	22,222	116,667	380,249
2002	256,962	22,222	116,667	395,851
2003	231,742	22,222	116,667	370,631
Total	2,571,277	222,220	1,166,670	3,960,167

[a]Only two-thirds of Nippon costs were included, since the project also had activities in other countries.

Benefit calculation

The project sought to generate production, environmental and human capital benefits. While we document the latter two, it is difficult to fully evaluate them. However, we can value the production benefits obtained via yield increases due to improved technologies and human capital related to cassava production. This can be used as a proxy for total project benefits. It is clearly an underestimate of total benefits since it does not include off-site environmental impacts or spillovers of human capital to non-cassava activities. Since the project was designed to generate plot-level benefits via better crop management, we would expect productivity growth to be the primary impact.

From the yield equation in Table 6.7, we see that adoption of hedgerows increased yields by 3.4 t/ha while participation in project activities was associated with an increase in yield of 8.3 t/ha. Adoption of improved varieties increased yields by up to 6.6 t/ha. Finally, spillover effects to non-participants within the village are also positive and significant, adding 2.7 t/ha. We value this supply gain at local cassava prices.[5]

Estimation of total benefits is restricted to project villages. Participation in project activities was obviously only possible in the

[5]Local prices for fresh cassava roots (at 30% starch content) from Nakhon Ratchasima province provided by the Thai Tapioca Trade Association are converted to US$/t using an average annual exchange rate. These prices are reduced by 15% to account for starch content which probably ranges from 20 to 30%. The average price for the period 1994–2003 was US$27.59/t. A parallel series does not exist for Vietnam. Using national data from the Food and Agriculture Organization of the United Nations and expert opinion, it was determined that prices for Vietnam largely exceed those from Thailand. In the absence of firm data for Vietnam, we use the Thai price as representative. Thus, the benefits for Vietnam are conservatively estimated. Prices in Vietnam probably averaged $28–30/t over the period 1994–2003.

villages where the project worked. Adoption of hedgerows occurred overwhelmingly in project villages – only 5% of farmers in non-project villages adopted hedgerows versus 34% in project villages. Use of improved varieties was common in project and non-project villages, but the average percentage of cassava area planted to improved varieties was higher in project villages than in non-project villages. This suggests that the project had only an incremental impact on varietal adoption in project communities. We assume this incremental increase in area planted to improved varieties that can be attributed to the project at 25%, based on observed differences in adoption levels between project and non-project communities (Table 6.9).

Table 6.9. Adoption of improved varieties by project status of village (percentage of households).

Area in improved varieties (%)	Non-project village (%)	Project village (%)
0	22	6
25	3	2
50	6	12
75	12	5
100	57	76
Total	100	100

Significant level of χ^2 statistic = 0.000.

The benefit at the village level is the sum of the benefits for each category of beneficiary, i.e. participants and non-participants, adopters and non-adopters. To obtain the benefit for each category, we need to know the average incremental increase in production per hectare and the average area planted to cassava for farmers in each category. To extrapolate to the village level, we need to know the total number of households per village, and how they are distributed across beneficiary categories. Table 6.10 presents this information for the project villages in the sample.

According to the analysis, the project resulted in an additional 2802 t of cassava per village at equilibrium. To allocate these benefits over time, we assume that this equilibrium is the survey year 2003. Between 1994 and 2002 we assume that the benefits are a fraction of the equilibrium that is directly proportional to the number of farmers who were trained in the FPR/FPE activities. Thus, the adoption profile increases at a logistic rate over the 10-year period (Griliches, 1957). These benefits are valued at the farm-level price of cassava, which varies from year to year. The gross annual research-induced supply shift (GARB) amounted to US$2.12 million in 2003 (the last year of the project).

Assuming that benefits remained the same in the following year, the GARB amounts to US$2.50 million. If we only account for the benefits

Table 6.10. Benefits of project by type of beneficiary and by village.

	Average yield increase to project (t/ha)	Households in category[a] (%)	Households in category[b] (*n*)
P+H+V	11.0	18	25
P+H	9.3	15	21
P+V	7.6	06	8
P	5.9	36	50
NP+H+V	7.7	5	7
NP+H	6.1	7	10
NP+V	4.3	3	5
NP	2.7	9	12
Total		100	137

P, participant; H, adopted hedgerows; V, planted varieties on 100% of area; NP, non-participant spillovers.
[a]From sample.
[b]Based on a sample average of 137 households per village.

that accrued during the project implementation period, the estimated internal rate of return (IRR) is 41.2%. If we extrapolate the benefits an additional 5 years, at the same rate as observed during the survey period, which is consistent with what was observed in communities where the project has been working for several years, then the IRR increases to 49.2%.

Various systematic alterations of the cost and benefit scenarios were simulated in order to determine the sensitivity of the results. These scenarios indicate that when intra-village spillover effects are not included in the base calculations, the IRR decreases to 28.1% during the project period and 38.9% when extrapolated to 2008. Conversely, if we assume that the farm-level costs were underestimated, i.e. the actual costs were higher than estimated costs, the IRR is reduced by approximately 0.5% for every 10% of cost increase. Overall, the IRR calculations are sensitive to the inclusion of the spillover effects and insensitive to the cost calculations.

Another conservative assumption is to lag the benefits by 1 year to allow for additional learning. If this is done during the project implementation phase, the IRR is reduced to 20.0% and 34.1% if the benefits are extrapolated for 5 years. This is highly restrictive, since some productivity gains accrued even in the first year of experimentation. Despite being extremely conservative, the estimated IRR generates sizeable productivity gains. At a plausible extreme, allowing the benefits to accrue at the same level observed in 2004 for an additional 5 years and including spillover effects, the IRR is 49.2%. At the most conservative, the IRR is 20.0%. Overall, the expected rate of return under reasonable assumptions lies between 34% and 41%. If varietal impacts are eliminated, the IRR for crop, NRM and participation drops to about 30% on average. This result is consistent with results published in Alston *et al.* (2000). Most importantly, though, is that the IRR figures only value the incremental productivity gain – only one goal of the project's objectives. None of the IRR calculations include the non-market contribution of resource degradation abatement or the long-term benefits of human capital accumulation. Tables 6.3 and 6.4 provide evidence of soil resource conservation associated with technology adoption that would increase the social rate of return to this project. Finally, there is evidence of an 'empowering' effect of participatory research that is not found in conventional passive extension activities. We cannot value the broader impact of empowerment without additional investigations, but we find evidence that it did impact cassava productivity.

Discussion

Assessing the impact of a participatory cropping systems research is complex. As this impact study has revealed, the initial selection of project villages and project participants determined how benefits were distributed and also found significant diffusion to non-participants. This diffusion effect is contrary to the lack of diffusion effects found in recent studies of Asian farmer field schools for integrated pest management (IPM) in rice systems (Feder *et al.*, 2004a,b). This may be explained by the diametrically different nature of the technologies: IPM is largely knowledge-based and non-visible to non-participants while soil conservation interventions are visible and tangible.[6]

The results indicate significant and positive impacts of the CIAT-Asia cassava project activities. First, survey results indicate that land allocated to cassava production is expanding and it is expanding at a faster rate on hillier terrain and in areas located near starch factories. This result is consistent with other published studies that have examined regional trends in cassava production (Fuglie, 2004; FAO, 2005). The technologies promoted by the project are important soil conservation and fertility management techniques designed to maintain (or increase) productivity capacity of hillier areas. The project achieved significant levels of adoption, especially for soil conservation practices. The adoption of hedgerows was linked to productivity impacts, while the adoption of contour ridging was linked to a reduction of cropped area.

Second, we find that there are additional benefits to participatory research activities that are not embodied in the adoption of soil conservation or fertility management techniques. Controlling for the treatment effects, participation was positively related to yield increases over non-participants. While this research cannot identify the particular mechanism that generated these effects, several hypotheses have been advanced. Practitioners argue that participatory research activities improve farmers'

[6]The authors are grateful to Gershon Feder for suggesting this explanation.

understanding of the relationships between the components of their farming systems, and this may generate efficiency gains based upon managerial modifications. Moreover, the participatory approach is an active learning activity and it may increase human capital and the ability to respond to and moderate production stresses that decrease productivity. We find that these gross measures of participation provide the rationale for more sophisticated investigations on the impact of participatory research activities upon adoption, land allocation and productivity growth.

The expected IRR was estimated to be between 34% and 41%. The calculations are likely to underestimate the total value of benefits, since they are based only on incremental cassava productivity gains. Other benefits that were not incorporated include the abatement of environmental externalities, human capital spillovers to other cropping activities and institutional benefits. The paradoxical finding that few of the soil conservation interventions contributed to productivity gains necessitates additional research. On the one hand it may be explained by soil physics, chemistry and processes. Soil quality improvements generally accrue over the long term and are slow to become visible. On the other hand, a series of interesting hypotheses on the value of active training through participatory research and extension merits further investigation. In particular, participatory research activities may provide an alternative vehicle to subsidy payments to enhance the adoption of soil conservation interventions and abate negative environmental externalities generated by agricultural systems in marginal production areas.

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Table A1. Descriptive statistics of variables used in regeneration analysis.

Variable	Description	Type	Mean	SD	Minimum	Maximum
PARTIC	Participation in project activities	Binary (1 = yes, 0 = no)	0.306	0.461	0.000	1.000
GENDER	Gender	Binary (1 = male, 0 = female)	0.799	0.401	0.000	1.000
NUMADULT	# adults	Continuous	2.821	1.235	0.000	9.000
NUMCHILD	# children	Continuous	1.554	1.054	0.000	7.000
POVERTY	Poverty status	Ordinal (3 levels)	0.060	0.484	0.000	2.000
LAND1	Initial land holding (ha)	Continuous	2.899	3.879	0.000	40.000
FISH	Presence of fishpond	Binary (1 = yes, 0 = no)	0.398	0.490	0.000	1.000
TLU	Tropical livestock units owned	Continuous	2.421	5.223	0.000	99.760
COUNTRY	Country	Binary (0 = Thailand, 1 = Vietnam)	0.456	0.498	0.000	1.000
SLOPE	Slope	Ordinal (0 = flat, 1 = rolling, 2 = hilly)	1.541	0.499	0.000	2.000
FACTORY	Proximity to starch factory	Binary (1 = yes, 0 = no)	0.717	0.451	0.000	1.000
TIME	Years since initiation of project activity	Continuous	4.335	3.669	0.000	9.000
VPARTIC	Village treatment dummy	Binary (1 = yes, 0 = no)	0.654	0.476	0.000	1.000
MGR01	Institution dummy	Binary (1 = yes, 0 = no)	0.189	0.392	0.000	1.000
MGR02	Institution dummy	Binary (1 = yes, 0 = no)	0.083	0.277	0.000	1.000
MGR03	Institution dummy	Binary (1 = yes, 0 = no)	0.038	0.191	0.000	1.000
MGR04	Institution dummy	Binary (1 = yes, 0 = no)	0.344	0.475	0.000	1.000
VARIETY	Area planted to improved cassava varieties (%)	Ordinal (5 levels) (0,1)	0.805	0.340	0.000	1.000
INTER	Adoption of intercropping	Binary (1 = yes, 0 = no)	0.343	0.375	0.000	1.000
HEDGE	Adoption of hedgerows	Binary (1 = yes, 0 = no)	0.243	0.429	0.000	1.000
CONTOUR	Adoption of contour ridging	Binary (1 = yes, 0 = no)	0.312	0.463	0.000	1.000
FYM	Adoption of farmyard manure	Binary (1 = yes, 0 = no)	0.477	0.500	0.000	1.000
CHEMFERT	Adoption of chemical fertilizer	Binary (1 = yes, 0 = no)	0.875	0.331	0.000	1.000
DLAND	Change in land cultivated (ha)	Continuous	0.127	1.067	–5.760	6.400
DCASSAVA	Change in cassava area cultivated (ha)	Continuous	0.141	0.790	–3.200	4.800
DYIELD	Change in yield (mt/ha)	Continuous	8.016	8.823	–18.750	38.556
DPRODUCT	Change in total farm production (mt)	Continuous	13.623	30.037	–120.000	400.000
DALLOC	Change in land allocated to cassava (%)	Continuous (–1,1)	0.031	0.191	–1.000	1.000

7

WorldFish Centre. Impact of the Development and Dissemination of Integrated Aquaculture–Agriculture Technologies in Malawi

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Fish is an important part of the nutrition of Malawians, providing essential protein and micronutrients. However, due to declining catches from the lakes and a doubling of the population since the 1970s, per capita annual fish consumption decreased from 14 kg in the 1970s to 4.2 kg in 2005, with a corresponding increase in fish prices. This has further worsened food insecurity, especially of the rural population in a country (Fig. 7.1) where an estimated 66% of the population does not consume the minimum daily energy requirement (Jamu and Chimatiro, 2004).

The Fisheries Department of Malawi designated aquaculture to play a complementary role to the capture fisheries sub-sector (ICLARM and GTZ, 1991). Aquaculture increases fish supply and therefore releases the pressure on capture fisheries. Various projects focusing on introducing small-scale fish farming to rural farmers were implemented from the 1970s to the mid-1990s by the United Nations Development Programme, the Oxford Committee for Famine Relief (OXFAM), the United Nations Children's Fund, Landell Mills Associates/European Economic Community, Official Development Aid and the German Agency for Technical Cooperation (GTZ) (ICLARM and GTZ, 1991). In essence, these initiatives upgraded the national extension and research infrastructure, conducted capacity-building activities of Fisheries Department staff, and implemented farmer training and technology support activities. However, the extended technology 'packages' required considerable investments on the side of the farmer, which they could not afford without project support (Banda, 1987; Brummett and Noble, 1995a,b). With the

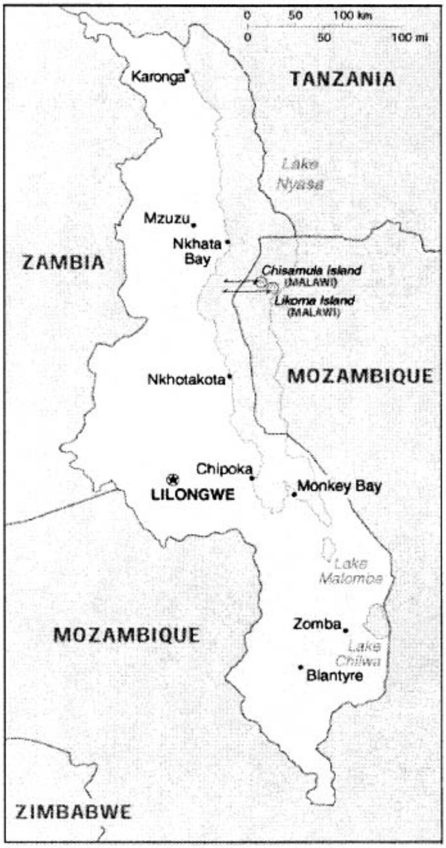

Fig. 7.1. Map of Malawi.

termination of externally funded extension and research projects, the support subsidies to farmers were discontinued. In many cases this resulted in a considerable decline in production levels in farmers' ponds, frequently leading to disadoption of aquaculture (Brummett and Noble, 1995a,b). Furthermore, there was no diffusion of the technologies from adopters to subsequent new adopters. The total estimated aquaculture production in Malawi in 1985 was only 173 t from 170 ha of ponds.

Responding to the challenge of introducing aquaculture into small-scale farming in sub-Saharan Africa, the WorldFish Centre[1] started aquaculture research in Malawi in 1985 with funding from the German Federal Ministry for Economic Cooperation and Development/GTZ. The objective of the project was to develop appropriate and sustainable aquaculture technologies for smallholder rural farmers. Box 7.1 provides an overview of the major milestones and key research outputs.

[1]Prior to 2002, the Centre's name was International Centre for Living Aquatic Resources Management (ICLARM).

Box 7.1. Major milestones of research by the WorldFish Centre and its partners that led to the development of integrated aquaculture–agriculture in Malawi.

1988	Understanding of agroecological and socio-economic environments in which Malawian small-scale farmers live.
1988–1990	Development of the integrated resource management concept, which refers to the synergistic movement and utilization of resources between and among farm and household enterprises. Assessment of local availability of potentially useful bio-resources and their efficiency as pond inputs. On-station testing of integrated aquaculture–agriculture (IAA) technologies. Demonstration of the impact of IAA through farmer-managed on-farm trials.
1991	Wide adoption of integrated rice-fish technology in Zomba district.
1991–1994	On-farm testing of IAA technologies. Development of the farmer–scientist research partnership (FSRP) approach to aquaculture technology development and dissemination utilizing RESTORE (Resource Tools for Natural Resource Management, Monitoring and Evaluation) through research extension teams.
2000	Incorporation of FSRP approach into the national Fisheries and Agriculture Policy.
2003–2004	The aquaculture sector has benefited from the Highly Indebted Poor Countries (HIPC) initiative funds that were allocated for the construction of fishponds for poor female-headed households. The funds paid for locally supplied labour. About 751 fishponds were constructed in 2003 with individual areas from 300 to 400 m^2.

The WorldFish Centre applied a new farmer participatory research approach in which the potential for farmers to add fish farming as an additional enterprise to their farms was assessed. This approach, termed RESTORE (Research Tools for Natural Resource Management, Monitoring and Evaluation), is a combination of farmer participatory field procedures and an analytical database (Lightfoot *et al.*, 1994, 2000). The approach focuses on the development and diffusion of integrated aquaculture–agriculture (IAA), in which existing resources (in the form of organic wastes and by-products) on and around the farm are utilized as much as possible as nutrient inputs to the pond and also to other agricultural enterprises.[2] The organic wastes and by-products do not flow exclusively to the pond, but from the ponds (in the form of pond mud and nutrient-rich water) to other enterprises such as vegetable production around the pond. Fishponds require fertilization, and because they also function as a biodigester (or an 'aquatic rumen') lend themselves ideally to be the central catalytic component of IAA systems. The most common pond inputs are plant-based residues and processing wastes such as leaves, straw, peels,

[2]For a detailed discussion on IAA systems, readers are referred to Edwards *et al.* (1988), Edwards (1998), Prein (2002) and Pant *et al.* (2005).

husks, bran and pulp. Livestock manures are used mainly if these are penned and no other use exists, or if these can be obtained in bulk from other sources away from the farm (e.g. chicken farms). Other on-farm wastes are kitchen scraps and slaughter wastes. Prior to engagement with the concept of recycling through IAA, farmers are often unaware of the nutrient management opportunities.

The IAA system leads to improved environmental soundness (Lightfoot *et al.*, 1993a; Lightfoot and Noble, 2001) and synergisms among various subsystems (e.g. crop production, aquaculture, etc.), resulting in a higher output of desired products from natural resources under farmers' control (Edwards *et al.*, 1988; Edwards, 1998). The farmer participatory research approach was implemented in Malawi by research extension teams (RETs) under the farmer–scientist research partnership (FSRP) concept (Chikafumbwa, 1994; Brummett and Noble, 1995a; Brummett and Haight, 1996; Brummett, 1999, 2002).

This chapter presents an *ex post* impact assessment of the development and dissemination of small-scale IAA technologies in Malawi over more than 15 years by the WorldFish Centre and its national and international partners.

Impact Pathways

The project has developed two broad categories of outputs.

1. IAA technologies → new technologies.
2. Development and transfer of aquaculture technology → new approach.

The impact pathway for the new technologies starts with the development of IAA by the WorldFish Centre and its partners, followed by dissemination via extension agents and farmers. Finally, after adaptation and adoption by farmers, IAA technologies have (market and non-market) impact on adopting households as well as at the national level. The new FSRP approach that was developed by the WorldFish Centre has been subsequently adopted by national agencies. This adoption resulted in the development and dissemination of IAA technologies, which have been adapted and adopted by farmers. Once adopted, IAA generated impact both at the household and national level.

The IAA technologies are being disseminated to farmers by: (i) government extension agencies, such as the Department of Fisheries through its various projects; (ii) various non-governmental organizations (NGOs); and (iii) farmer cooperators who have been involved during the development of technologies. By 1994, 86% of Malawian farmers who had been exposed to IAA technology through the FSRP had adopted at least one of the demonstrated technologies, 76% had adopted at least two and 24% had adopted four (Brummett and Noble, 1995a). Currently, at least 50% of the over 5000 fish farmers in Malawi have adopted some form of IAA technology developed through this project (Brummett and Chikafumbwa, 1999). This project has increased the number of farmers incorporating fish farming into their existing farming systems. Once in the rural community, the IAA technologies have spread and often evolved without further extension support (Baker, 2003).

Methodology and Data Used

Conceptual framework

The case study rests on the overall hypothesis that IAA leads to improved farm productivity. This arises first because IAA offers a set of technologies in which conventional inputs such as labour, organic fertilizer and capital can be used more effectively. Second, IAA improves human and social capital, thus increasing farmers' efficiency and improving efficiency in the use and conservation of natural resource capital, such as soil, water and biodiversity. Improvements in human and social capital result from learning new input-use techniques via extension or technology transfer between farmers and from formation of social institutions such as fish farmers' clubs. Finally, IAA offers an opportunity to increase utilization of biodiversity. In this way, through the improved use of natural capital and other inputs, farmers are likely to increase their productivity (Fig. 7.2).

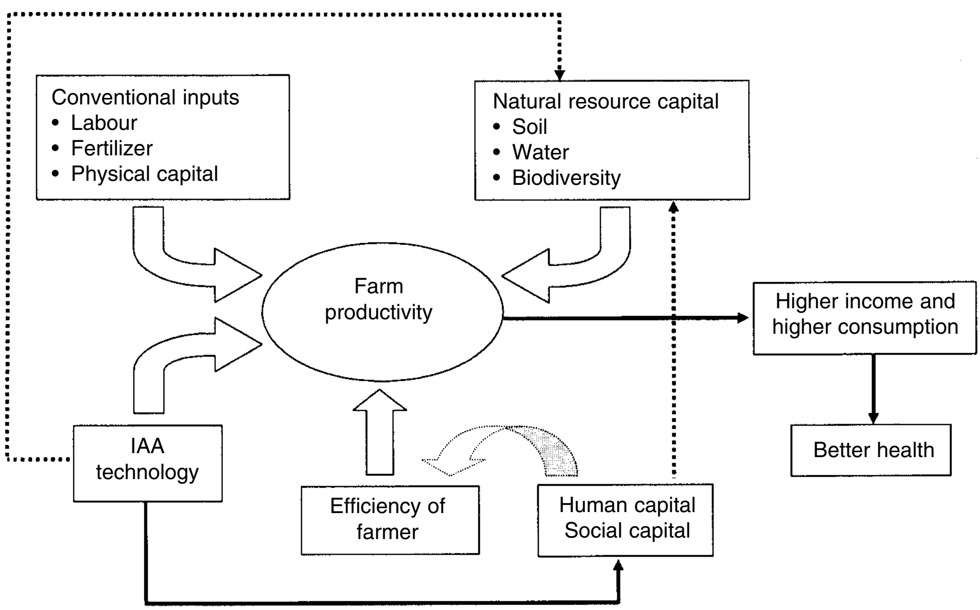

Fig. 7.2. Schematic diagram of farm productivity and household welfare (IAA, integrated aquaculture–agriculture).

This results in households realizing higher incomes and higher consumption, which lead to better health. From this, the following hypotheses can be drawn.

1. Compared with a non-IAA household, an IAA household is likely to have: (i) higher farm productivity; (ii) larger technical efficiency; and (iii) greater human and social capital (i.e. increased capacity of farmers and farmers' organizations).
2. Higher human capital and social capital result in higher efficiency of farmers.
3. Increased farm productivity leads to higher household income and higher consumption.
4. Higher income and higher consumption lead to better household health.

Thus, it is of interest to determine which factors facilitate the adoption of the technology, and which factors bring about productivity and therefore lead to an improved health status. A two-stage framework was used for this *ex post* impact assessment of IAA research in Malawi. Stage one identified which technical, socio-economic, institutional and policy factors influence IAA adoption. In stage two, the effect of IAA adoption on efficiency, food security, employment and sustainability was assessed. The respective impact indicators are listed in Table 7.1.

The welfare impact of IAA technologies on producers and consumers at the national level was estimated using standard economic surplus techniques. In addition, the internal rate of return (IRR) of investment in IAA research and development was estimated.

Table 7.1. Impact themes and related indicators used in the *ex post* impact assessment.

Theme	Indicator
Efficiency	• Fish production (kg/ha/year)
	• Total farm productivity (total factor productivity score)
	• Profitability (US$/ha)
	• Total farm income (US$/ha/year)
	• Technical efficiency (score)
Food security and health	• Fish consumption (kg/capita/month, frequency)
	• Food security of household
	• Animal protein consumption (kg/capita/month)
	• Nutritional status of children under 5 years of age
Sustainability	• Diversity (number of managed enterprises)
	• Recycling and integration with other farm enterprises (number of bio-resource flows)
	• Soil fertility (farmers' perception, nitrogen loss)
Employment	• Employment opportunity generated (person-days/ha)
Institutional capacity	• Increased capacity of farmers and farmers' organizations

Survey framework

The case study applied *ex post* impact assessment based on a 'with and without' scenario. A survey of IAA-adopting and non-adopting farmers was conducted in early 2004 at six sites in Malawi representing various agroecological and socio-economic conditions (Table 7.2). All sites have high water resources, therefore having a good potential for fish farming, and are dominated by small landholding sizes with the opportunity to intensify production. With small numbers of livestock, fish are an important source of protein.

Table 7.2. Distribution of household respondents included in the analysis.

District	Number of IAA respondents	Number of non-IAA respondents	Total
Zomba West	28	26	54
Zomba East	22	12	34
Mwanza	30	25	55
Mulanje	29	26	55
Thyolo	28	30	58
Mangochi	29	30	59
Total	166	149	315

IAA, integrated aquaculture–agriculture.

In each study site, 30 IAA and 30 non-IAA (i.e. 'control') respondents were selected for the survey. NGO or government extension workers provided sampling frames for the respondents. In cases where the aquaculture farmers operated in groups, only a sample of farmers was selected randomly per group. Out of 360 sample farmers, 315 were interviewed; the remaining 45 farmers were not available for interview. The survey covered information for the 2003/04 season on: (i) socio-economic profile of farmers; (ii) farming environment; (iii) sources of income and wealth status; (iv) production systems; (v) input, output and profitability of various farming enterprises; (vi) social and institutional environments; and (vii) food and fish consumption. In addition, available information collected by the WorldFish Centre was used (baseline survey data, survey on health status of IAA and control farmers, on-farm trial data).

Adoption of Integrated Aquaculture–Agriculture

Characteristics of adopters (versus control farmers)

An IAA adopter is defined as a farmer who has a fishpond as part of his/her farming operations and who recycles resources among various enterprises. The average age of the household head was 45 years among the IAA respondents and about 40 years among the non-IAA respondents (Table 7.3). The age difference between the two groups was significant. This suggests that as households become older they tend to acquire more farming skills, resources and experiences that enable them to undertake fish farming. The average family size of the IAA respondents was 5.2 family members and that of the control group was 4.9 persons (Table 7.3) although this difference was not statistically significant. Also, there were no significant differences between the two groups with regard to the number of male and female adults. The number of male farmers was higher among the IAA respondents (1.12) compared with the non-IAA respondents (0.97). This has implications on the type and quantity of labour available to undertake aquaculture farming. Aquaculture is generally undertaken by male-headed households individually or by female-headed households in groups. However, there were a few cases of individual female-headed households having fishponds.

Table 7.3. Key characteristics of respondents who did and did not adopt integrated aquaculture–agriculture (IAA).

Variable	IAA respondents (n = 166)	Non-IAA respondents (n = 149)
Average age of respondents (years)	45.36	39.88
Average household size	5.19	4.9
Average number of male farmers	1.12	0.97
Average number of female farmers	1.25	1.20
Average farm size (ha)	1.98	1.49
Land type (%)		
Homestead	22	30
Lowland	37	28
Upland	32	31
Wetland (*dimba*)	10	10
Topography (% of parcels)		
Flat	27	21
Gentle slope	57	62
Others	16	17
Source of water (%)		
Rainfall	75	78
Water course (natural)	9	8
Well	6	4
Others	10	10

The IAA respondents had a significantly larger average farm area than the non-IAA respondents (Table 7.3). The total farm area can include different natural resource types that can be considered as separate management units with distinct usage. Farmers distinguish such management units (homestead, lowland, upland and wetland) based on tenure, topography, soil type and water supply (Lightfoot *et al.*, 1993b). The IAA respondents had more land in the lowland than the non-IAA respondents (Table 7.3). Access to low-lying areas enables the households to participate in fish farming. The difference in access to flat land (gentle slopes) between IAA and non-IAA respondents was statistically significant in absolute terms. Such flat land is usually suitable for fishpond construction and operation as it is usually associated with clay soils. A majority of respondents indicated that they had exclusive access to the parcels that were being farmed (96% and 94% for IAA and non-IAA respondents, respectively).

For both groups of respondents, rainfall was the primary source of water for farming enterprises (Table 7.3). Even in areas such as Chingale, where gravity and furrow irrigation is fairly widespread and is a recent development, respondents stated that the principal source of water is rain. At least for farming, rainfall is important even when people irrigate during the dry season. The majority of the water sources was seasonal in nature (reported by 70% of IAA respondents and 74% of non-IAA respondents). A majority of the respondents indicated that the water they use is not polluted (96% of IAA and 99% of non-IAA farmers).

Adoption model

The main assumption is that critical factors such as human, social and natural resource capital facilitate the adoption of the IAA technology. The hypothesized related variables X_i that might affect IAA adoption are as follows.

Human and physical capital

- Age or level of education (years in school) of household head and household members.
- Gender of household head (male = 1, female = 0).
- Number of household members who are trained in IAA.
- Person:land ratio (n/ha).
- Land area as proxy to income (ha).

Social capital

- Access to credit programmes (access = 1, no access = 0).
- Access to extension activities (access = 1, no access = 0).

Natural resource capital

- Access to irrigation (access = 1, no access = 0).
- Biodiversity (number of species on the farm) or number of enterprises.
- Presence of wetland area (*dimba*) on the farm (present = 1, not present = 0).

It is also hypothesized that adoption is a continuum process, as the intensity of technology use varies among the adopters (Rauniyar and Goode, 1996). Thus, a two-stage framework was applied to model the adoption process. In the first stage, a Logit model was estimated to determine the significance of factors on the adoption of IAA:

$$P[Y_1 = 1] = \log\left(\frac{P}{1-P}\right) = \beta_0 + \sum_i \beta_i X_i + \varepsilon \qquad (7.1)$$

where Y_1 is a binary variable representing adoption with a value of 1 if the respondent is an IAA adopter and 0 if otherwise; P is the probability of adopting IAA; X_i are the explanatory variables as defined above; β_i are the corresponding coefficients to be estimated and ε denotes the error term. In the second stage, a Logit model was estimated among the adopters to determine the significance of the same factors with regard to the intensity of adopting IAA (defined as the fraction of the number of bio-resource flows over the total number of enterprises per farm, henceforth termed level of integration):

$$P[Y_2 = 1|Y_1 = 1] = \log\left(\frac{P}{1-P}\right) = \beta_0 + \sum_i \beta_i X_i + \varepsilon \qquad (7.2)$$

where Y_2 is a binary variable representing the level of integration with a value of 1 for higher integration (defined as integration of 0.75 or above) and 0 if otherwise; and the other variables are as defined above.

Results indicate that farmers who have access to extension services are more likely to adopt IAA than farmers who have no access to extension services, *ceteris paribus*. Also, the likelihood of adopting IAA is higher for older farmers with a larger farm area and a greater number of enterprises than for younger farmers with a smaller farm area. Contrary to expectations, the coefficient of education shows that higher education did not lead to higher adoption. However, the level of education increased the level of integration of IAA practices. At the same time, access to irrigation enabled a higher intensity of adoption (Table 7.4).

Socio-economic Impact of Integrated Aquaculture–Agriculture at Household Level

Impact on land use, farm income, productivity and profitability

Within an IAA system, the availability of pond water and nutrients allows intensified land use and enables farmers to grow additional crops.[3] Farmers in the sample who adopted IAA practices have a larger area for vegetable cultivation specifically around their homestead and in the uplands (Table 7.5).

The encouragement to increase cropped area to grow higher-value

[3]In Malawi, marginal areas such as waterlogged depressions (*dambo*) have been utilized for IAA technologies, i.e. without sacrificing existing farmland (Brummett and Noble, 1995a; Noble, 1996).

Table 7.4. Determinants of integrated aquaculture–agriculture adoption (n = 270)[a].

	Stage 1: Adoption		Stage 2: Level of integration	
	Estimate	SE	Estimate	SE
Intercept	2.66***	0.74	–0.19	0.75
Age (years)	0.07**	0.03	<0.01	0.01
Age×Age (quadratic term)	<0.01*	<0.01		
Education of household head (years)	–0.06	0.06	0.14*	0.08
Gender of household head (male = 1)	0.23	0.30	–0.87*	0.53
Persons in household trained in IAA (*n*)	0.46***	0.16	–0.03	0.16
Extension dummy (access = 1)	0.62***	0.18	–0.17	0.28
Credit dummy (access = 1)	0.14	0.25	0.01	0.27
Land area (ha)	0.15**	0.07	0.02***	0.01
Person:land ratio (*n*/ha)	<0.01	<0.01	–0.01	0.01
Dimba area dummy (present = 1)	0.02	0.21	0.19	0.32
Irrigation dummy (access = 1)	0.10	0.18	0.58**	0.25

SE, standard error.
[a]Dependent variable: Stage 1 – 1 if integrated aquaculture–agriculture is adopted, 0 if otherwise; Stage 2 – 1 if high integration, 0 if otherwise.
*Significant at α = 0.10; **significant at α = 0.05; ***significant at α = 0.01.

crops (i.e. vegetables) in combination with pond activities was also reported by other studies (e.g. Brummett and Noble, 1995a; Chimatiro and Scholz, 1995). The technical reasons for the very high cropping intensities realized by IAA respondents and additional impact on the farming system are explained further in the section 'Input and sustainability' later in the book.

The most conventional measures of productivity and profitability are

Table 7.5. Impact of integrated aquaculture–agriculture (IAA) adoption on land use.

		Area			
		IAA respondents		Non-IAA respondents	
Land type	Crop	ha	%	ha	%
Homestead	Maize	0.35	5.56	0.49	9.23
	Vegetables	0.60	9.52	0.20	3.77
	Other crops	0.29	4.60	0.62	11.68
Lowland	Maize	0.86	13.65	0.71	13.37
	Vegetables	0.92	14.60	1.00	18.83
Upland	Maize	1.20	19.05	0.52	9.79
	Vegetables	0.56	8.89	0.20	3.77
	Other crops	0.44	6.98	0.60	11.30
Wetland (*dimba*)	Maize	0.38	6.03	0.27	5.08
	Vegetables	0.70	11.11	0.70	13.18

production (yield) and return (gross margin) per unit area. Such measures, however, fail to account for differences in input and output prices across farmer groups and sites. More importantly, partial productivity measures such as yield are not appropriate in a multiple output–multiple input setting (such as the IAA system with strong linkages between the enterprises). To overcome such limitations, the concept of interspatial total factor productivity (TFP)[4] was used to measure the farm productivity of each farmer and compare the productivity of IAA and non-IAA farmers. TFP values were further analysed using the interspatial Tornqvist index (TI).

Following Dey *et al.* (unpublished),[5] the interspatial TI is defined as:

$$TI_i = \frac{\sum_l \ln[Y_{il}/Y_l](s_{yil} + s_{yl})}{2} - \frac{\sum_k \ln[X_{ik}/X_k](s_{xik} + s_{xk})}{2} \quad (7.3)$$

where the subscript i refers to the ith farmer, l refers to the lth output (maize, vegetables, other), k refers to the kth input (seed, fertilizer, labour), Y_{il} is the quantity of output (kg/ha), Y_l is the average across farmers, X_{ik} is the quantity of input, s_{yil} is the share of the lth output to the total gross return, s_{xik} is the share of the kth input to the total cost input, and s_{yl} and s_{xk} are the average shares of the lth output and kth input, respectively. TI_i is the interspatial Tornqvist index. The exponentiation of TI_i gives the productivity difference between the ith farmer and the average farmer (TFP_i), indicating how much more or less it would cost a particular farmer (say farmer i) than the average farmer to produce the same quantity of output per unit area using the same technology.

Table 7.6 presents the results of the comparison of TFP, profitability and input use. Results show that, on average, IAA farmers in the southern region of Malawi are 11% more productive than non-IAA farmers. IAA farmers had 133% more income per hectare than non-IAA farmers. One of the reasons for the higher income is the increased cropping intensity (due to increased cultivation of vegetables and other crops, Table 7.5).

Of interest is the difference in productivity and profitability as the level of integration increases. As shown in Table 7.6, there is a positive association between productivity and profitability with the level of integration, i.e. productivity and profitability increase as the level of integration increases. Previous studies have also found a positive effect of the adoption of IAA on pond productivity and farm income (Brummett and Noble, 1995a; Chimatiro and Scholz, 1995).

Total household income was almost 1.5 times higher for the IAA households (US$254) compared with the non-IAA respondents' average

[4]Total factor productivity refers to the ratio of total farm production given all inputs used on the farm.

[5]Dey, M.M., Prein, M., Paraguas, F., Lopez, T., Shah, W.A. and Grover, J. (2001) Integrated agriculture–aquaculture, natural resources and overall farm productivity. International Centre for Living Aquatic Resources Management/WorldFish Centre, Penang, Malaysia, unpublished manuscript.

Table 7.6. Comparison of farm profitability (US$/ha/year) and productivity.

	By household type			Level of integration	
	IAA	Non-IAA	Difference (%)	Low	High
Gross income	163	93	76	101	205
Total cost	67	51	30	54	74
Seed	14	10	32	11	16
Fertilizer	22	16	35	18	22
Manure	3	2	38	2	5
Labour[a]	28	22	25	23	32
Net income	96	41	133	47	131
TFP	1.33	1.20	11	1.18	1.52

IAA, integrated aquaculture–agriculture; TFP, total factor productivity.
[a]Labour was valued based on ruling wage rates.

income of US$174 (Table 7.7). This huge difference is mainly due to the difference in farm income (income earned from farming activities), whereby IAA farmers had a farm income of US$185, which is 1.8 times as much as the non-IAA farmers' average of US$115. Around 80% of the total income of the IAA respondents was derived from farming compared with only 66% of the total income of the non-IAA respondents (difference is statistically significant at the 5% level). Out of the farm income of IAA farmers, an average of US$21 (about 10%) is directly contributed by fish culture (Table 7.7). Also, the IAA farmers had a higher average income from remittances. The results are in line with previous studies that have shown that IAA adoption increased farm income substantially (Brummett and Noble, 1995a,b; Chimatiro and Scholz, 1995; Petry, 1996; Scholz and Chimatiro, 1996).

Table 7.7. Household income of farmers who did and did not adopt integrated aquaculture–agriculture (IAA), by source (US$/year).

	IAA farmers	Non-IAA farmers	Difference (%)
Total income	254	174	46
Farm income	185	115	60
Income from fish	21	–	–
Non-farm income	26	36	–27
Off-farm income	15	18	–17
Remittances	7	4	67

While farm productivity and profitability as well as farm income were higher for IAA farmers, non-IAA respondents had a higher off-farm income (earned from outside the homestead, e.g. employment or piece-work) and more income from non-farm activities (e.g. business within the homestead), although the difference is not statistically significant. IAA farmers spent an average of 72% of their time farming compared with 66% of the time spent by non-IAA respondents. On average, IAA farms spent 24 person-days per hectare a year more than non-IAA farms.

IAA farmers generally recycled their produce or by-products among the various enterprises. This requires additional labour; for example, to move by-products between enterprises and the pond, to manage the pond dykes, and stock, harvest and sell the fish. However, pond maintenance activities are normally scheduled in times of low labour demand from agricultural activities, thus smoothing the labour demand over the year and providing an alternative to off-farm employment during slack times for agricultural labour (February–March, May–September).

As the productivity of family labour in IAA activities is higher than that through alternative opportunities of selling family labour for off-farm activities, the overall return to labour from IAA is higher. Therefore, although non-IAA farmers can generate a higher income from non-farm activities (through sale of family labour), IAA farmers will have higher overall income by using their family labour in IAA practices instead of selling it.

To control the effect of other factors on income, a regression analysis was run on farm income. It was assumed that farmers are profit maximizers facing production constraints such as farm size, access to irrigation and credit, and the level of education of the household head. In the regression, the technology (IAA) was introduced to measure the shift in farm income, controlling for the effect of other variables or production constraints. Since farm income, which is the dependent variable, was expressed in the form of its natural logarithm, the coefficient can be considered as elasticity, i.e. percentage change in farm income due to adoption of the technology. However, IAA adopters differ from non-adopters in characteristics that cannot be observed and affect both the decision to adopt the technology and its outcome (e.g. ability or motivation). To correct for this possible selection bias, the instrumental variable technique was employed using predicted probability of adoption as an instrument (Heckman *et al.*, 1998).

The probability of adoption was estimated using the adoption model as defined in Eqn (7.1). The positive sign of the coefficient for the predicted probability indicates that, on average, IAA adopters have a higher net farm income than non-adopters (Table 7.8).

Moreover, access to irrigation increases per hectare farm income by 35%, *ceteris paribus*, while an increase of farm size by 1 ha will decrease the per hectare farm income by 75%. This can be explained by a shortage of labour, so that large areas are not cultivated intensively.

Table 7.8. Farm income function[a].

	Estimate	SE
Intercept	8.58***	0.16
Probability of IAA adoption[b]	0.91***	0.27
Ln farm size (ha)	–0.75***	0.07
Irrigation dummy (access = 1)	0.35***	0.10
Credit dummy (access = 1)	0.13	0.14
Education of household head (years)	0.03	0.03
F value	23.05***	
R^2	0.27	

IAA, integrated aquaculture–agriculture; SE, standard error.
[a]Dependent variable: ln farm income per hectare.
[b]Probability of IAA adoption of model = probability that was estimated using Eqn (7.1).
***Significant at α =0.01.

Impact on technical efficiency

The impact of IAA on overall farm technical efficiency was evaluated using the stochastic frontier approach (Battese and Coelli, 1995). The level of technical efficiency was computed for each farmer to identify the causes of (in)efficiency and to analyse whether IAA farmers have increased efficiency.[6]

Following Battese and Coelli (1995), the stochastic production frontier is defined as:

$$\ln Y_i = \beta_0 + \sum_{j=1}^{6} \boldsymbol{\beta}_j \ln(X_{ij}) + (v_i - u_i) \tag{7.4}$$

where subscript i refers to the ith farmer; ln represents the natural logarithm; Y is the observed farm output (US\$/ha); X is the vector of production inputs, where X_1 is the total seeding rate of all crop seeds combined (US\$/ha); X_2 is the fertilizer rate (kg/ha); X_3 refers to the amount of organic fertilizer applied (kg/ha); X_4 is the pre-harvest labour use of family and hired labour (person-days/ha); and X_5 and X_6 are dummy variables for inorganic and organic fertilizer applications, respectively, which hold values of 1 if fertilizer is applied and 0 if otherwise. These dummy variables were introduced to correct for the statistical bias that may be caused by the numerous zero values in the fertilizer input variables (Battese, 1996).

The equation 7.4 has two error terms: one (v_i) to account for random effects (weather conditions, disease, measurement errors in the output variable, etc. and the combined effects of unobserved/uncontrollable inputs on production) and the other (u_i) to account for technical inefficiency in production. The v_i is a random error which is assumed to be independently and identically distributed (iid) $N(0,\sigma_v^2)$ and independent

[6]An alternative would have been the Multi Production Distance Function approach, which we did not use due to zero values in some of the outputs (i.e. not all farmers used all enterprises).

of the u_i; u_i is a non-negative random variable. The model, defined by equation 7.3, is a stochastic frontier function because the random error (v_i) can be positive or negative and the output values are bounded above the stochastic (random) variable, exp ($X_i\beta + v_i$).

It is assumed that u_i is independently distributed as a truncation (at zero) of the normal distribution function with mean μ_i that is defined as:

$$u_i = \delta_0 + \sum_{i=1}^{7} \delta_i Z_i \tag{7.5}$$

where Z_1 are farm-specific variables that may cause inefficiency and δ_0 and all δ_i are coefficient to be estimated. The farm-specific characteristics are defined as follows: Z_1 is a dummy variable for the type of respondents (1 if the farmer is practising IAA and 0 otherwise); Z_2 represents age as a proxy for experience of the operator (number of years); Z_3 represents the education of the farmer (number of years formal schooling); Z_4 represents the farm area (ha) as proxy for income; Z_5 is a dummy variable for gender of household head (1 if the head is male and zero otherwise); Z_6 is a credit dummy variable (1 if the farmer has access to credit and zero otherwise); and Z_7 is an extension dummy variable (1 if the farmer has access to extension services and zero otherwise).

All but one variable in the stochastic production function are highly significant, indicating their importance in determining yield levels (Table 7.9). In the technical inefficiency function, the dummy variable for IAA being practised is significant, indicating that on average IAA farmers are more technically efficient than non-IAA farmers. Results also indicate that older farmers are more technically inefficient than younger farmers.

Table 7.9. Stochastic production and technical inefficiency function.

	Estimate	SE
Stochastic production function		
Constant	3.187***	0.515
Ln seed (US$/ha)	0.419***	0.047
Ln fertilizer (US$/ha)	0.131***	0.055
Ln manure (US$/ha)	1.555***	0.726
Ln labour (US$/ha)	0.510***	0.108
Fertilizer dummy	–0.230	0.242
Manure dummy	–1.406***	0.597
Technical inefficiency function		
Constant	0.291	0.537
IAA practice dummy	–0.310**	0.162
Age (years)	–0.007*	0.001
Education (years)	–0.022	0.066
Farm area (ha)	0.033	0.025
Male household head dummy	–0.534	0.472
Access to credit dummy	0.089	0.277
Extension dummy	–0.224	0.167
Variance parameters		
Σ^2	0.422***	0.056
δ	0.813***	0.067

IAA, integrated aquaculture–agriculture.
*Significant at $\alpha = 0.10$; **significant at $\alpha = 0.05$; ***significant at $\alpha = 0.01$.

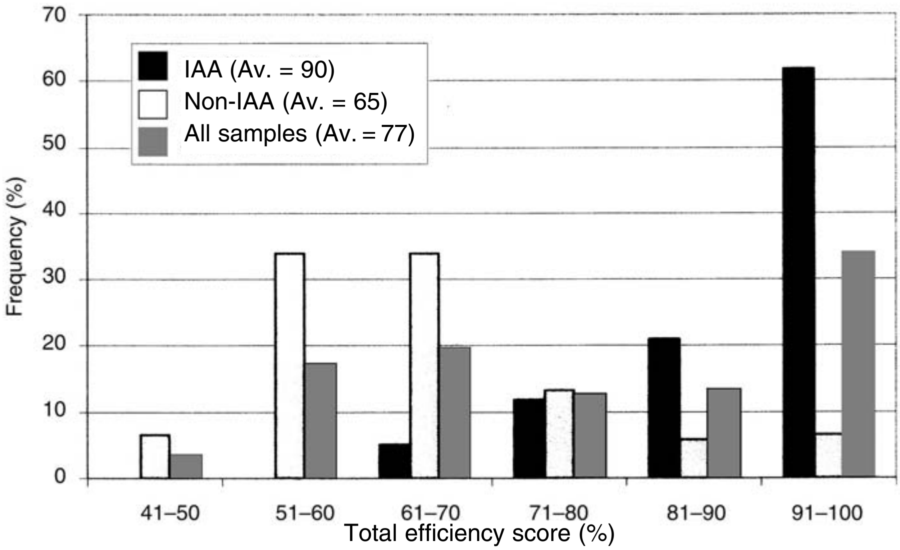

Fig. 7.3. Distribution of technical efficiency score of farmers who adopt (IAA) and do not adopt (non-IAA) integrated aquaculture–agriculture.

Figure 7.3 shows the distribution of technical efficiency of IAA and non-IAA farmers. On average, the technical efficiency score of IAA farmers is 90%, while it is only 65% for non-IAA farmers. None of the IAA farmers has a technical efficiency score of less than 50%, while around 40% of the non-IAA farmers have a technical efficiency score lower than that.

Impact on consumption of fish and other protein food

The respondents were requested to indicate the number of times their household had eaten a given type of protein food (beans, meat, dried fish, fresh fish and chicken) during the previous month. Figure 7.4 shows the frequency with which the various foods were consumed in the month prior to the interview.

Overall, dried fish was the protein food most frequently consumed during the previous month, followed by beans and fresh fish. IAA respondents consumed fresh fish more frequently than non-IAA respondents and also on average stated higher frequency for all other animal protein foods. Non-IAA farmers on average consumed slightly more beans than IAA respondents. The quantity of protein food (by type) consumed by IAA and non-IAA farmers was recorded (Table 7.10). As expected, IAA respondents consumed more fresh fish, dried fish, chicken and meat compared with non-IAA respondents. While there were no significant differences between the two groups in the average consumption of beans, meat and dried fish, there was a significant difference between the two groups in the consumption of fresh fish and chicken. It can be assumed that the

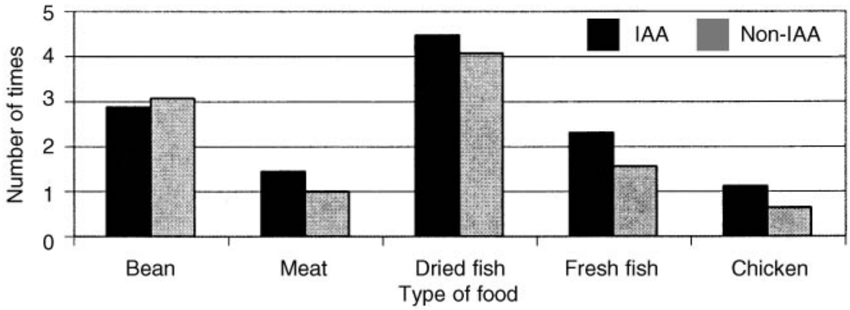

Fig. 7.4. Frequency of protein food consumption over the previous month among farmers who adopt (IAA) and do not adopt (non-IAA) integrated aquaculture–agriculture.

consumption of fresh fish (which is more expensive than dried fish) is higher for fish-growing households that do not have to purchase this food. The higher consumption of chicken, however, can be explained by the higher household income of IAA farmers that leads to an increase in purchased animal protein on top of increased on-farm production. Still, beans were the major protein source in terms of the amount consumed for both groups. However, non-IAA respondents consumed more beans, the cheapest source of protein, while IAA respondents consumed higher value protein sources such as meat and fresh fish. Table 7.10 clearly shows that adoption of IAA practices leads to an overall increase in protein food consumption and to a more varied food consumption pattern.

Table 7.10. Protein sources (kg/capita/month) of respondents who did and did not adopt integrated aquaculture–agriculture (IAA).

Type of protein food	IAA respondents (n = 167)	Non-IAA respondents (n = 149)	P value for difference of means
Beans	2.20	3.69	0.370
Meat	1.52	1.03	0.122
Dried fish	1.95	1.61	0.274
Fresh fish	1.91	0.62	0.000
Chicken	1.08	0.48	0.000

Based on data collected in a nutrition survey, no significant impact of IAA adoption on the nutritional status of children below 5 years of age could be demonstrated. The results of the analysis of consumption patterns and amounts, however, allow the conclusion that in the long term such an improved diet will ultimately have a positive impact on the nutritional status of household members, and especially children. For an econometric analysis of this issue, a larger data set would be required and additional health data need to be collected. Finally, such long-term impacts may only be measurable several years after technology adoption.

Impact of Integrated Aquaculture–Agriculture at the National Level

Apart from farm-level impacts, the use of IAA as a strategy to promote the development of aquaculture in Malawi has resulted in sustained increases in fish production from small farms. When the WorldFish Centre started its operations in Malawi in 1986, the total annual fish production from all fishponds combined was around 90 t/year. The total fish production from fishponds has currently increased to around 1000 t/year.

Aquaculture production in Malawi increased at an annual rate of 7.36% during the period 1970 to 2001. Much of the increase can be attributed to the dissemination of IAA since 1995. During the phase from 1985 to 1995, i.e. the period when basic research and on-farm trials on IAA technologies were conducted, the annual growth rate was 2.4%. However, after the dissemination of the technology (i.e. the years from 1996 to 2001), the annual rate of production increased exponentially to 22% (Fig. 7.5).

The IAA technology was developed and introduced by a WorldFish Centre project that ran from 1986 to 1994. The total cost of the project research activities during this period was around US$1.5 million. A substantial amount of resources spent from 1986 to 1990 (about US$0.6 million) was for collecting baseline information, which has been utilized not only by the WorldFish Centre and its direct partners, but also by various R&D agencies in Malawi. From 1994 onwards, dissemination was undertaken by the WorldFish Centre, NGOs and the Government of Malawi. The following impact assessment uses *ex post* economic surplus

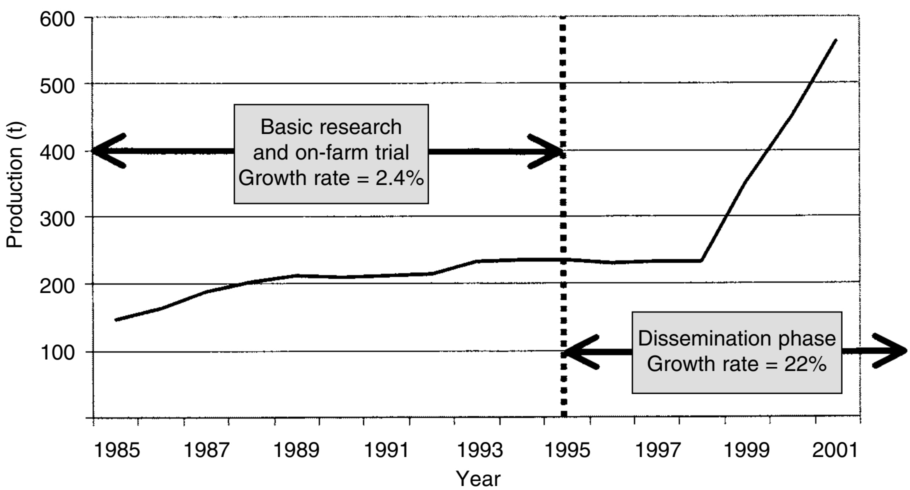

Fig. 7.5. Aquaculture production (t) in Malawi during the research and dissemination phases of the WorldFish Centre's integrated aquaculture–agriculture project.

analysis from 1986 to 2001, the last year from which data are available (through the FishStat database of the Food and Agriculture Organization of the United Nations; FAO, 2004). From 2001 onwards, *ex ante* analysis was applied up to 2016 (30-year time horizon of evaluation). Calculations of present value use a discount rate of 10% and all economic values are stated in US dollars.

Project benefits and costs are calculated based on a number of assumptions. The WorldFish project costs were divided annually. Other IAA activities were valued at US$100,000 per year during the project period to reflect the cost of the collaborating MAGFAD (Malawi–German Fisheries and Aquaculture Development) project (Scholz, U. and Gloerfelt-Tarp, T., personal communications, 2004). From 1994 onwards, a constant cost of US$100,000 annually was applied for further dissemination work by the government of Malawi and various NGOs (Chimatiro, S., personal communication, 2004).

The measure of gross project benefits is the change in economic surplus. To calculate economic surplus, a multi-commodity model was constructed following the framework of Dey *et al.* (2005). Benefits accrue only from 1994 onwards (a conservative assumption). For 1994 to 2001, the model is calibrated to 1994 baseline data. For 2001 to 2016, the model is calibrated to 2001 data. The FAO data were corrected for reclassification of miscellaneous freshwater fish to tilapia in 1998.

The supply impact of R&D on IAA in Malawi is estimated as follows:

- Increases in aquaculture production are attributed to growth in the production area (price-response independent), yield and demand.
- A quarter of the growth is attributed to demand, consistent with population and income trends.
- The remainder is divided equally between yield and area growth.
- The actual annual growth of culture production during the period 1994–2001 is 24.7%. This is rounded off to 20%; hence, the area expansion is set to 7.5% per year, the same figure applied for productivity growth.

Two different scenarios were simulated. In the first, the counterfactual (without-project) scenario assumes 0% growth (counterfactual I) in area and productivity without the project throughout the evaluation period. In the second scenario 2.4% growth (counterfactual II) in area and productivity throughout the evaluation period were assumed to allow for the impact of other projects.

The present value of project costs is US$2.23 million and the present value of benefits is US$0.15 million for the *ex post* evaluation, and US$2.9 million for the *ex ante* evaluation (under counterfactual I). Over the entire evaluation period, the bulk of the project benefits are enjoyed by the consumers (estimated as 69% and 63% for counterfactuals I and II, respectively). Consumers benefit due to lower prices, which tend to depress the benefits received by producers from adopting the improved technology (this is also why consumer surplus is higher in the 0% growth scenario). The benefit:cost ratio is well beyond 1 for both simulations (Table 7.11). The IRR for scenarios I and II, respectively, are reasonably high by World Bank standards.

Table 7.11. Economic surplus analysis of the integrated aquaculture–agriculture technology.

	Value ('000 US$)	
	Counterfactual I (0% growth)	Counterfactual II (2.4% growth)
Producer surplus	1087	1120
Consumer surplus	2396	1936
Net present value of benefits	3483	3056
Benefit:cost ratio	1.56	1.37
Internal rate of return	13.2	12.2

The assumptions for the welfare analysis are conservative estimates for the following main reasons: first, the IAA technology that was developed during the basic research phase can be considered a public good that is used by other organizations and in other countries as well. However, the benefits from such additional use or spillover effects are not included in the simulation and research costs are fully charged to the project. Second, the positive non-market impact (e.g. environmental effects) that is described in the next section was not included in the computation, hence assumed benefits are rather at the low end. Finally, the calculation incorporates additional costs of the collaborating MAGFAD project, so cost assumptions are rather at the high end.

Non-market Impact of Integrated Aquaculture–Agriculture

Impact on sustainability

To assess whether IAA technologies improve the sustainability of natural resource use, four sustainability indicators computed by an analytical procedure in RESTORE are monitored over time (annual cycles). These indicators are:

- Diversity – number of species/enterprises maintained and utilized in the farming systems, i.e. managed biodiversity or agrodiversity.
- Recycling – number of movements of biological output or by-product/waste from one natural resource enterprise to another within the farming system.

- Capacity – product biomass yield in t/ha.
- Economic performance – profit:cost ratio.

The findings can be presented in a ‘kite’ diagram such as the ones shown in Fig. 7.6. The values are specific to each farm and the season analysed, and can vary considerably between years due to changes in the climatic conditions or other shocks (death or illness of a family member, marriages or other social events, or disturbances such as theft).

In Malawi, some 40 farms were monitored using the RESTORE approach. Since not all cases can be presented here and average values are not meaningful for the interpretation, two farms were selected as examples. Increases in the ‘kite’ size reflect improvements in farm sustainability, including the farm’s endowment of natural resources (Fig. 7.2, ‘Natural resource capital’). However, all sustainability indicators need to be considered simultaneously, and annual comparisons and other information about the household and its context factors have to be included.

Results from RESTORE analyses indicate that farmers who have integrated their farms with fish farming increased enterprise diversity, recycling flows among enterprises, the overall biomass production and improved economic performance, even though results might vary over time (Lightfoot and Noble, 2001). It is further hypothesized that farmers increase their aquaculture knowledge and integrated pond management skills, selecting what fits best in the often variable agroecological and socio-economic context.

The case study farm of Mr Ismael Amadu experienced typical variability over the 6 years shown here. Two years were affected by drought (1991/92, 1994/95) and in 1993/94 the farm was stressed by a severe

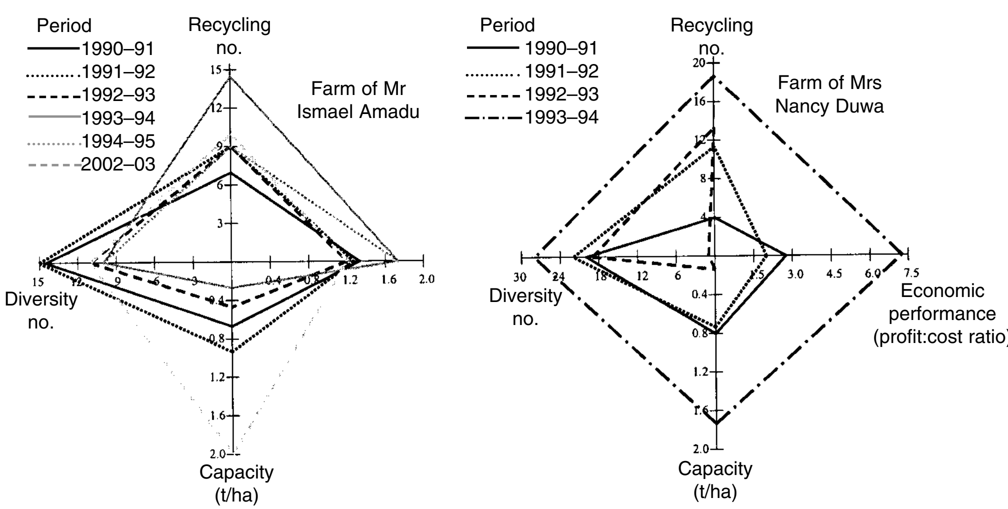

Fig. 7.6. RESTORE (Research Tools for Natural Resource Management, Monitoring and Evaluation) ‘kites’ of sustainability indicators – integrated farms of Mr Ismael Amadu (left) and Mrs Nancy Duwa (right).

drought. Although enterprises were affected (reflected in reduced production), the farmer managed to achieve high profit:cost ratios during the two latter drought years through IAA-enabled strategies such as growing additional varieties of vegetables around ponds in residual moisture of dried-out ponds.

In the early years of the Centre's IAA research in Malawi (1987–1988) five out of six smallholder farms were not recycling any materials at all. With the adoption of IAA, the number of bio-resource flows increased to an average of eight (Brummett and Noble, 1995b). The same authors reported that integrated fish farms recycle four times as much material (in terms of flow counts) as non-integrated fish farms and retain nitrogen and phosphorus better. These results are a reflection of the potential improvement of soil characteristics arising from IAA farming.

Fishponds act as on-farm mini-reservoirs that store nutrient-loaded water, enabling the cultivation of vegetables on the pond dykes or in the pond vicinity (see results on land-use change in the section on socio-economic impact of IAA on the household level). Often, ponds are constructed in locations adjacent to streams, or farmer groups organize small and simple irrigation/conveyance systems to have year-round access to water. Although the primary motivation for establishing the water supply and holding facilities was that of fish culture, the complementary production of fish and vegetables or use of the water for other (agricultural) activities can increase household income and overall sustainability of the farming system. However, issues of finiteness and fragility of the water sources need to be considered in scaling up and adopting irrigation by larger numbers of farmers.

Other studies have documented that the adoption of IAA technologies has reduced nitrogen loss and has made farming systems more durable (Jamu, 2003; Brummett and Noble, 1995b; Chimatiro and Scholz, 1995). By practising IAA, farmers are reducing the loss of nitrogen by 50%. Specifically, it was shown that nitrogen loss in maize plots where fishpond sediments are applied as a basal fertilizer is half (5 $mg/m^2/day$) that of maize plots where inorganic fertilizer is applied as basal fertilizer. This finding has important implications, since nitrogen is the most limiting soil nutrient in Malawi. Furthermore, the same study showed that IAA tended to improve nitrogen use efficiencies, defined as the quantity of nitrogen produced per kilogram of nitrogen applied. IAA farmers had nitrogen use efficiency of about 0.4–0.6 compared with only 0.2–0.3 among the non-IAA farmers. Brummett and Costa-Pierce (2002) also found that adoption of IAA has a positive impact on the sustainability of farming systems through resource recycling and use of pond water and nutrients for growing agricultural crops.

Impact on institutions

The impact of IAA dissemination and adoption on institutions is presented as thematic summaries of impact categories, based on information collected through case studies conducted in five locations (Zomba West, Zomba East, Mulanje, Thyolo, Mangochi) representing different geographic and social–political–institutional settings (e.g. presence/absence of NGOs, proximity to aquaculture research station, presence/absence of externally funded aquaculture projects).

The first impact resulting from IAA dissemination and adoption is a change in human capital (Fig. 7.2, 'Human capital'). Knowledge of farmers is enhanced through interaction with or training provided by extensionists from sources such as the Department of Fisheries, NGOs, scientists or fellow farmers. The very nature of the IAA technology is a farming systems approach that is tailored to the specific location and prevailing on-farm conditions (Molnar *et al.*, 1987). This means that training is mainly concerned with imparting underlying principles and concepts to farmers. At the same time, the FSRP approach explicitly includes farmers in the technology development and encourages adopters to experiment and adapt the technology to suit their individual situation and needs. This enhanced knowledge enables them to take a leading role in community organizations (e.g. the establishment of fish farmers' clubs), and in teaching other interested farmers and neighbours about integrated aquaculture. For example, Mr Nikoloma (of Thyolo District), Mr Chitonya and Mrs Kuunde (of Zomba District) are helping other farmers set up their ponds, advising them in pond management and in some cases providing fingerlings. Their success in IAA-based fish farming has influenced numerous other farmers in their villages to adopt IAA.

The second observed institutional impact is a change in the social structures and improvement in social capital (Fig. 7.2, 'Social capital'). IAA introduction strengthens social institutions such as fish farmers' clubs. In fish farmers' clubs farmers jointly establish and operate infrastructure such as small irrigation schemes, purchase inputs or sell produce together, and exchange knowledge and experiences. Such clubs were established in a number of villages, for example in Zomba East and Zomba West, Mawira and Kunenekude. These clubs are key mechanisms for spread-over and sustainability of newly adopted technologies. In many cases, NGOs support these groups by providing inputs or microcredits and technical expertise, but in other cases successful individual farmers voluntarily assume the role of an extension worker and advise other farmers in pond management. Progressive farmers usually gain social recognition, which is manifested by becoming the chairperson of the fish farmers' club for example, or an otherwise locally recognized authority and source of technical information. Such lead farmers are often already among the better-off farmers in the community. However, in some cases farmers of 'lesser social rank' can gain social stature within a community through displays of technical accomplishment and socially beneficial involvement, in particular when an 'exciting' innovation such as a cluster of fishponds is introduced.

Another change in institutions as a consequence of IAA introduction is the development of markets for fingerlings and fish as well as marketing or production cooperatives. In Mawira for example, 30 farmers who received training in IAA from the NGO World Vision produced and sold fingerlings in 2003. In Mulanja, OXFAM is promoting IAA technologies and purchases fingerlings from farmers that are then provided as inputs for new entrants from established fish farmers.

Finally, the FSRP approach applied for development and dissemination of IAA also had an impact on local governments and strengthened national institutions. The FSRP approach was incorporated into the Malawi Fisheries and Aquaculture Policy in 2000 and a Presidential Initiative on Aquaculture Development in Malawi was issued and signed by the President in early 2006 (DOF, 2006). RETs have been formed in all five fish-farming stations in southern Malawi and implementation of the policy is underway in other parts of the country. The RETs and fish farmers jointly design and test IAA technologies so that farmers become good 'extensionists' who encourage and advise other farmers in their communities on IAA.

Summary of Findings and Lessons Learned

This chapter examines the *ex post* impact of the development and dissemination of small-scale IAA technologies by the WorldFish Centre and its national and international partners in Malawi over more than 15 years. The results indicate that the adoption of IAA technology in Malawi has improved total farm productivity by 10%, increased per hectare farm income by 134% and total farm income by 61%, and improved the technical efficiency of farming by almost 40%. In addition, the increased per capita consumption of fresh fish by about 208% and per capita consumption of dried fish by 21% have resulted in an enhanced consumption of protein-rich food. IAA has improved the sustainability and environment of the adopters' farms, reduced nitrogen loss by half and improved nitrogen use efficiency. The development and dissemination of IAA technologies in Malawi have also institutionalized the natural resource management approach within the Malawi Department of Fisheries, strengthened local institutions and improved the overall welfare of both producers and consumers. The IRR from research and dissemination of IAA technologies in Malawi is at least 12.2%. This estimated rate of return is a very conservative estimate and does not include many of the positive non-market benefits of IAA technology such as impact on ecosystem health and local institutions.

Regression analyses show that better extension, higher amounts of training opportunities in IAA, better access to water, higher number of farm enterprises and bigger farm size have positively affected the adoption of IAA technologies in Malawi. While the results imply that it is the somewhat larger farmers (i.e. average farm area of 2 ha) that tended to adopt IAA technology, it does not necessarily mean that the technology is unsuitable for farmers with smaller landholdings. In fact, such farmers would be best suited since IAA would offer a safety-net effect in which farmers would improve their access to food in general and protein intake in particular. Moreover, the smallholder farmers would use the water to grow high-value crops, which would increase their on-farm income. The adoption by larger farmers suggests what has been observed in many other farming communities: small-scale farmers tend to be more averse to taking risks and are therefore not likely to be among the first to adopt new technology; instead, they follow a wait-and-see approach. Group- or community-based approaches and farmers' training help small-scale farmers to adopt IAA technologies more easily.

Through the development of IAA technologies, the WorldFish Centre has been able to clearly demonstrate the viability of aquaculture not only for the benefit of targeted communities, but also for whole countries. In fact, the results in Malawi have also provided a blueprint for the development and dissemination of IAA technologies elsewhere. Other African countries such as Zambia, Mozambique and Cameroon are currently adopting the IAA technology. At the same time, the FSRP approach to aquaculture technology development and transfer is also used in Cameroon and Zambia. This international spillover effect has not been quantified in this study.

One major reason for the Malawi project's success has been its inclusive nature. Instead of using a 'top-down' approach to technology dissemination, the WorldFish Centre has engaged directly with farmers, utilizing their resource base and recognizing the various constraints they face. One major institutional challenge to the implementation of the IAA approach has been the inadequate human and institutional capacity of the government institutes (e.g. Department of Fisheries, Malawi). It is therefore important to establish and strengthen partnerships with community-based organizations (such as NGOs and farmers' groups) to effectively develop and disseminate innovations such as IAA.

Acknowledgements

Numerous individuals have contributed to this study. First, our gratitude goes to the farmers who participated in the survey and dedicated their time and experience. The fieldwork was facilitated by the excellent support of the Malawi Department of Fisheries, students and staff of the Chancellor College of Malawi and the team of the regional WorldFish Centre office in Malawi. Although we do not have enough space to name all persons who have been involved, we want to acknowledge their input to this work. Also, we would like to thank four anonymous reviewers for valuable comments on an earlier draft of this chapter. Financial support for this study was provided by the Standing Panel of Impact Assessment of the Consultative Group on International Agricultural Research and the WorldFish Centre. Finally, we thank Professor Dr David Zilberman and Professor Dr Hermann Waibel for inspiration and guidance during the whole course of this undertaking.

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8 World Agroforestry Centre. Impacts of Improved Tree Fallow Technology in Zambia

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This chapter presents a case study of an improved fallow using trees to replenish soil fertility – a natural resource management (NRM) technology, the development of which was led by the World Agroforestry Centre (the International Centre for Research in Agroforestry, ICRAF). The work synthesizes different studies that were carried out in Zambia to describe the technology, provide historical information on its development, discuss patterns of its adoption, evaluate its impact to improve the lives of resource-poor smallholder farmers and identify the positive effects of the technology on the environment.

Research Leading to the Technological Innovation

Constraints addressed by improved tree fallows in Zambia

One of the greatest biophysical constraints to increasing agricultural productivity in Africa is the low fertility of the soils (Sanchez, 1999), as soils in sub-Saharan Africa are being depleted at annual rates of 22 kg/ha for nitrogen, 2.5 kg/ha for phosphorus and 15 kg/ha for potassium (Smaling *et al.*, 1997). The need to improve soil fertility management in the continent has become a very important issue in the development policy agenda (Scoones and Toulmin, 1999) because of the strong linkage between soil fertility and food insecurity. To mitigate declining soil fertility, farmers in many areas had traditionally left their land under fallow for significant lengths of time. However, given the relative fixed quantity of available cultivable land, as the population increased fallow periods became shorter and were unable to restore soil fertility. Mineral fertilizers could

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be used to substitute fallow periods but, due to limited access to credit and high market prices of fertilizer, most African farmers purchase and use limited amounts of mineral fertilizer.

This assessment took place in the Eastern Province of Zambia, where the main soil types are loamy-sand or sand alfisols, interspersed with clay and loam luvisols. The agricultural economy is dominated mainly by maize, which covers up to 70% of the planted area.

After the country's political independence in 1964, the agricultural strategy in Zambia, as in many other southern African countries, focused on increasing maize production through broad interventions in input and output markets. These included generous subsidies on fertilizer, easy access to agricultural credit to purchase fertilizers and a range of government-supported institutions and fertilizer depots located in rural areas to supply farm inputs and assure the purchase of maize output from farmers. Following the collapse of these support systems in the late 1980s, the ratio of prices of fertilizers and the major crop (maize) increased fourfold, leading to a 70% decline in fertilizer use (Howard and Mungoma, 1996). While the government has continued to be involved in distributing fertilizer to smallholders and encouraged private traders to do the same, only 20% of smallholder farmers use fertilizer in Zambia (Govereh *et al.*, 2002). In response to the challenges enumerated above, the World Agroforestry Centre initiated research on sustainable soil fertility management options that are suitable for smallholder farmers to replenish soil fertility within a short time. Improved tree fallows allow farmers to produce nutrients through land and labour rather than cash, which they lack.

Description of improved tree fallows and identification of technology intervention

Improved tree fallows were not practised by farmers in Zambia until after the arrival of ICRAF in southern Africa.[1] The development of improved tree fallows in southern Africa began with diagnostic and design surveys (Ngugi, 1998) and ethno-botanical surveys in the late 1980s, which revealed a breakdown of traditional strategies, such as long fallow periods, in sustaining food production. Nitrogen was identified as a key missing nutrient in the soils. At the beginning, ICRAF contemplated and carried out initial research on alley cropping and biomass transfer systems, but these technologies were discontinued because they were too labour intensive and did not perform well technically (Ong, 1994). The quest for a new approach to respond to soil fertility problems led to research on improved tree fallows. Based on nutrient recycling

[1]There was very little practice of improved fallows in the region. The maize–pigeon pea intercropping system had been practised by some farming communities in Malawi for years prior to ICRAF's arrival in the region, however.

principles, the technology involves planting fast-growing tree species that are (usually) nitrogen-fixing and produce easily decomposable biomass, to provide nitrogen for the subsequent food crop, increase soil organic matter and improve soil physical conditions (Kwesiga and Coe, 1994).

It must be noted that the improved fallow trees do not provide all the major nutrients, as they are capable of fixing only nitrogen, which is the most limiting. The two other macronutrients required by crops, phosphorus and potassium, can be recycled by the tree fallows, but the two nutrients must be sourced externally if they are depleted from the soil. Technical details on improved tree fallows have been described elsewhere (Kwesiga and Coe, 1994; Kwesiga *et al.*, 1999; Mafongoya *et al.*, 2003, 2005). In addition to improving soil fertility, tree fallows intervene in several other constraints, as presented in Table 8.1. As seen from the table, the impact of improved fallows is multidimensional, and some of these intervene beyond individual farmers who adopted the technology. The details of some of the main impacts are discussed below.

ICRAF's contribution to the development and dissemination of the technology

ICRAF's contributions to the technology can be classified into two main phases. The first was the research phase, from 1988 to around 1996, initially focusing on scientist-managed research and then expanding into farmer-managed research. Since the technology was new to the region, research was required on the methods to establish tree fallows, screening suitable species and provenances, identifying the most appropriate rotation periods and configurations of trees and crops, cutting and incorporation of tree biomass. In the mid-1990s, ICRAF coordinated a multi-country trial to test the biophysical limits of promising fallow systems and species. Although some of this research has continued, the emphasis of ICRAF's efforts shifted after 1996 following the conclusion that the improved tree fallow system was beneficial both biologically and financially. The success of the improved tree fallow crucially depends on the suitability to local conditions that was realized by the participation of farmers in technology development and adaptation. As a result, a constructivist approach was adopted in the development of the technology, i.e. farmers assessed the technology and made several modifications and adaptations based on their experiences. The continuous modification and adaptation of the technology were actively encouraged by researchers (Kwesiga *et al.*, 2005). The second phase consisted of efforts to improve the effectiveness and reach of seed and nursery systems, on institutional mechanisms for managing potential conflicts between tree growing and free grazing, and how to manage second-generation issues (e.g. pests) that may be associated with wider adoption of improved fallow species.

Further efforts to modify the technology and generate diverse options of improved tree fallows included experiments conducted to evaluate the

Table 8.1. Private and social costs and benefits of improved tree fallows. (After Ajayi and Matakala, 2006.)

	Private	Social
Costs	• Loss of land	• Incidence of *Mesoplatys* beetle pest (restricted to specific species only)
	• Additional labour	• Reduction of free grazing area during dry season
	• Tree seeds and nursery establishment	• Risk of uncontrolled fire outbreak
	• Pest control (some tree fallow species only)	
	• Working equipment	
	• Risk of uncontrolled fire outbreak	
Benefits	• Yield increase of subsequent crops	• Carbon sequestration
	• Opportunity for farm diversification (e.g. compatible with fish farming and growing of high-value vegetables)	• Suppression of weeds
	• Increase in fodder and maize stubble (for livestock)	• Improved soil infiltration and reduced runoff
	• Fuelwood available in the field, reducing time spent searching for wood	• Enhanced biodiversity
	• Use of tree leaves (*Tephrosia vogelii*) as 'pesticides' to remove ticks from livestock	• Serves as windbreaks
	• Suppresses the growth of weeds	• More fuelwood available to reduce deforestation weeds
	• Potential to mitigate the effects of drought during maize season	
	• Stakes for tobacco curing	

interaction between chemical fertilizers and improved tree fallows. Results show that there is a synergistic effect between low doses of mineral fertilizer and tree fallows, producing a higher yield increase, especially in later years following a fallow (Kwesiga and Coe, 1994; Ayuk and Mafongoya, 2002). In addition to these efforts, ICRAF facilitated development through: (i) writing extension materials for distribution; (ii) hosting visiting farmers and others at the station or nearby farms to view the performance of the fallows; (iii) provision of training to farmers, extension and project staff on the management of improved fallows; (iv) training to entrepreneurs on seed collection and nursery development; (v) establishment of a network within which organizations involved in improved fallows could exchange information; and (vi) collaboration with development organizations to help them raise funds for development activities.

Adoption of Improved Tree Fallows

Level of adoption

Improved tree fallows are a new technology, and dissemination to farmers on a larger scale took place only recently. Consequently, few farmers have implemented more than one cycle to date. Agroforestry adoption decisions are more complicated than those for annual crops and modern agricultural development packages based on chemical inputs (Scherr and Müller, 1991; Mercer, 2004) due to the multiple components and the multiple years through which testing, modification and eventual 'adoption' take place. As a result, the literature has a less precise definition of 'adoption' of agroforestry. Farmers who have planted improved fallow trees for a second cycle (on a reasonable size of land) are most appropriately labelled as 'adopters', while those still in the first cycle of tree fallows could be described as 'users', as it is not known whether they will continue to grow the trees. Some socio-economic research took place before there were any farmers who had planted at least two cycles, while other studies on which this work is based have lumped together first-time planters and those who have repeatedly planted the fallow trees. To avoid confusion, we have referred to farmers who have established one or more plots of improved fallow trees simply as 'planters'. The scaling up of the technology to different parts of Zambia was coordinated by the Adaptive Research and Development Network (ARDN) – comprising ICRAF, government research and extension services, farmer organizations and non-governmental organizations (NGOs). The ARDN framework enhances collaboration and exchange of germplasm and information among the different organizations. From less than a hundred planters in the early 1990s, the number of farmers who have planted improved fallow trees has been steadily increasing each year and, especially from 2000 onwards, to tens of thousands of farmers (see Fig. 8.2 below). The data are obtained from regular assessments conducted by agroforestry partners in Zambia through the ARDN framework, with some spot-checking by ICRAF. Further information on the number of farmers planting improved tree fallows and the economic impact is presented in the section 'Estimated number of farmers planting improved fallows'.

Policy and institutional factors affecting the planting of improved fallow trees

The degree to which improved tree fallows are used by farmers is influenced by several factors (Place and DeWees, 1999; Ajayi *et al.*, 2003). Such factors include access to information and management of the technology, incentives for farmer investment, active promotion of the technology by research partners in ARDN, government extension services and several major NGO projects. Also, mechanisms for the introduction of germplasm and technical support for managing tree fallows are vitally important. Another important factor in the adoption decision is the increased cost of fertilizer due to currency devaluation and the withdrawal of subsidies and government-sponsored credit programmes. This situation prevailed throughout the 1990s and certainly increased farmers' interests in seeking alternatives to the purchase of mineral fertilizer (Peterson *et al.*, 1999). Lastly, several local institutions have implications for the adoption of improved tree fallows. In particular, bushfires and free grazing present threats to the spread of tree fallows but, through the enactment of local by-laws, local leaders have found ways to integrate the fallows into local resource management systems and to protect farmers' investments in them (Ajayi and Kwesiga, 2003). A study of land tenure institutions found that almost all land is acquired by inheritance or allocation by the chief and is held in perpetuity by households, with little fear of losing land (Place, 1995) (the special case of land ownership by women is discussed below). Thus there were no serious tenure impediments to tree planting by households in Zambia. The absence of tenure impediments in Zambia is also partly due to the small size of land area (average of 0.20 ha only) grown to improved fallows. With a higher level of adoption and/or an increase in the area devoted to the technology, the influence of land tenure may become more important than it is presently, especially in locations where land is more limiting.

Household and farm variables affecting the planting of improved tree fallows

Many studies have been conducted over the past few years to better understand which types of households are using or expanding area under improved fallows. Many of the studies used descriptive statistics, while two applied multivariate econometrics. The results from selected adoption studies on this topic have been synthesized in Ajayi *et al.* (2003a). The summary of the synthesis is presented in Table 8.2 and discussed below.

- *Farmer training and awareness.* Given that improved tree fallows are relatively more knowledge-intensive, access to information about the management of the technology is one of the important driving factors for its adoption. Farmers who plant improved tree species have been formally trained by organizations that support agroforestry or have benefited from informal knowledge-sharing by fellow farmers who have adopted earlier and through farmer exchange visits.
- *Wealth status.* Wealthier farmers were more likely to test the technology. This is most probably because their wealth confers on them a lower risk aversion as it a measure of insurance against innovation risks. However, the wealthy were less likely to continue with improved

Table 8.2. Summary of factors affecting farmers' decisions to plant improved tree fallows in eastern Zambia. (From Ajayi *et al.*, 2003.)

Study (no. of households in sample)	Wealth	Age	Sex	Education	Labour/ household size	Farm size	Uncultivated land	Use of fertilizer	Off-farm income	Oxen ownership	Village exposure to improved fallows
Factors affecting decision to plant improved tree fallows for the first time											
Franzel *et al.* (1999) [157]			N		N						
Phiri *et al.* (2004) [218]	+		N								+
Kuntashula *et al.* (2002) [218]	+	N		N		+	N		N	+	
Ajayi *et al.* (2006c) [305]			N		+, N	N		+			
Peterson *et al.* (1999) [320]	+					+				+	
Factors affecting decision to continue to plant											
Keil *et al.* (2005) [100; Tobit analysis]	+/–	N	N	N	+	+					
Place *et al.* (2002) [101; Logit analysis]		+	N	N	N	N					+

+, enhances planting of fallow trees; –, decreases planting of fallow trees; N, no effect on tree planting; +/–, can increase or decrease tree planting; blank means the variable was not included in the specific study.

fallows than other social groups (Keil *et al*., 2005). The fact that the poor had no means with which to purchase fertilizer was a contributing factor. Whether this pattern continues now that fertilizer prices are partly subsidized has not yet been studied.

- *Gender*. Several studies (Franzel *et al*., 1999; Gladwin *et al*., 2002; Phiri *et al*., 2004; Keil *et al*., 2005; Ajayi *et al*., 2006b,c) found no significant differences between the proportions of female- and male-headed households planting improved tree fallows. However, women may be disadvantaged in benefiting from improved fallows because of the traditional power structure between men and women and the difference in decision making and ability to control benefits from productive resources, as sales activities involving cash transfers are dominated by men. The existing power structure, which has both economic and social consequences, may also affect the area that a woman can allocate to the technology.
- *Size of land owned*. Availability of land and size of landholding are positively associated with the establishment of improved tree fallow plots. This is because farmers who have larger uncultivated land could more easily afford to keep some part of their fields under fallow (Place *et al*., 2002). This limitation led to the introduction of a permanent tree intercrop system, which does not require that cropping phases be interrupted.

Economic Impact of Improved Tree Fallows

Inventory of costs and benefits

Benefits from improved tree fallows

The main benefit from improved tree fallows is increased yield of crops that follow the fallows. The very first trials were conducted from 1988 to 1993 and many others have been conducted on different soils and with different management treatments (for a synthesis see Kwesiga *et al*., 2003). One example of the results of maize yield obtained during the three seasons after fallow is given in Table 8.3. In summary, the trials show that maize yields from improved tree fallows consistently reached two or more times the yields from the farmers' practice of continuous maize production without application of fertilizer. In addition to increasing crop yields, improved tree fallows provide other benefits to farmers in terms of reduced risk from drought, other by-products such as insecticides made from *Tephrosia vogelii* leaves, and increased availability of fuelwood. A study carried out in Zambia shows that 10, 15 and 21 t of fuelwood per hectare were harvested after 1, 2 and 3 years of *Sesbania sesban* fallow, respectively (Kwesiga and Coe, 1994). Financial analysis showed that improved tree fallow systems were profitable and had positive net benefits (Place *et al*., 2002; Franzel, 2004; Ajayi *et al*., 2006b,c).

The main environmental benefits are improved soil physical properties, such as better infiltration and aggregate soil stability, which reduce soil erosion and enhance the ability of the soil to store water (see below).

Table 8.3. Maize grain yield after two-year *Sesbania sesban* fallow with and without recommended fertilizer in eastern Zambia during 1998–2000 (n = 48). (From Kwesiga *et al*., 2003.)

	Maize grain yield (t/ha)		
Type of land-use system	Year 1	Year 2	Year 3
Sesbania fallow + no fertilizer	3.6	2.0	1.6
Sesbania fallow + 50% recommended fertilizer[a]	3.6	4.4	2.7
Sesbania fallow + 25% recommended fertilizer[a]	3.6	3.4	2.3
Continuous maize + 100% recommended fertilizer[a]	4.0	4.0	2.2
Continuous maize + no fertilizer	1.0	1.2	0.4
Least significant difference (lsd) (0.05)	0.7	0.6	1.1

[a]Recommended fertilizer rate is 112 kg N, 20 kg P and 16 kg K/ha.

Sesbania fallows were also found to greatly reduce the occurrence of *Striga* weeds, which generally thrive under conditions of low soil fertility (Kwesiga *et al*., 1999). Tree fallows may also help to reduce the pressure on woodlands by providing an alternative source for fuelwood. However, rigorous field studies are needed to test this hypothesized linkage between planting trees on farms and reduced deforestation.

The positive productivity effects on smallholders and their yields will have the effect of shifting the supply curve for maize (see Fig. 8.1). The shape of the supply curve has not been empirically estimated, but there is likely to be an inelastic portion reflecting the fact that maize is the main staple food and much of it is grown for subsistence purposes. The equilibrium under the farmers' practice where mineral fertilizer is not used is point A. The adoption of improved fallows will shift the supply curve and move the equilibrium from A to C. Such a shift is predicted to bring about a fall in the price of maize, yielding consumer surplus. However, there is no evidence to suggest this has happened in eastern Zambia. That may be because demand is highly elastic: there have been food distribution programmes almost annually (distribution of 'relief maize' to food-deficit households) somewhere in the region.[2] Thus, from the supply shift, we have increased private benefits accruing to farmers (mainly for self-consumption), but we do not have an indication of consumer surplus resulting from lower prices.

The contribution of improved tree fallows to environmental services such as carbon sequestration and others (listed in Table 8.1) may one day increase the demand for the maize production system that includes a carbon-storing improved fallow system. In such a scenario, society would articulate its demand through environmental service payments. This would result in a shift in the equilibrium from C to D and boost the price received by farmers. This has not yet occurred, partly because food security attracts much more emphasis than environmental quality at present.

[2]On the other hand, there is evidence that cabbages grown under improved fallow systems fetch a higher market price as they are perceived as being sweeter than the normal marketed cabbages.

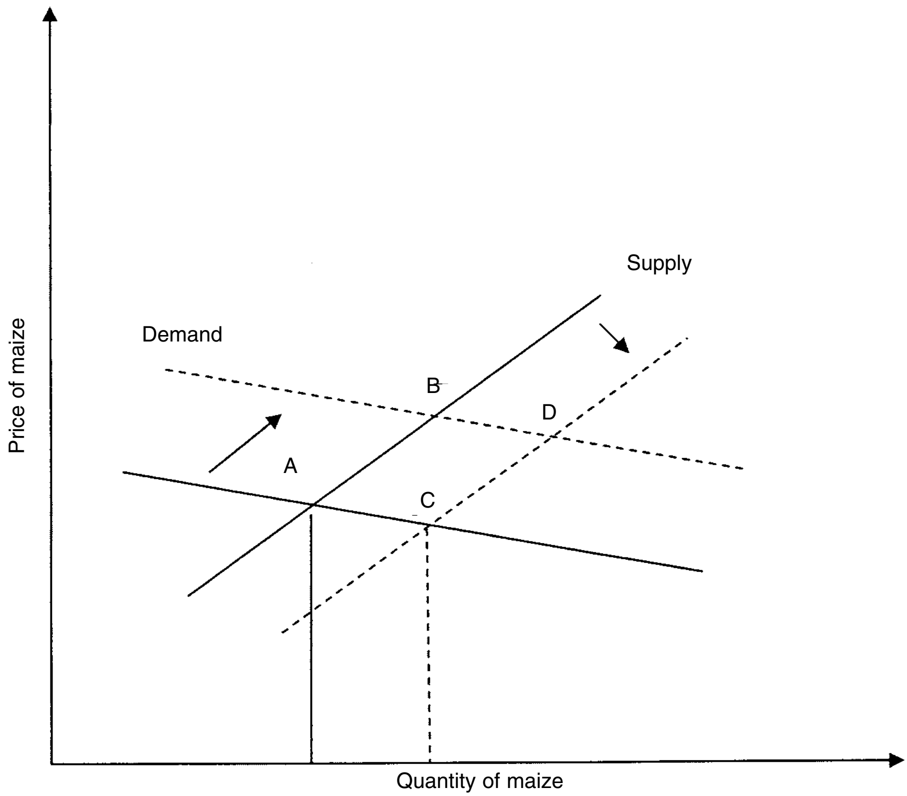

Fig. 8.1. Effect of improved tree fallows on the demand for and supply of maize.

Costs of improved tree fallows

The main costs of improved fallows to farmers are the cost of taking land out of cultivation and the cost of labour for planting and managing the trees. The opportunity cost of land is relatively low because maize yields without inputs are low and land scarcity is not acute. Labour use over the entire fallow rotation is not much higher than that under continuous maize production, but farmers still perceive labour investments in the establishment and cutting of fallows, as well as the nursery labour time, as an additional burden. In a 5-year cycle, the total labour inputs for a continuously cultivated maize field (without fertilizer) is 462 person-day equivalents per hectare, 532 person-days in maize production (with fertilizer), 434 person-days for *Gliricidia* fallows,[3] 521 person-days for *Sesbania* fallows and 493 person-days for *Tephrosia* fallows (see details on labour inputs below).

In addition to these investment costs, the development and promotion of improved tree fallows resulted in some unexpected problems resulting

[3]Some of the *Gliricidia sepium* fields monitored during the study were burnt by bushfires. The farmers spent little to no labour inputs to weed the plots. As a result, the overall labour inputs and the maize yields recorded in such fields were low.

in additional costs. These costs include the increased incidence of pests such as *Mesoplatys* beetles and nematodes. Thus far, damage from these pests has occurred only on the fallow trees and not on other plants. Other social and institutional problems are due to reduced grazing areas and lower tolerance to bushfires as farmers protect their fallow fields. In some cases, these incidents caused unintended social problems resulting from a conflict of economic interests among different sections of the community (details of an in-depth study on this issue have been documented in Ajayi and Kwesiga, 2003). Collaborative efforts by traditional chiefs, village headmen, farmers and R&D organizations, and policy dialogues among the different stakeholders, have resulted in various approaches to successfully deal with the problem of livestock browsing and fire.

Profitability of improved tree fallows

The technical effectiveness of improved fallow species to replenish soil fertility has been well established. Questions have, however, been asked regarding the labour input requirements for tree fallow management. Given the HIV/AIDS pandemic and its potential impact on the quantity (and quality) of household labour supply, labour input implications of agricultural technologies are essential to consider, especially in the relatively land-abundant areas of eastern Zambia where labour is a much more limiting resource as compared with land. The profitability of improved tree fallows compared with other land-use and production systems is also addressed. Using primary data collected from 89 farmers' maize fields that were monitored on a weekly basis throughout the 2002/2003 agricultural season, the profitability and returns to the following five different land-use systems were evaluated: (i) *S. sesban* fallow; (ii) *G. sepium* fallow; (iii) *T. vogelii* fallow; (iv) continuous cropping with fertilizer; and (v) continuous cropping without fertilizer. For improved tree fallows, farmers were selected so as to represent different phases of the 5-year cycle, i.e. 2 years of fallow establishment and 3 years of cropping. The analysis factored in opportunity costs of taking land out of production by valuing all five seasons of maize production from the non-fallow options and comparing them with just three seasons of maize production in the fallow systems. Also, the increased maize under the fallow options occurs starting in the third year and is therefore appropriately discounted. A rather high discount rate of 30% is used (based on banks' base lending rate in Zambia at the time of the study), which makes the discounted returns from the fallow systems all the more conservative.

The results show that improved fallow options are more profitable than current farmers' practices but less profitable than full fertilizer application (Table 8.4). One of the reasons is the government subsidy of chemical fertilizer that is as high as 50% of the market price in Zambia. Using non-subsidized fertilizer prices, the fertilizer option becomes much less profitable (reduced by 30%) and its net present value (NPV) is very close to that of the fallow options (NPV of US$349 compared with US$309). The higher profitability recorded for the mineral fertilizer option was achieved through a higher investment cost and hence its benefit:cost ratio (BCR) is lower as compared with the fallow systems. Farmers obtain US$2.65 benefit per dollar invested in fertilizer fields compared with BCR ranging between 2.77 and 3.13 for the different fallow options. In terms of returns to labour, the differences between fully fertilized maize and the improved tree fallow systems are small, even if fertilizer is subsidized. The return to a labour day is US$3.20 for fertilized maize and US$2.50, 2.40 and 1.90 for the three fallow species tested. Return to labour for the unfertilized maize system was US$1.10, while the daily agricultural wage is around US$0.50. Thus, while the recommended dose of fertilizer option is the highest performer at subsidized rates, the tree fallow options are only slightly less economically attractive when a non-subsidized price is used. In rural areas where road infrastructure is poor and transport costs of fertilizer are high, the profitability of tree fallow options will be competitive with the fertilizer option.

Table 8.4. Profitability[a] of maize production per hectare using tree fallows and subsidized fertilizer options over a 5-year cycle in Zambia (n = 193). (From Ajayi *et al.*, 2006a,b.)

Description of land-use system	NPV (ZMK)	NPV (US$)	BCR
Continuous maize for 5 years + no fertilizer	584,755	130	2.01
Continuous maize for 5 years + fertilizer (subsidized at 50%)	2,243,341	499	2.65
Continuous maize for 5 years + fertilizer (non-subsidized price)	1,570,500	349	1.77
Two years of *Gliricidia* fallow followed by 3 years of crop	1,211,416	269	2.91
Two years of *Sesbania* fallow followed by 3 years of crop	1,390,535	309	3.13
Two years of *Tephrosia* fallow followed by 3 years of crop	1,048,901	233	2.77

NPV, net present value; ZMK, Zambian Kwacha; BCR, benefit:cost ratio.
[a]Figures are based on input and output prices and an annual discount rate of 30%.

Different price and other policy scenarios affect the financial attractiveness and potential adoption of maize production systems even when agronomic relationships between inputs and outputs remain the same. For example, if the subsidy on fertilizer is removed in the analysis, the difference in the financial profitability between the mineral fertilizer option and improved tree fallows is greatly reduced, as shown in the third row of Table 8.4.

Performance of improved tree fallow systems under drought

Franzel and Scherr (2002) identified three major ways in which improved tree fallows can help mitigate risk for small-scale farmers compared with the use of mineral fertilizers or production without external inputs. First, farmers who plant tree fallows would lose less investment (usually only labour) than those who invested in mineral fertilizer bought by cash or credit. Second, the benefits of improved fallows are spread over multiple years whereas those of mineral fertilizer usually take place in a single year. Third, tree fallows improve the soil structure and organic matter content of the soil, thus enhancing the soil's ability to retain moisture during drought years.

The findings from our data analysis support these benefits of improved tree fallows. In addition, simulations were made using data from a long-term researcher-managed trial between 1988 and 1993, during which there was a severe drought in 1992. In the researcher-managed trial, a one- or two-season fallow always performed better than the no-input continuous maize system if a drought were to occur in any single year. The 1-year and 2-year fallows performed surprisingly well even if two drought years were to occur. The only case where a 2-year fallow was found to be worse than the no-input continuous cropping case was when drought occurred in consecutive seasons immediately after the fallow phase. The most critical season in the 5-year fallow cycle is the first cropping year just after the fallow has been cut.

Estimate of total benefits to farmers and internal rate of return to research investment in eastern Zambia

Estimated number of farmers planting improved fallows

The number of farmers who have planted improved fallow trees is shown in Fig. 8.2. From less than 100 planters in the early 1990s, the number of farmers who have planted improved fallow trees has been steadily increasing each year, especially from 2000 onwards. The data are obtained from regular assessments conducted by agroforestry partners in Zambia through the ARDN network, with some spot-checking by ICRAF. During the annual planning and review forum of the ARDN, each member institution presents an overview of their activities for the previous season, including the number of farmers they work with who have established improved tree fallow plots, the challenges they faced and the plan for the new agricultural season. The forum provides opportunities for other member institutions to ask questions regarding their peers' activities. Information on the number of farmers who have planted improved fallow trees is collated and aggregated for all the members of ARDN.

The increase in the number of planters from the late 1990s is due to increased intensity of activities by ARDN members to disseminate the technology to different farming communities. The commencement of operations by several agricultural development organizations that were interested in

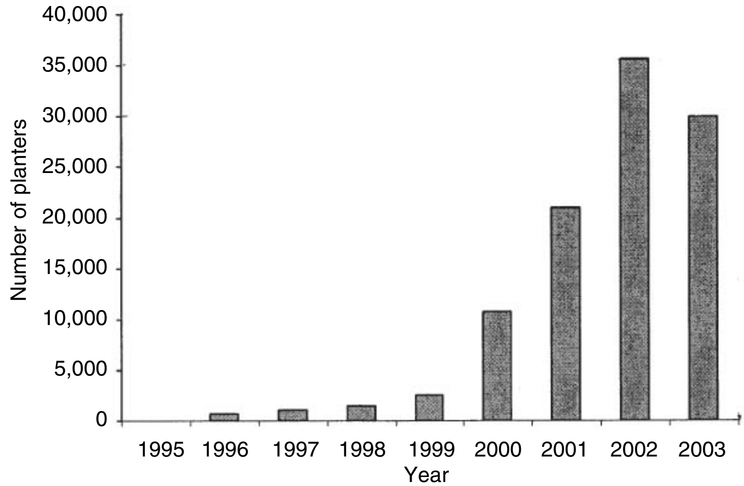

Fig. 8.2. Number of farmers planting improved tree fallows in eastern Zambia. (From Zambia ICRAF annual report, 2005.)

promoting NRM technologies to farmers in eastern Zambia provided added impetus to enhance the uptake of the technology. Such organizations include the Zambia Integrated Agroforestry Project, the Eastern Province Development Women Association, the US Agency for International Development-supported Accelerating Impact of Agroforestry Technologies on Smallholder Farmer Livelihoods Project, the Soil Conservation and Agroforestry Extension Project supported by the Swedish International Development Agency (SIDA), and new interests in agroforestry technology by international NGOs such as Plan International (an international NGO focusing on child nutrition and welfare) and the Service Centre for Development Cooperation (a service centre for Finnish NGOs interested in development work and global issues). In partnership with ICRAF, these institutions reached a nucleus of farmers through direct training and provision of initial seed to farmers. These contributed to 'kick start' the spread of the technology, mainly through catalysing a farmer-to-farmer exchange process.

In addition, the period also coincided with a time when ICRAF's operational strategy placed an increased emphasis on the development phase ('scaling up') of the technology in Zambia and the southern Africa region. There is also an emerging interest by private sector organizations, including tobacco companies and individual entrepreneurs in Zambia, in the provision of inputs for improved tree fallows. Another factor for the increase in number of planters is that tobacco companies train and support their out-grower scheme farmers to use branches of the improved trees to make sheds for curing tobacco, to avoid further deforestation in addition to improving the soil. Individual entrepreneurs establish large hectares of seed orchards to meet rising demand for the seeds of improved tree fallows, especially *G. sepium*. In addition to an increase in the number of farmers planting improved tree fallows, the average size of improved tree fallow plots has also increased. From an average field size of 0.07 ha in 1997, the average size of improved tree fallow fields had increased to 0.20 ha in 2003[4] (Ajayi *et al.*, 2006a,b,c).

The number of planters fell in 2003 compared with 2002, mainly because of the phasing out of the Zambia Integrated Agroforestry Project, one of the leading agroforestry training and dissemination organizations in eastern Zambia and an important member of the ARDN. Other partners within the ARDN have, however, continued their normal activities on agroforestry dissemination.

Total benefits to farmers

Using the numbers of farmers planting improved tree fallows, it is possible to integrate the information on average size of fallow, average maize yield response as shown above and average wood value (which is about 20% of the value of the increased maize crop) to produce an overall estimate of the economic benefits to farmers using the system. This information is most accurate for Eastern Province in Zambia, where the bulk of the analyses have been done. In 2004, the planters of fallows in 2000, 2001 and 2002 reaped some benefits. We estimated the total benefits to be about US$1.32 million, accruing to approximately 67,000 planters. In the 2003/04 season, it has been estimated that a cumulative figure of 77,500 farmers had planted a fallow. The economic impact was estimated to have increased to nearly US$2 million by the 2005/06 agricultural season.

One may also value the impact of improved tree fallows in terms of food security – by determining the number of days of additional food they provide to a household. To do this, we take the mean incremental increase in yields from the results presented and smooth these out into annualized returns. Such a system provides between 425 and 850 extra kg of maize per hectare per year (depending on species and performance). However, the average fallow plot of 0.20 ha for the year 2002/03 would generate on average between 85 and 170 kg additional maize per year. Daily maize consumption per adult in Zambia is about 1.5 kg per capita. Thus, the systems generate between 57 and 114 extra person-days of maize consumption.[5]

Internal rate of return to research and development

The calculation of the internal rate of return (IRR) was challenging because of the difficulty in separating costs that are unique to the Project and in monitoring benefits of the Project that accrue to farmers in other locations. Thus both costs and benefits may be underestimated. On the benefit side, ICRAF has been collecting data on the number of farmers

[4]The field size varies widely, ranging from 0.01 to 0.78 ha.

[5]Another method of valuation of the system is through the substitute value of nitrogen. Nitrogen fixation by improved tree fallows is estimated at 150 kg N/ha per year. The nitrogen level may translate into amounts as high as US$6 million per year for the whole of southern Africa at the estimated adoption level of 180,000 planters and assuming the same average plot size of 0.20 ha.

planting improved fallows in eastern Zambia. However, the spillover effects of adoption of the technology by farmers elsewhere in the region are not as reliably documented, although they are known to be high. For the baseline IRR, we have included only Zambian farmers (within and outside Eastern Province), thus using conservative assumptions of the generated benefits. We have assumed that the number of plantings of fallows each year remains the same as it was in the 2002/03 period, i.e. 30,000. Eventually, this will decline around 2014, taking note of the rural population in Zambia and because we assume those wishing to adopt the fallows will have done so over the next 10 years. As benefits, we have included the impact on crop yields and production of firewood, assuming constant prices for both. We have not yet factored in any benefits for carbon sequestration because it is unlikely that the Kyoto type of carbon projects for smallholder communities will be viable in the near future. On the cost side, it was not possible to obtain clear figures for soil fertility R&D for Zambia alone, so we had to make assumptions on the costs incurred. Some costs such as vehicles were depreciated (straight line method) over time. It was not possible to separate out ICRAF's investments between research and development facilitation. We thus assumed that all pre-1995 investments were in research and that the share invested in development facilitation increased steadily after that. Over the period 1989–2004, the average annual cost in R&D for soil fertility ranged between US$230,000 and US$350,000. Costs were assumed to increase slightly over time due to inflation, but to diminish around 2010. Development costs of two major projects in the late 1990s and early 2000s were included and a figure of around US$70,000 was assumed to persist over time for these two development projects. Because of the long period of research expenditure before benefits were observed on farm, we calculated an IRR for three different time horizons – 20, 25 and 30 years – to reflect the long-term nature of research, each beginning in 1988 (the year of first research costs). The results show that the benefits begin to be larger than R&D costs only from 2001. Cumulative net benefits (non-discounted) become positive only in 2005. The IRR calculated for the 1988–2008 period is very low, at 3.2%. However, if the time period is expanded to 25 years, the IRR increases to 15.2% and finally, for a 30-year horizon, it is 20.8%.

Ecosystem Impacts

Effect on soil physical and biological properties

The ability of trees and biomass from trees to maintain or improve soil physical properties has been well documented (Hullugalle and Kang, 1990). Tree fallows can improve soil physical properties also due to the additional quantities of litter fall, root biomass, root activity, biological activities and roots leaving macro-pores in the soil following their decomposition (Rao *et al.*, 1998). In addition to improved soil fertility, soil aggregation is higher in tree fallow fields; this enhances water infiltration and water-holding capacity and reduces water runoff and soil erosion compared with maize fields that are continuously cultivated (Phiri *et al.*, 2003). Improved tree fallows enhance soil biodiversity by increasing soil invertebrates, which perform important ecosystem functions that can affect plant growth. A long-term study (Sileshi and Mafongoya, 2006) concluded that the improved tree legume fallows not only increase maize yields, but they also have a positive impact on biodiversity and enhance the ecosystem services rendered by soil invertebrates.

Effect on soil nutrient balances

Organic inputs of tree legumes supply enough nitrogen for crops, but these organic inputs do not supply enough phosphorus and potassium to support crop yields over time. The question for sustainability is: do improved fallows reduce soil stocks of phosphorus and potassium over time, even while maintaining a positive nitrogen balance? To answer this question, an 8-year nutrient balance trial was conducted. For all the improved fallow species, there was a positive nitrogen balance in the two years of cropping after the fallow (Table 8.5). Fertilized maize had the highest nitrogen balance due to the annual application of 112 kg N/ha in each year. Unfertilized maize had lower balances, even though maize grain and stubble yields were very low over time. The tree-based fallows had a positive nitrogen balance due to biological nitrogen fixation and capture of nitrogen from depth, but the nitrogen balance became very small in the second year of cropping. Most of the land-use systems showed a positive phosphorus balance due to low uptake of phosphorus in maize grain yield and stubble (relative to nitrogen), and increased mycorrhizal populations in the soil. Most land-use systems showed a negative balance for potassium. The highest negative potassium balance was obtained in fully fertilized maize fields due to higher maize and stubble yields, which extract a lot of potassium.

Effect on deforestation of *miombo* woodlands

Farmers who establish improved tree fallow fields satisfy some of their household fuel and other wood requirements from their own fields. This may reduce the exploitation of wood from the communally owned *miombo* forests and thus reduce deforestation. A study was carried out in eastern Zambia to determine whether this was observed or not (Govere, 2002). Of the total amount of firewood consumed (3.1 t/household), the improved fallows contributed 11% on average. The value to individual farmers varied according to local supply conditions for fuelwood. For the two study sites in Chipata North and South, non-adopters of improved fallow trees collected more fuelwood from the *miombo* woodlands.

Table 8.5. Nutrient budgets for land-use systems in 2-year non-copping fallows (0–60 cm). (From Mafongoya *et al.*, 2005.)

	Nitrogen			Phosphorus			Potassium		
Land-use system	1998	1999	2002	1998	1999	2002	1998	1999	2002
Cajanus fallow	44	17	84	21	8	33	37	9	27
Sesbania fallow	47	19	110	39	24	32	–20	–25	–20
Fertilized maize	70	54	48	14	12	12	-56	–52	–65
Unfertilized maize	–20	–17	–22	–2	–1	–2	–31	–30	–38

However, although the fallows in Chipata South are contributing firewood that ultimately reduces the amount of fuel energy collected from the *miombo* woodlands, this is not the case in the other district, where collection amounts are nearly the same despite the additional wood from the fallows. Thus there are some positive signs that the fallows may be able to reduce the pressure on natural woodlands, but this is not guaranteed; further monitoring will be necessary. We have not yet studied whether the adoption of tree fallows has reduced the demand for clearing of new land, nor whether the dramatic reduction in fertilizer use has increased clearing. Also, we are not aware of such a study.

Effects on carbon sequestration

Agroforestry land-use systems sequester amounts of soil carbon (Montagnini and Nair, 2004). The amount of carbon stored in the biomass and in the soil was measured in long-term trials involving improved fallows and other land uses in Zambia. The results, showing different potentials of various fallow types and rotational woodlots (a rotational woodlot is a longer-term fallow of about 5 years, in which the wood product is a major product sought by farmers) to sequester carbon in the above- and below-ground biomass, are presented in Table 8.6. Although much of the carbon stored in the biomass would be lost if the wood was burned for energy, indications are that in at least some cases the fallow wood replaces that of naturally growing trees, resulting in a net storage of carbon on the landscape. Soil carbon under improved tree fallow systems varied according to species and location, with highest amounts being 2.5–3.6 t/ha.

Table 8.6. Carbon sequestration in tree fallows and woodlot fields (t/ha).

	Rotational fallows (one to two seasons)	Permanent intercrops (two to three seasons)	Woodlots (five seasons)
C fixation in biomass (t/ha)	1.9–7.0	3.0–8.9	32.6–73.9
Intake of C (t/ha)	1.6–3.2	1.4–4.2	3.5–8.0
Root C input (t/ha)	0.7–2.5	1.0–3.6	17.6

Current prices of carbon for land managers are between US$3 and 8/t, so the potential for improved tree fallows to increase the incomes of farmers is limited at this point in time (even if the full carbon stored of 12.7 t/ha over 2 years were to be compensated, for a fallow of 0.2 ha this amounts to about US$7.50 per year).

Summary and Conclusions

This case study focuses on the development, adoption and impact of improved tree fallows on smallholder farmers in Zambia. It shows that, in order to make a sustainable impact, agricultural technology innovations should be targeted to the real needs of farmers in relevant locations, with active encouragement of user modification and adaptation of the technology. The adoption of the technology by farmers is not a direct relationship based exclusively on technological characteristics, but is influenced by several broad groups of factors including institutional and policy factors (especially fertilizer subsidies), spatial and geographical factors and household-specific variables. Wealth and gender do not appear to be highly related to the use of rotational tree fallows, but land size was found to be an important determinant. About 66,000 farmers were practising improved fallows in Zambia in 2003.

Improved tree fallows generate large increases in subsequent maize yields. A 0.20 ha fallow system can generate between 57 and 143 extra days of maize consumption. The fallow system is much more profitable than the traditional practice of continuous maize cultivation without fertilizer application. However, the tree fallow system is less profitable than fully fertilized plots, especially when fertilizer is subsidized. Still, the tree fallow system is quite competitive, most notably in terms of returns to labour. The case study identified different types of costs and benefits of improved tree fallows for the individual adopters and a wide range of environmental services that accrue to society at large. Some of these have been quantified, but a detailed study is required to assign a quantitative value for others. The economic impacts of improved fallow trees in Zambia alone are nearly US$2 million (2005) with cumulative net benefits (above research costs) reaching US$20 million by 2010. This is a very conservative estimate that underestimates the returns to research, since the improved tree fallow technology has been disseminated in many other countries in the region.

In the absence of massive government investment in roads, credit and fertilizer subsidies, there will remain a large proportion of the rural population who will not be able to afford mineral fertilizer. For the many maize farmers who will not benefit from these types of public investments, improved tree fallows provide a productive and profitable option for increasing maize production. Because the system performs well in terms of returns to labour, it is expected to remain a demanded technology even during increased growth of agriculture and the development of better agricultural labour markets. Despite the impacts that tree fallows can have, the ability to alleviate poverty through production of maize or any other cereal on relatively small farms is limited. Thus, the technology is likely to be transitory for some farmers and more lasting for others; in either case, it can provide a needed boost to income and can potentially help to finance a shift into more profitable undertakings. There are very few other available technologies which could provide such a boost for the very poor in rural southern Africa while at the same time not requiring cash investments.

Acknowledgements

The authors acknowledge the consistent financial support provided by the Canadian International Development Agency, Rockefeller Foundation and the Swedish International Development Agency, and the Government of Zambia for improved fallow technology over several years. The usual disclaimer applies.

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9

ICARDA. *Ex post* Impact Assessment of Natural Resource Management Technologies in Crop–Livestock Systems in Dry Areas of Morocco and Tunisia

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The low rainfall areas (200–350 mm) of the West Asia and North Africa (WANA) region are characterized by low levels of economic activity, a high incidence of land degradation and a high percentage of rural population. Agriculture accounts for nearly 30% of the total labour force in the region. Public and private sector investment in agricultural research and technology transfer is small and hence adoption rates of improved technologies are low. Coupled with increased incidences of drought, the lack of appropriate new technologies has resulted in increased poverty among small producers and environmental degradation in rural areas. More than 38 million people in the WANA region live in rural areas, and depend mainly on farming for their livelihoods.

Crop–livestock systems are the predominant farming systems, with the major share of household income generated from small ruminant production. Traditionally, the source of livestock feed during winter and spring is extensive rangeland grazing. In summer and autumn livestock depend on crop areas for grazing of cereal stubbles and other crop

 International Research on Natural Resource Management (eds H. Waibel and D. Zilberman)

residues. But the contribution of native rangeland to animal feed requirements has decreased from 70% five decades ago to no more than 25% at present, mainly due to an increased animal population. Inappropriate land-use policies and the absence of secure property rights have often contributed to unsustainable use of land and rangeland resources. Land degradation resulting from the loss of vegetation through overgrazing, ploughing and fuelwood extraction, and consequent soil erosion via wind and water, is also common to WANA countries (Thomas *et al.*, 2003). This problem is exacerbated by land ownership and tenure issues, where land is either collectively owned or public.

Research at the International Centre for Agricultural Research in the Dry Areas (ICARDA) and collaborating national agricultural research systems (NARSs) has led to the development and promotion of technologies that can improve crop/livestock integration in the drier areas by enhancing and stabilizing the production and quality of animal feed and by controlling soil erosion, thus reducing pressure on common rangelands. The alley-cropping systems using fodder shrubs with other annual forage alternatives are one of the cropping systems alternatives that can increase feed availability, particularly under low rainfall and marginal land conditions. This cropping system was introduced in the marginal lands of Morocco and Tunisia through a natural resource management (NRM) R&D project coordinated by ICARDA. The Mashreq/Maghreb (M&M) project was initiated and designed as an adaptive research programme for the development of integrated crop–livestock production systems in the low-rainfall areas of WANA. During the first phase of the M&M project, 1995–1998, participatory approaches were used with individual farmers and through farmer-managed field trials of technology components. The approach evolved during the second phase, 1999–2002, into an integrated natural resource management approach (INRM). The initial entry points were the technologies that addressed the constraints of limited feed resources and increasing land degradation.

Introduction of *Atriplex* and cactus for animal feeding and resource conservation in alley-cropping systems are two cited examples of NRM technologies. The M&M research project has established technical information on the agronomic and ecological performance of new alley-cropping techniques as well as its effects on animal feeding. In a biological innovation, the rows are constituted with spineless cactus (*Opuntia ficus indica*) in Tunisia and with *Atriplex* (sandbush) species in Morocco, and the spacing between rows is covered with cereal crops or pastureland. Cactus and *Atriplex* species are fodder shrubs that can generate the following benefits: (i) buffering of seasonal fluctuations as standing fodder crops; (ii) as protein or energy supplement for livestock in poor native rangelands or low-quality roughage; (iii) as a substitute feed during drought years; (iv) as a source of fuelwood; and (v) as a means of soil erosion control. One main research question that had to be answered prior to the implementation of the technology on a larger scale was to find the appropriate plant density of these species. Hence, on-farm experimentation in collaboration with selected communities in both countries was carried out.

The objectives of this chapter are to assess the impacts of the cactus and *Atriplex* alley-cropping technology on farmers' income, the poverty reduction effects in the communities that have adopted the technology and the efficiency of the R&D investment by ICARDA and its collaborating NARSs from the social point of view. The counterfactual defined to assess the effects of the technology was the traditional barley/fallow production system. Benefit–cost analysis was applied to calculate the financial and economic rate of return of the public and private investment in implementing and disseminating the cactus and *Atriplex* alley-cropping technology.

In the next section a common theoretical framework is outlined. Thereafter, the Tunisia and Morocco cases are presented separately because the technologies and the framework conditions differ between the two countries. Finally, the chapter concludes with some salient points for technology introduction in dry land areas of both countries and their implications for the WANA region. Also, some lessons are drawn in terms of the methodology used in impact assessment of NRM.

Theoretical Framework

Unlike agricultural research investments for high-potential areas, it is unclear whether the rate of return of research investment for marginal areas is sufficient. It is known that adoption of new technologies in these environments is often low because of the generally highly variable returns of such technologies and because of institutional constraints such as land property rights issues. Hence, it can be hypothesized that public incentives are necessary to foster technology adoption and to realize the potential benefits of NRM technologies. In particular, if the technologies require investments, governments may have to subsidize the establishment of the plantations. Subsidies are justified if public benefits can be generated whose value exceeds the amount of the subsidy.

For example, cactus/*Atriplex* alley cropping as a new NRM technology for these areas can reduce soil erosion in the marginal environments. Reducing soil erosion has private and public benefits, some of which can be quantified and monetized (e.g. soil fertility), while other effects (biodiversity) are less tangible. Hence, it is useful to start with a conceptual framework that identifies the conditions for investment efficiency.

To illustrate the problem in a general but simplified way, let L be the target area in hectares of the cactus/*Atriplex* alley-cropping technology. To generate the technology requires research costs (RC), which are incurred by ICARDA. Costs for developing the NRM technology further in order to make it adaptable to the local agroecological conditions create further development costs (DC) incurred by the NARS. Adoption of cactus/*Atriplex* alley cropping by farmers causes establishment costs (EC), which are proportional to the area planted. There may be other constraints to adoption (OC), such as land property rights issues. Furthermore, since the farming environment is highly vulnerable, the notion of risk premium (RP) can be introduced. The risk premium is a payment that has to be deducted from the average annual benefits of the technology to account for its riskiness.

Dissemination of the technology in the target area requires a subsidy (s) that must be sufficiently high to stimulate a farmer to adopt the technology. The minimum amount of subsidy should cover the proportion of EC that makes farmers adopt the technology and meets the target of the programme. The technology will generate private (B) and environmental benefits (EV) like the reduction of off-site externalities, as well other social benefits (SV) such as, for example, reducing social conflicts and preventing out-migration. One of the challenges is to monetize these benefits. Benefits occur over time and commence only after the cactus/*Atriplex* has reached a biological stage where outputs can be produced. Thus benefits must be discounted at the private (r_p) or social (r_s) opportunity costs of capital. Benefits are understood as net benefits after deducting, for example, the cost of maintaining the alley-cropping system.

From the viewpoint of the farmer, investment in the cactus/*Atriplex* alley-cropping technology is likely to be uneconomical without subsidy, hence:

$$L(B - RP)/r_p < L(EC + OC) \tag{9.1}$$

Introducing the subsidy as a proportional rebate on EC reverses the situation if the subsidy is sufficiently attractive:

$$L(B - RP)/r_p > L(EC^*(1 - s) + OC) \tag{9.2}$$

To assess the impact to the NRM technology, the financial (private) and the economic (social) internal rates of return (FIRR and EIRR) can be derived. FIRR (r_r^*) is obtained by turning condition (9.2) into an equality, so that:

$$r_r^* = L(B - RP)/ L(EC^*(1 - s) + OC) \tag{9.3}$$

To assess the investment from the social point of view, all costs and benefits must be factored in. Assuming that EV and SV are known and the social discount rate is r_s, the R&D investment is justified if:

$$[L(B - RP) + L_s(EV + SV)]/r_s > [L(EC + OC) + RC + DC] \tag{9.4}$$

Note that the target area where environmental and social benefits are being realized may be different from the target area of the cactus/*Atriplex* alley-cropping programme. This is denoted by L_s in Eqn (9.4).
Turning condition (9.4) into an equality, the EIRR (r_s^*) is derived as:

$$r_s^* = [L(B - RP) + L_s(EV + SV)]/[L(EC + OC) + RC + DC] \tag{9.5}$$

However, failure to include EV and SV may indicate that the R&D investment is unjustified if:

$$L(B - RP)/r_s < [L(EC + OC) + RC + DC] \tag{9.6}$$

If the EV and/or SV are not known and the social rate of return is greater than r_s^L (let this lower bound be called the break-even rate of return),

$$r_s^L = L(B - RP)/(EC + OC + RC + DC) \tag{9.7}$$

then investment in the technology is justified. If r_s^L is greater than r_p then no subsidy is needed to obtain the optimal policy. If r_s^L is smaller than r_p and Eqn (9.4) holds then a subsidy is needed. From Eqn (9.2) the minimum subsidy s^* that will trigger adoption can be derived:

$$s^* = [(OC + EC - (B - RP))/r_p]/EC \tag{9.8}$$

Under the condition that there is no discrepancy between the private and the social discount rate, the subsidy is desirable from a society perspective if:

$$EV + SV > sEC \tag{9.9}$$

These simple formal deliberations allow identification of the factors that determine the private and social rates of return of the R&D investment, including extension. The rates of return are higher the smaller public and private investment, the greater technology dissemination in terms of planted acreage, and of course the higher its private and environmental benefits. The theoretical analysis provides some guidance on the empirical question of subsidies for agricultural development in marginal areas of the WANA region.

In the next two sections of this chapter, the methodology, data and results of the impact assessment of the NRM technologies in Tunisia and in Morocco are presented.

The Tunisia Case

The analysis of the Tunisia case[1] is based on data collected from the Zoghmar community, central Tunisia, a community included in a dry area characterized by less than 350 mm rainfall and periodic droughts. Agropastoral systems with a high degree of livestock and crop integration are the dominant production systems. In this area, spineless cactus was introduced in alley cropping as a new technology to overcome the problem of the existing low productivity and unsustainable traditional barley/fallow cropping system.

[1]The Tunisia case study was led by Véronique Alary.

Methodology

The methodology used in the case study followed a multi-faceted approach. First, impact indicators were developed and the interactive effects of the technology (including economic, agronomic and environmental effects) were assessed using a community-based, multi-period mathematical programming model. Second, the rate and degree of adoption were assessed from project records. Econometric analysis was carried out to identify the determinants of adoption, which facilitated projection of the adoption rate over the lifespan of the project. Third, the rates of return on investment at the farmer, aggregated project and society levels were calculated.

To quantify impacts of NRM one often has to go beyond the farm level and integrate the complexity of the socio-economic, biophysical and environmental conditions at community level. Moreover, analysis of the impacts of NRM technologies requires integration of the dynamic and heterogeneity effects at different time and geographical scales. The model used in this case study integrates the complexity of the activities at the farm and community level, the individual technical and socio-economic constraints that limit or condition the adoption and the common constraints due to social or economic arrangements in the community (Fig. 9.1).[2] The model is primarily being used to investigate the technology adoption among different types of producers. It is also a tool to simulate the impact of technological change (such as the introduction of the cactus in alley cropping) and/or policy change (such as the subsidies) on the level of adoption for each farm type; the model allows capturing of all the changes induced at the farm and community level in terms of new allocation of inputs, change of well-being (increase or not of income) and market strategies. The model also allows capture within the community of the effects between farms, such as changes in feed supply as a result of technology introduction. Through this, externalities of the technology, which may affect the economic conditions of non-adopters, are taken account of. However, the model has not been used in generating the impact data; instead, it was used to confirm the empirical observations on adoption.

The community model comprises several components. First, a set of typical farms had been identified by cluster analysis from household surveys. A typical farm is characterized by its different resource endowments (land, labour and capital) and its management (crop and livestock systems, family objectives). The second component of the community model is the community factor markets depicting farmers' interactions through exchanges of factors like non-storable fodder, exchange labour, land and even capital. The third component is the incorporation of external markets for input purchases and output sales. Finally, existing

[2]For a more detailed exploration of the community model the reader is referred to the background working paper of the Tunisia case study (Alary *et al.*, 2004).

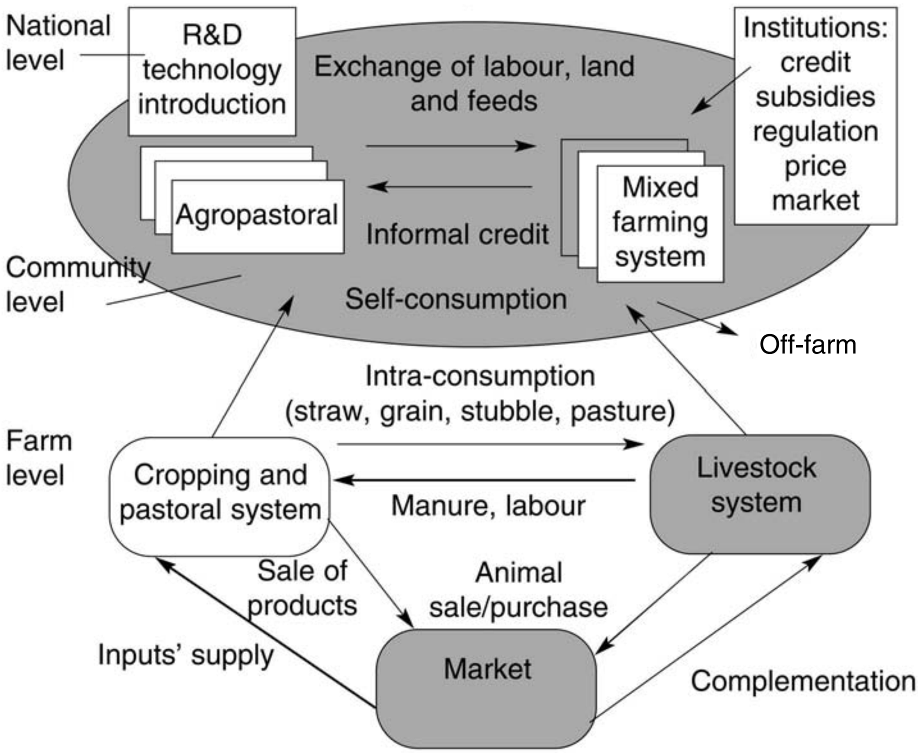

Fig. 9.1. Structure of the community model.

institutional arrangements for access to credit land and labour are included.

For the adoption and rate of return calculations, data were collected from a cross-sectional sample of farmers within the target area and a larger survey conducted within the M&M project and the FEMISE (Euro-Mediterranean Forum of Economic Institutes) project,[3] respectively. Through OEP (Office de l'Élevage et du Pâturage) monitoring, additional data such as the number of adopters and the planted area were collected. The sample farmers used were selected by stratified random sampling on the basis of an exhaustive survey in the community (317 households). The household surveys provided (unbalanced) panel data of 45 farm households from Zoghmar community, surveyed in 1999, 2002 and 2003. Household surveys included data from the plot, the farm and household levels. These data were used for the community model and for econometric analysis. Crop and livestock monitoring activities within the M&M project were performed in order to gather data on the farmers' practices and productive performances and to establish 'engineering production functions'.

[3]The FEMISE project (2003–2004) focused on the obstacles to technology adoption for small and medium farms in the arid and semiarid areas of Maghreb, funded by the European Commission and coordinated by ICARDA.

Supplementary data – including soil pH, soil moisture, soil organic matter content and biomass produced from cactus, crops and natural vegetation – were collected from on-farm trials of four types of cropping systems: (i) natural rangeland; (ii) barley without fertilizer use (farmer practice); (iii) alley cropping with natural vegetation between the alleys; and (iv) alley cropping cactus with barley between rows but no fertilizer for barley.

Results

Technology adoption

Adoption of cactus alley cropping is measured using two indicators: (i) the number of adopters in the total population; and (ii) the total area where the technology was introduced relative to the total potential area. At the community level based on the survey of 317 households, in 2002, the adoption rate was 30.6% with a degree of adoption of 29.7%. Using the sample of 40 households, results show that the adoption rate increased slightly from 37.5% to 40.0% between 2000 and 2004. A general pattern that can be observed is that adoption of cactus alley cropping increased with farm and herd size (Table 9.1). We also observe that farmers without animals adopted the technology. This could reflect the attractiveness of the technology in terms of new market opportunities but also because of the subsidies. Most of these farmers were also small-scale farmers who had recently lost their animals due to the drought years (1999–2002).

Table 9.1. Adoption of cactus alley cropping by farm and flock size. (From: Farm household surveys, *Mashreq/Maghreb Project Annual Report*, 2002.)

	Indicators according to farm size		Indicators according to flock size		
Farm size (ha)	Rate of adoption (%)	Degree of adoption (%)	Flock size (head)	Rate of adoption (%)	Degree of adoption (%)
> 20	61.3	43.20	> 50	46.15	36.83
10–20	41.0	24.56	25–50	38.18	35.31
5–10	34.5	23.54	15–25	36.07	26.99
1–5	12.6	14.51	<15	25.83	22.62
Landless	0.0	–	0	20.00	21.23
Total	30.6	28.99		30.60	28.99

Looking at the factors that affect adoption, it was found that non-adoption is mainly due to lack of land or livestock. Also, without market opportunities for cactus pads and fruits, the technology is unattractive for small-scale livestock keepers. The situation is different for large or medium herders, as they require large amounts of feed which cactus can supply, especially during drought periods.

In order to identify the determinants of the technology adoption, a censored regression was estimated.[4] Results show that older farmers with more land area and irrigation facilities were more likely to adopt the cactus alley-cropping technology. For large farms, cactus plantation is a way to extend cultivated land and increase fodder stock. The availability of irrigation allows farmers to increase their productivity on irrigated areas and reduce low-productivity cereal production on rainfed areas, and thus save family labour for irrigated areas. Thus cactus plantation is a way to maintain fertility of the rainfed land.

Further investigations of the technology adoption process were performed using the community-based simulation model. Simulations were carried out to assess the effect of the government subsidy. In the first, a subsidy package where the government pays for the costs of cactus establishment and buys the cactus pads at a fixed price was modelled. In the second, a reduced-subsidy package (limited to dissemination cost) was assumed.

It was found[5] that, without subsidy, three groups of farmers invested in the technology. These groups represent the better-off groups in the sample, with secure off-farm activity and some plots in the irrigated perimeter. This high level of adoption confirms the precedent result that irrigation is a determinant of adoption. On the other hand, in an uncertain environment and without any secure source of income, adoption without governmental support may not take place. In the scenario without direct subsidies to farmers but with the assumption of a high yield increase instead,[6] the model predicts a similar level of adoption to that with subsidies. These results may suggest that, even without direct subsidies, farmers may adopt the technology if they can be sure of significant productivity gains. On the other hand, in uncertain environments productivity effects are highly variable. Unless farmers have a good understanding of and confidence in the technology, governmental support may still be necessary.

Output increase and input saving

The first results of agronomic yields observed on a sample of five plots for each treatment show the possibility of achieving interesting performances in rainfed areas. The total barley biomass yield registered an increase of 57% resulting from an increase of 29% in herbs (weeds plus straw), but mainly the dramatic increase of grain yield (171%). However, changes in

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[4]For details the reader is referred to the detailed country-specific paper (Alary *et al.*, 2004).
[5]For details of the model results the reader is referred to the background paper (Alary *et al.*, 2004).
[6]The cereal yields estimated from on-farm trials in 2004 are the first measurements of the expected cereal yields with the technology in Tunisia and will serve as reference in this case study. These registered a 30% yield increase of cereals.

yields were highly variable, which may be due to the small sample size. On the natural rangelands, the average herbaceous biomass yield was estimated at 4.98 t/ha, compared with less than 3.3 t/ha without cactus.

These yield effects are a result of the microenvironment created by the cacti, which serve as 'wind breaks' that reduce water loss and increase soil moisture. Also, cactus plants play a role as a trap for several 'moving seeds', creating a niche for the emergence of valuable pasture plant species.

Introducing cactus in barley cropping does not have a detrimental effect, resulting from competition for available moisture and nutrients, on cactus total biomass (pads plus fruits) yields. Indeed, fresh biomass yields of total pads and fruits (cumulative of three consecutive years) are increasing. Also, these particularly high yields are the result of two consecutive favourable years.

The additional feed supply has caused a reduction of feed costs, which was around 13.2% per animal in 2001/02. The results are more mitigated between adopters and non-adopters of the technology. On average, the feed cost reduction in the period 2000/03 was about 0.16% with 1 ha of cactus. This is mainly due to the young age of the spineless cactus plantations; the majority of these plantations are not yet producing.

Return on investment

The FIRR and EIRR of the investment in developing and introducing the cactus/*Atriplex* alley-cropping technology show the financial and economic profitability of this NRM R&D project. The private rate of return takes the perspective of a farmer who invests in cactus establishment and who participates in the government programme. In the economic rate of return we account for full resource costs and the economy-wide productivity effects of the project. However, in the latter we do not take into account other social and environmental benefits due to the lack of data. Hence, the EIRR is actually the break-even rate of return because we did not value the environmental and social benefits but considered only the economic cost of the subsidy.

The productivity effects of the project were mainly estimated from the databases at the community level. These results were then applied to the total area, targeted by the year 2011 to reach an area of 96,000 ha. Hereby, a linear rate of diffusion was assumed. The lifespan of the project was assumed as a total of 22 years, the equivalent of the productive life of a cactus. A simplified yield–age function was assumed to calculate the aggregate productivity effects of the cactus over this period. Accordingly, a cactus plantation starts producing in the fourth year with 40% of the potential yield. Production goes up to 60% in the fifth year and 80% in the sixth year, reaching full production in the seventh year. Likewise, cereal yield increase and pasture biomass achieve their full effect with the technology in the seventh year.

The output of cactus included the yield of cactus pads and the additional barley yield for the barley cropping system or the biomass output for the rangeland system.[7] Hence, the reference systems used in this study are barley or rangeland without alley cropping. On the cost side, two types of research cost were estimated: (i) the development research cost incurred by ICARDA in collaboration with the national research institutes for the period from 1999 to 2003; and (ii) the adaptive research cost that corresponds to the minimum research cost before implementing the technology out of the study area, incurred by the Tunisian NARS. Furthermore, the cost of cactus establishment was included, calculated at 475 Tunisian Dinar (DT)/ha, out of which over 80% was taken over by the government's livestock and pasture programme (OEP).

To account for the uncertainty in the critical assumptions, the FIRR and EIRR were calculated using stochastic simulation by the @Risk program from Palisade, assuming Gamma distributions for the yields of barley, cactus and pasture, and normal distribution for the prices. We consider two scenarios for enhanced values of pads: (i) with market – the pads are sold at around 0.040 DT each; and (ii) without market – the pads are used as animal feed and are estimated with their energy equivalent (forage unit) compared with barley grain. These two scenarios were tested on marginal cereal land (cactus/barley system in Fig. 9.2) and on pastoral area (cactus/pasture system in Fig. 9.3).

Results demonstrate the effectiveness and economic feasibility of research investments in the NRM technology. In the barley cropping system, government subsidies and the introduction of a market for cactus pads have a strong effect on the internal rate of return (IRR), as demonstrated in Fig. 9.2. The mean FIRR is 20% without pad market and 40% with pad market, while the EIRR is 7% and 15%, respectively, for the two scenarios. We observe similar results for the cactus pasture system. Hence, under the current conditions and considering the riskiness in the IRR, subsidies will be required to assure technology adoption.

The higher IRRs in the case of pad markets show the expected profitability of the technology if there were public efforts to develop a market for pads. But until now, due to the young age of the plantations in the zone and the recent long drought that has affected all farms, farmers prefer to keep their pad production *in situ* and privilege a security strategy.

Considering the hypothesis on climatic change, pasture land produces around 370–500 UF/year.[8] With a unit price of 0.17 DT/UF, the product is estimated from 62.9 to 85.0 DT/ha. The observed yield of pasture in alley cropping reveals a production of 4.98 t/ha or 1245 kg dry matter (DM)/hectare in a good year, compared with 825 DM kg in natural

[7]Note in this analysis that the market value of cactus fruits is not considered even if they are used for self-consumption. In the area considered in this study, fruits are not sold. Only children collect small quantities of fruits and sell them by the roadside to buy some items needed for school.

[8]UF = forage unit based on the energy of 1 kg barley grain.

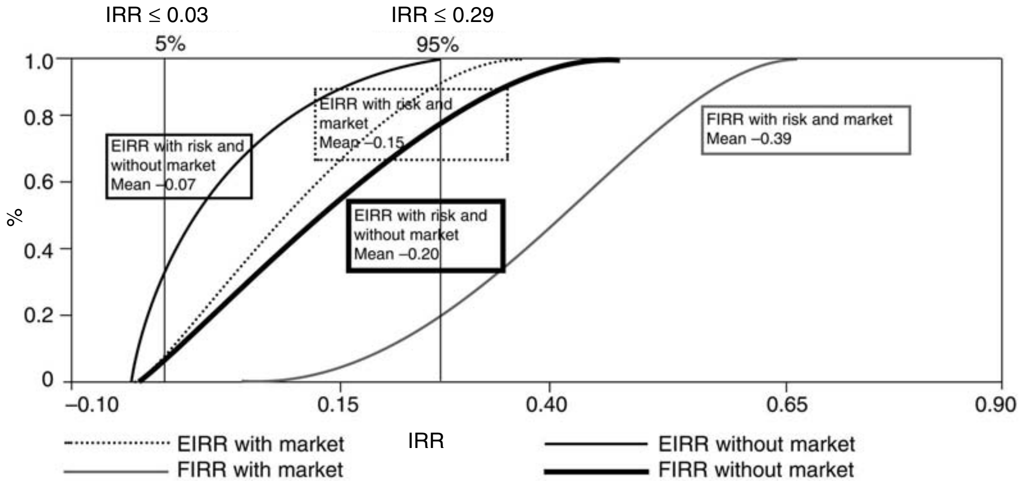

Fig. 9.2. Internal rates of return for the cactus/barley system. FIRR, financial/private rate of return; EIRR, economic/social rate of return.

rangelands. Thus we obtain an increase of 50% of biomass on pastureland thanks to the NRM technology.

Aggregate environmental impacts

In addition to the productivity effects of the cactus technology there are additional environmental benefits. Planting cactus on marginal lands improves soil characteristics. Monitoring of organic matter, carbon, phosphorus and potassium contents of soil samples showed that planting cactus improves soil nutrients, especially for organic matter, carbon and phosphorus, with relative increases of 350%, 450% and 100%, respectively.

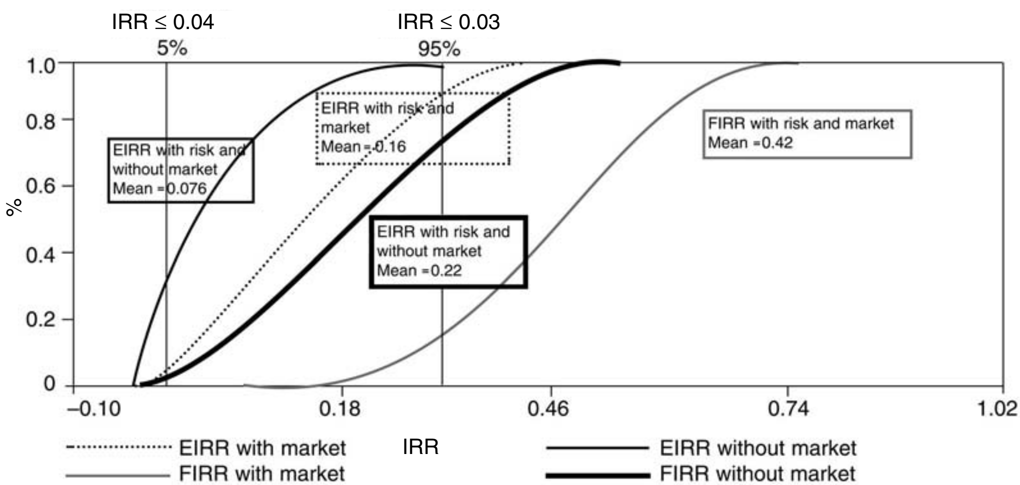

Fig. 9.3. Internal rates of return for the cactus/pasture system. FIRR, financial/private rate of return; EIRR, economic/social rate of return.

These increases follow the same trend as marginal land cropped to barley without fertilizer application. Cropping barley between cactus lines reduces the amount of nutrients, and values recorded are very similar to those obtained with eroded rangeland cropped or not with barley. It can be assumed that the nutrients made available by cactus planting are used by the barley crop, and may explain, in addition to 'wind breaks' and 'niche' effects, the significant increase in cereal yields.

In addition we observe two opposite effects of cactus: (i) soil enrichment in potassium; and (ii) soil exhaustion in calcareous. Cactus is known to be rich in calcium and quite poor in potassium. The increase of active calcareous with barley is explained by the low content of calcium in barley products compared with not only cactus, but also herbaceous species in the rangelands.

The Case of *Atriplex* Alley Cropping in Morocco

The case of Morocco[9] is similar to the Tunisia case in many aspects but also has some important differences. One of them is the NRM technology itself, where the alley crop is *Atriplex* species. Research recommended the use of nummularia species due to its palatability, summer growth, resistance to biotic and abiotic stresses and richness in nitrogen. *Atriplex* is different from cactus because no fruits can be harvested. It is considered a protein supplement for livestock fed on poor native rangeland or low-quality roughages, whereas cactus is taken as an energy source. *Atriplex* is a source of fermentable nitrogen and minerals that help the rumen make efficient use of crop residues and grazed natural pasture, whereas cactus is rich in water. The feeding value of *Atriplex* varies from 0.35 to 0.45 feed units/kg DM, while cactus pads make a palatable feed high in energy.

The background situation in Morocco is similar to that of Tunisia, i.e. the continuation of the existing cereal-based production systems has resulted in increasing soil erosion and declining soil fertility. Thus, the introduction of an NRM technology in the form of *Atriplex* alley cropping is expected to offer the chance to bring the system back to a sustainable path and maintain the productivity of the traditional crop–livestock integration. The case also offers an excellent opportunity to assess investments in NRM in the dry areas and thus provides a good complementary case to the Tunisia study.

The study was carried out in the Irzaine area, located in the rural commune of Tancherfi, in Oujda Province of Morocco. In this community the total arable land is 5800 ha. The agroecological conditions in the study site are typical for the dryland areas of Morocco, characterized by poor soils under shifting cultivation with a barley/fallow system, where the alley-cropping system with *Atriplex* was introduced in 1999 by the

[9]This case study is led by Kamel Shideed.

Research and Development Project of Taourirt-Tafouralet, funded by the International Fund for Agricultural Development. The project aims to improve rangeland productivity through the introduction of fodder shrubs (mainly *Atriplex*) in pastoral zones and the provision of in-kind subsidy (establishment costs, including land preparation, provision of transplants, one or two irrigations during the first year and labour cost) to farmers to enhance the adoption of *Atriplex* plantation. The most frequent crops are cereals such as soft wheat, durum wheat and barley. Alley cropping with *Atriplex* is mostly done with barley or oats.

Methodology

The methodology used for estimating the biophysical and economic effects of the NRM technology is the application of a bio-simulation model called the 'Soil Change Under Agro-Forestry' (SCUAF) model (Young and Muraya, 1990). SCUAF was calibrated using data from field trials and farm household surveys of traditional barley/farming and *Atriplex* alley cropping in the communities of the study area.

This model has been applied to similar cases (e.g. Menz and Grist, 1996; Trewin, 1997; Young *et al.*, 1998). The advantage of the model is that it links relevant parameters such as soil texture, soil and topsoil depth and agroclimatic factors to long-term productivity of crops. SCUAF is a deterministic model designed to predict the effects of various tree/shrub and crop combinations on the characteristics of specific soils (fertility and erosion) and commodity outputs. No explicit production function is used to determine commodity outputs, only values given for annual net primary production or biomass growth in terms of kilograms of DM per hectare per year for specific soil fertility. Erosion is calculated in terms of kilograms per hectare per year from a formula incorporating climate, soil erodibility, slope, and cover crop and tree factors.

The biophysical module of the SCUAF model generates yield and erosion outcomes for both cropping systems. These physical measures are combined with a simple economic module to generate the revenues over time. Using the opportunity costs of capital as the discount rate and applying the @Risk procedure allows the calculation of cumulative distribution functions of the net present value (NPV) and IRR of the NRM technology.

Application of this modelling approach to the case study in Morocco will provide location-specific information on erosion and its cost in terms of lost production and losses in land productivity. While SCUAF does not directly include an economic component, this can be attached to the ecological model. The economic model used in this study is designed to run in parallel with SCUAF. The two models are linked via the yield data, which are generated by SCUAF and then transferred to the economic model. However, there have been various ways in which location-specific environmental impacts have been aggregated on some probabilistic basis to higher levels of aggregation (Trewin, 1997). Extrapolating the farm-level impacts to obtain economy-wide (macro-level) and social impacts can be done by incorporating aggregates of productivity and soil erosion changes into a general equilibrium model. Unfortunately, such a general equilibrium model is not available at the moment for Morocco, and thus macro-level analysis was not done. Instead, a simpler extrapolation method is explored in subsequent sections to elicit the potential adoption of *Atriplex* alley cropping in similar agroecologies at the national level.

The farm survey data, conducted in 2004, were used to assess factors affecting the adoption of *Atriplex* alley cropping and to document the *ex post* impact of the technology on barley production, changes in the use of feed resources, flock size and feeding costs. Farmers' costs and prices were combined with the yield results of the SCUAF model to estimate NPV and IRR. The SCUAF model was calibrated and validated using soil sample surveys taken in 2004 and the results of research trials conducted during 1999–2002 in the project area. The conceptual framework is depicted in Fig. 9.4.

To document the adoption status of the alley-cropping technology in terms of the rate and degree of its adoption and factors affecting the adoption process, a survey of 100 farmers was conducted in the study area in

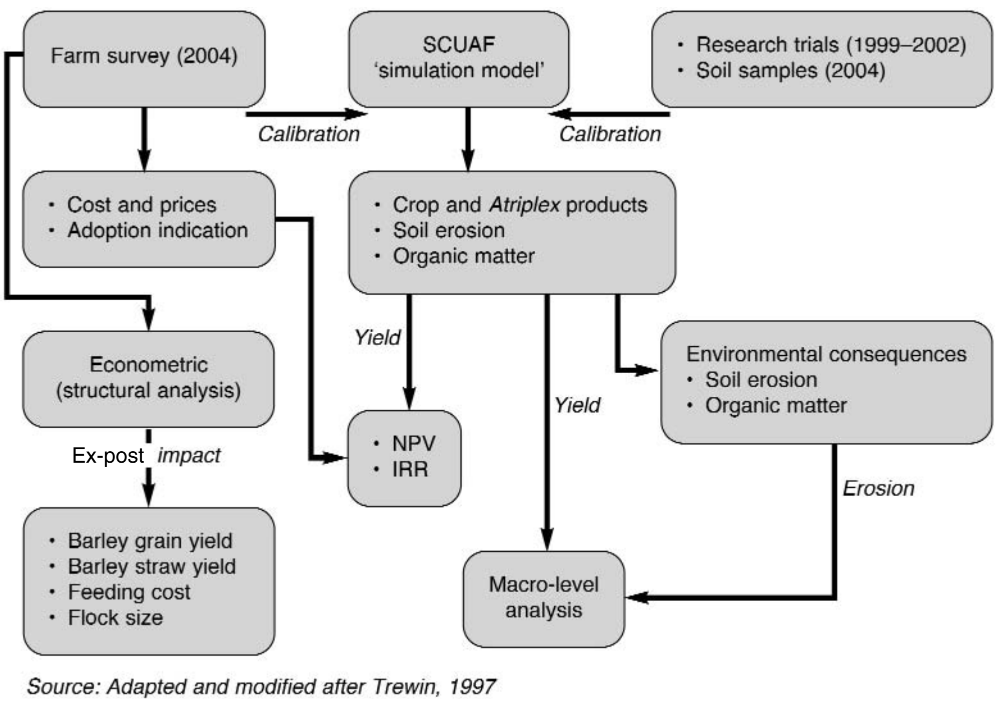

Fig. 9.4. Conceptual framework for assessing the impact of alley cropping. SCUAF, 'Soil Change Under Agroforestry' model; NPV, net present value; IRR, internal rate of return. (Adapted and modified after Trewin, 1997.)

March 2004. A stratified sampling approach, based on type of participation in the programme, and proportional allocation (in relation to the total population in each stratum) were used in selecting the sample farms. Based on extension records the sample was stratified into adopters and non-adopters of the NRM technology, by type of enterprise (specialized crop production, specialized livestock production, integrated crop and livestock) and by place of residency (within and outside Irzaine community). The adoption and use of *Atriplex*, as soil conservation technology, can be modelled as a decision-making process and be decomposed into three stages (Garcia, 2001): (i) perception of soil erosion problem (perception); (ii) decision to adopt the soil conservation technology (adoption); and (iii) investment in *Atriplex* alley cropping (conservation). Both 'adoption' and 'conservation' components of the decision-making process are determined in this analysis. Accordingly, two dependent variables were defined to correspond to each component. The 'adoption' dependent variable was constructed as a dichotomous variable, taking a value of 1 if the farmer is an adopter of the *Atriplex* alley cropping, and 0 otherwise. The 'conservation' dependent variable was constructed as a censored variable for the proportion of farmland under *Atriplex* plantation, with double limits (a lower limit equal to zero for non-adopters and an upper limit of 100% for adopters). The adoption regression equation can be estimated using Logit and Probit models, while the conservation regression can be estimated by a Tobit model. The three models were estimated using farm survey data to study the adoption of the *Atriplex* alley cropping, where the probability of adoption depends on the characteristics of the technology, farming systems and farmers.

Results

Adoption

Data from extension records reveal that, out of a total targeted area of nearly 6290 ha, *Atriplex* alley cropping had been adopted to an area of 1650 ha until 2002/03. This represents nearly 24% of the land in the targeted Irzain community. However, it must be noted that adoption often means partial rather than full adoption. On average adopters devote nearly 27% of their farmland to *Atriplex* alley cropping. Farm survey data indicate that about 20% of adopters use the technology on up to 20% of their land, while about one-third allocate up to 40%, and only 18% devote most of the land to the new technology. Overall the area planted in *Atriplex* has increased by 6% annually since 1999/2000 and, in 2004, the proportion of farmers who had adopted the technology had reached 33%. Among the adopters only a small percentage of farmers (7%) adopted the technology without subsidy. All farmers, regardless of their size and social capital, have equal opportunity to participate in the programme and be granted the subsidy provided that they allocate part of their land to *Atriplex* plantation. However, intensity of adoption increased as farm size increased. The subsidy is a key determinant for the area planted in *Atriplex*. Regression analysis results imply that the net impact of the subsidy was to increase the area devoted to *Atriplex* plantation by 79%.[10]

The farm survey also demonstrates the importance of farm size in the adoption of the *Atriplex* alley cropping. All large farmers (average farm size of 77 ha) adopted the *Atriplex* technology.[11] However, only about half of the small farmers (< 20 ha), which is the majority of farmers in the study area, did so.

Flock size is another important factor affecting the technology adoption. All farmers who do not own small ruminants (12% of the sample farms) did not adopt the technology. Nearly half of small-flock farmers (less than 40 heads) adopted alley cropping, and the majority of the medium-flock farmers (40–80 head) adopted the technology. Meanwhile, almost all large-flock farmers (average flock size of 104 head) have adopted the *Atriplex* alley cropping. Regression analyses of Logit and Probit models confirmed these results. Their estimated coefficients show that policy subsidy, farm size and flock size are the three main factors affecting the probability of *Atriplex* adoption, with the subsidy having the major positive and highly significant impact on the likelihood of technology adoption.

Economic impacts

The benefits from *Atriplex* are the increase in barley and biomass production and the reduction in the costs of animal feed. As a secondary benefit, the flock size of small ruminants increases. Among the environmental benefits, reducing soil erosion and improvement in soil organic matter must be considered. Due to lack of data no economic evaluation has been performed of environmental benefits.

The methodology to assess the productivity effects of the technology was to estimate a Cobb–Douglas production function in order to separate the effects of the technology from those of other factors. Results are presented in Table 9.2. It is shown that *Atriplex* significantly increased the straw yield, but no significant effect could be confirmed for grain yield although the regression coefficient has the expected sign. Changes in barley grain and straw yields obtained from SCUAF simulation model were used in the benefit–cost analysis.

The technology effect on flock size was accounted for by comparing the number of productive animals (ewes) between 2001 and 2004 for adopters and non-adopters. Results indicate that sheep-owners who adopted the technology increased their flock sizes on average by 136%. Non-adopters also increased the number of productive animals, but only by 89%. Care needs to be taken in interpreting this increase, since the

[10]Detailed regression results are presented in the country-specific paper (Shideed *et al.*, 2005a).
[11]No dropouts among adopters were observed or anticipated because, once the land is planted with *Atriplex*, the farmer cannot drop the technology as *Atriplex* is a perennial plant.

Table 9.2. Estimated coefficients of barley grain and straw production functions[a,b].

Explanatory variable	Grain production function	Straw production function
Intercept	–2.43 (–0.70)	1.44 (0.34)
Log seeds (kg)	0.20 (0.80)	0.30 (0.92)
Log machinery (h)	0.12 (1.03)	0.17 (1.11)
Log farm size (ha)	0.29 (1.42)	0.02 (0.06)
Log farmer age (years)	0.73 (1.30)	0.36 (0.52)
Log labour (h)	0.02 (0.97)	0.04 (1.29)
Log fertilizers (kg)	–0.10 (–2.15)*	–0.05 (–0.79)
Log farmer education (years)	0.04 (0.18)	–0.03 (–0.12)
Atriplex dummy (0, 1)	0.16 (0.38)	1.09 (2.01)*
R^{-2}	0.54	0.59
F statistic	7.63**	8.93**

[a]Dependent variables are log grain yield for grain production function and log straw yield for straw production function.
[b]Numbers in parentheses are the estimated *t* statistics' level of significance.
*Significant at 5% level; **significant at 1% level.

difference between adopters and non-adopters can only partly be attributed to *Atriplex* plantation. To assess this influence, a regression model was specified relating changes in flock size to explanatory factors, including the adoption of alley-cropping technology, and estimated using an OLS estimation procedure. The estimated equation is presented in Table 9.3 (regression 1). A Heckman procedure was used to estimate the specified model and Mills ratios were used as mechanisms to correct and to estimate the impact of the technology on the flock size. This was done by replacing the *Atriplex* dummy variable by Mills ratios and re-estimating the model (regression 2).[12] The estimated coefficient of the dummy variable of 0.220 (regression 2) implies that alley cropping increased the number of small ruminants by 25% among technology adopters compared with the non-adopters (Shideed *et al.*, 2005b).

The third component of the benefits that were attributed to *Atriplex* plantation is the reduction of feed costs attributable to the technology. The use of *Atriplex* in animal feeding has resulted in a reduction in the consumption of sugarbeet pulp, wheat bran and barley grain, which are used as livestock feed. On the other hand, the consumption of oat grain has increased. The quantity of sugarbeet pulp fed by adopters is less than that of the non-adopters by 89%. Likewise, the average wheat bran and barley grain consumption of adopters are less than those of non-adopters by 70% and 42%, respectively. On-station trials have shown that the use of *Atriplex* to supplement barley grain in animal feeding has reduced barley grain consumption by 50% compared with farmer practice, which

[12]The authors would like to greatly thank the Standing Panel on Impact Assessment's anonymous referees for their comments related to sample selection bias.

Table 9.3. Estimated regression equation of small ruminants' flock size[a,b].

Explanatory variable	Regression 1	Regression 2
Intercept	0.895 (0.93)	1.686 (1.218)
Log farm size (ha)	0.525 (5.87)**	0.439 (3.08)**
Atriplex dummy (0, 1)[c]	0.267 (1.44)	0.220 (0.62)
Log farmer age (years)	–0.110 (–0.46)	–0.081 (–0.277)
Log barley grain feed (kg)	0.258 (3.51)**	0.267 (2.781)**
Log straw feed (kg)	0.160 (2.37)**	0.159 (1.928)*
Log wheat bran feed (kg)	0.082 (1.09)	0.045 (0.525)
Log sugarbeet feed (kg)	0.208 (1.03)	0.138 (0.469)
Log oat grain feed (kg)	–0.048 (–1.06)	–0.067 (–1.22)
R^2	0.61	0.58
R^{-2}	0.57	0.51
F statistic	15.47**	8.90**

[a]Dependent variable is log flock size of small ruminants.
[b]Numbers in parentheses are the estimated *t* statistics.
[c]*Atriplex* dummy variable was replaced by Mills ratios in regression 2 following the Heckman procedure. Feed variables in these equations are production plus purchased feed. Thus, their inclusion with the technology dummy is not expected to create a simultaneous-equation bias. In addition, the models were re-estimated using 2SLS and the estimates did not improve on the efficiency of the estimated coefficients.
*Significant at 5% level; **significant at 1% level.

is predominantly barley grain.[13] This provides further support to the findings of this analysis.

To assess the effect of *Atriplex* on feed a regression approach was used to isolate the net impact of the technology adoption on the consumption of available feed sources. The estimated Cobb–Douglas equations are presented in Table 9.4. The estimated coefficients of the technology dummy variable imply that adoption of this technology significantly reduced the consumption of sugarbeet, wheat bran and barley grain compared with non-adoption. The reduction in feed cost was calculated at 52% for small farmers, whereas that of the large sheep owners was 70%, while the medium sheep owners experienced the lowest reduction in feeding cost of 11%.[14] On average, reduction in feeding costs is estimated at 33%.

To translate the physical effects of the *Atriplex* technology, like increasing the biomass output of *Atriplex* into financial benefits for

[13]El Mzouri, E.H. (2004) The alley cropping system: a way for drought alleviation and environment protection for the livestock/barley based farming systems of the semi arid areas of Morocco. Unpublished manuscript.
[14]Sheep owners with medium flock size had lowest cost reduction because they are the more diversified and most efficient group, already producing at the minimum cost level. This is supported by the fact that actual feed cost (per head) data are the lowest among other producers.

Table 9.4. Estimated regression equations for the use of alternative feed resources[a,b].

Explanatory variable	Sugarbeet pulp	Barley grain	Wheat bran	Cereal straw	Oat grain
Intercept	0.247 (1.21)	0.725 (1.37)	0.751 (1.35)	0.615 (1.03)	–0.910 (–0.97)
Log flock size (head)	0.067 (1.08)	0.525 (3.51)**	0.171 (1.02)	0.410 (2.36)*	–0.275 (–0.98)
Log barley grain (kg)	0.055 (1.28)	–	–0.008 (–0.07)	0.234 (1.92)*	–0.132 (–0.67)
Log cereal straw (kg)	–0.056 (–1.47)	0.188 (1.92)*	0.162 (1.57)	–	0.465 (2.77)**
Log wheat bran (kg)	0.151 (4.02)**	–0.007 (–0.07)	–	0.185 (1.57)	0.161 (0.86)
Log oat grain (kg)	–0.008 (–0.31)	–0.043 (–0.67)	0.057 (0.86)	0.188 (2.77)**	–
Log farm size (ha)	–0.037 (–0.63)	0.135 (0.89)	–0.05 (–0.31)	–0.328 (–1.97)*	0.472 (1.80)
Log sugarbeet pulp (kg)	–	0.368 (1.28)	1.112 (4.02)**	–0.470 (–1.47)	–0.157 –0.31)
Atriplex dummy (0, 1)	–0.206 (–2.09)*	–0.305 (–1.17)	–0.642 (–2.42)**	0.033 (0.11)	0.496 (1.08)
R^2	0.37	0.41	0.38	0.29	0.16
R^{-2}	0.32	0.35	0.33	0.23	0.09
F statistic	6.73**	7.82**	7.00**	4.64**	2.16*

[a]Feed variables are production plus purchased feed.
[b]Numbers in parentheses are the calculated values of *t* statistics.
*Significant at 5% level; **significant at 1% level.

farmers, the *Atriplex* biomass needs to be valued applying the opportunity cost principle. Thus the 'substitute valuation' method has been used, assuming that *Atriplex* is a perfect substitute for barley, which is a market product[15] (FEE, 2002).

Programme costs

As in the Tunisia case, research investment in the M&M project for Morocco and the national in-kind contribution were accounted for. The R&D period for the introduction of *Atriplex* in Morocco lasted from 1991 to 1999. The dissemination period can be specified as taking place from 1999 to 2015. On the cost side, the ICARDA research attributable to Morocco, as well as the costs of conducting adaptive research by the Moroccan NARS, has been accounted for in this analysis. Likewise, dissemination costs of 2700 Moroccan Dirham (MD)/ha paid by the development programme in the form of in-kind subsidy (which covers the establishment costs of land preparation, transplants, irrigation and labour) were added. All other related operation costs for the research and dissemination periods, represented by the actual national spending made by the Institut National de la Recherche Agronomique research centre in Oujda, were included in the cost estimates.

Internal rates of return

Benefit–cost analysis was used to calculate the financial and economic rates of return of the investment in developing and disseminating *Atriplex* alley-cropping systems in Morocco. The analysis requires definition of the stream of benefits and costs over the life span of the project. With regard to the latter it needs to be pointed out that the impact analysis is in fact a mixed *ex post*/*ex ante* assessment conducted for the period 1992–2015. During this period the adoption rate was assumed to be constant at 6% per year. By the end of the project period a total of 2340 ha at the programme level and 350,000 ha at the national level would be reached. Extrapolation beyond the programme area targets similar ecological zones in north-east and central Morocco, assuming an adoption rate of 6% without subsidy. Both research and dissemination costs (including the subsidy provided by the development projects) were included in the calculation of the costs and benefits of alley cropping. Benefit streams include the values of *Atriplex* biomass and increased barley production (which is mainly increased in straw yield). It was assumed that the additional barley production due to the *Atriplex* does not affect the market price of barley. Hence only producers' welfare was considered.

Based on the above information, the FIRR and the EIRR were calcu-

[15]The price of barley grain in the project area was estimated at 2×DM. The substitution rate of *Atriplex* with barley was obtained as the ratio between the digestible DM of *Atriplex* and the digestible DM of barley, estimated at 0.35. The value of non-traded good was calculated by multiplying the price of the marketed good in the study area by the technical substitution rate, resulting in an *Atriplex* biomass value of 0.70 DM/kg.

lated using stochastic simulation by the @Risk program from Palisade, assuming Gamma distributions for barley yields and *Atriplex* biomass. These estimates are presented in Table 9.5 and their cumulative distributions are depicted in Fig. 9.5.

Table 9.5. Assumptions and results of rates of return calculations.

	Programme area (community level)		Beyond the programme area (national level)	
Item	IRR (%)	Cost components	IRR (%)	Cost components
FIRR	50	• Opportunity costs	90	• Opportunity costs • Establishment costs
EIRR	25	• Opportunity costs • R&D costs • Subsidy (establishment costs)	48	• Opportunity costs • R&D costs • Establishment costs

IRR, internal rate of return; FIRR, financial (private) rate of return; EIRR, economic (social) rate of return.

Results clearly support the effectiveness and economic feasibility of research investments in *Atriplex* technology. The EIRR is 25% at the community level, which will increase to 48% at the national level due mainly to larger *Atriplex* area. Provision of establishment cost by the development programme would double the IRR from the private point of view (FIRR = 50%). The cumulative distribution of IRR shows that nearly 55% of the time a farmer would have a negative IRR if he pays all costs. This will decrease to 47% if only opportunity cost of land is included (FIRR at the programme level). At the national level, the possibility of having negative IRR will become 48% and 36% for EIRR and FIRR, respectively. These results show that the likelihood of obtaining a positive IRR increases with the expansion of the *Atriplex* alley cropping system beyond the community level, and with the provision of establishment cost by the development project.

Impacts of Atriplex *alley cropping on the environment*

The *Atriplex* technology generates positive environmental effects. The SCUAF model explained above allows some of these effects to be quantified, although no economic valuation has been carried out. Results of simulations show that *Atriplex* plus continuous barley and *Atriplex* plus barley in rotation with fallow systems reduce soil erosion considerably and stabilize soil losses after about 10 years compared with farmers' conventional practice of barley/fallow cropping. However the system does not quite achieve the levels reached by agroforestry systems (Young, 1990).

Another environmental benefit of *Atriplex* is the time change of soil

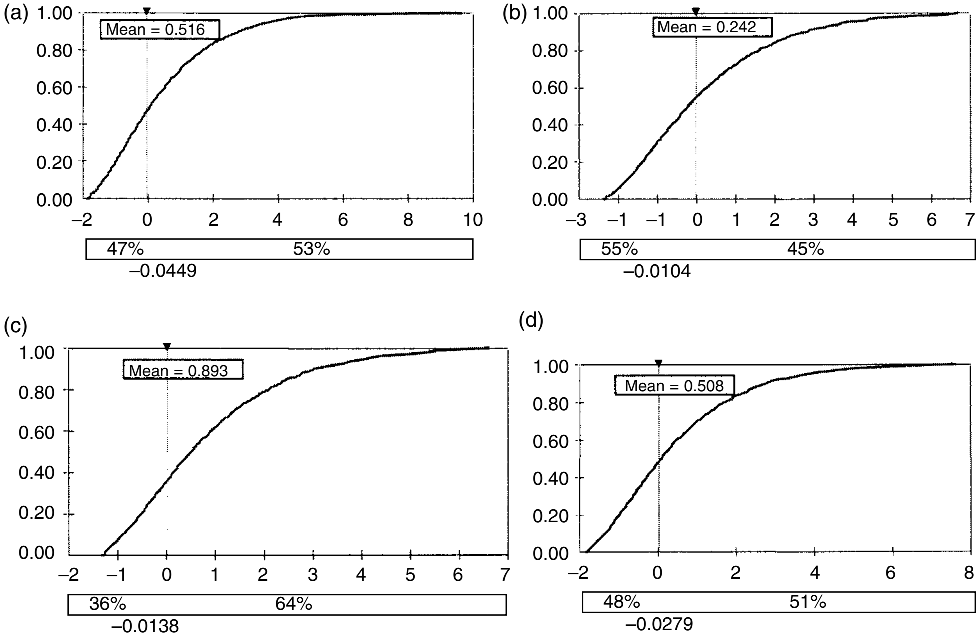

Fig. 9.5. Cumulative distribution of internal rates of return (IRR) under risk: (a) financial (private) rate of return (FIRR) under risk at the programme level; (b) economic (social) rate of return (EIRR) under risk at the programme level; (c) FIRR under risk at the national level; (d) EIRR under risk at the national level.

organic carbon under the alley-cropping system. Continuous barley with *Atriplex* alley cropping can help to maintain the level of soil organic carbon during this same period. However, adding fallow periods to this system can help to sequester additional organic carbon.

Using the opportunity cost approach, the monetary value of the environmental benefits of *Atriplex* can be calculated (Dung, 2001). The benefits of soil erosion were defined as the difference between the present values of the cumulative net financial returns of *Atriplex* alley cropping and barley/fallow systems. The difference was calculated at 22.2 million MD (or US$2.2 million). Meanwhile, the difference in soil loss is 17 t/ha over the study period, implying that the cost of soil erosion is about 1288 MD/ha. Considering the estimated marginal effect of the subsidy on the probability of adopting *Atriplex* of 0.33 suggests multiplication of this probability by per-hectare net benefits of 12,886 MD/ha. This yields a value of 4252.4 MD/ha, which is well above the subsidy of 2500–3000 MD/ha provided to farmers by the development project to disseminate the technology. Based on these indicative calculations the subsidy can be justified due to the environmental benefits generated by the NRM technology.

Lessons Learned

There are important lessons that can be drawn from the case studies presented in this chapter, which pertain to two countries that have similarities as well as differences.

First, the development of the cactus/*Atriplex* alley-cropping technology has been successful as it has encouraged public investment in agriculture in the dry areas. Such public investment has resulted in increasing the productive capacity of these households' main natural asset, which is land. Through this the livelihoods of rural communities will improve on a sustainable basis. The benefits of the technology are expected to encourage wide adoption by farmers in similar agroecological zones in Morocco and Tunisia, as well as in other countries. Cactus/*Atriplex* alley cropping can be considered a technology that can help to mitigate drought through increasing and stabilizing the fodder reserve, and therefore the technology can be an effective risk-hedging strategy for the dry areas.

The analysis of both country cases has shown that investments in these environments can be economically justified, if appropriate technologies are being introduced. Results of the two country studies provide evidence of the effectiveness of alley-cropping systems in increasing barley straw yield (and, to some extent, barley grain yield), biomass production, reducing feed costs through reduction of purchased feeds, maintaining livestock production during drought seasons, improving soil organic matter and reducing soil erosion. On the other hand, the financial analysis showed that the rates of return for farmers to invest in these soil conservation technologies are often not high enough to trigger technology adoption. Therefore, incentives provided by development projects are important to stimulate technology adoption. Such subsidies can be justified because the EIRR is satisfactory if these costs are accounted for. In addition, there are environmental benefits. In the case of Morocco, conservative valuation shows that the environmental benefits are justifying the additional investment the government is making.

Comparing this analysis with evidence provided by previous research on investment in agriculture in the dry areas (cited examples are in Algeria, Iraq, Jordan, Mexico and Syria, where alley cropping is demonstrated in farmers' fields) in the WANA region (*Mashreq/Maghreb Project Annual Reports*, 1998–2002), another lesson emerges. Most previous public investments have targeted irrigated areas. Thus, the results of this study will encourage policy makers and donors to invest in marginal areas.

The third lesson is that assessing the impact of NRMR requires methodologies and approaches that go beyond the conventional and biophysical models and that capture the holistic nature of the problem through integrating economic, environmental and social aspects. For example, dynamic and recursive programming and econometric models proved to be useful tools that facilitate the generation of appropriate indicators to assess the *ex post* impact of NRMR.

Assessing the long-term environmental impacts of natural resource technologies often is best done through the use of simulation models, which are not always readily available. For example, the SCUAF model originally developed for agroforestry had to be calibrated for the *Atriplex* case. It is recommended that some research efforts should be focused on the development of efficient biophysical models, adapted to marginal lands in the dry areas.

There are also issues that need more attention in future studies. For example, results of this study showed that land tenure is an important factor affecting the adoption of alley cropping. Almost all adopters are of privately owned land tenure. The long-term benefits of conservation of alley cropping may be irrelevant to farmers whose planning horizon is limited by insecure land tenure. Accordingly, this technology is recommended for private and secured land tenures because the dissemination is difficult for common rangeland areas. Results of this study would help policy makers to make decisions leading to investments in productive assets, like the drought-resistant *Atriplex*/cactus shrubs, rather than on feed subsidy.

Future research on the impact of NRM R&D requires the setting up of baseline data collection in project and control areas at an early stage of project implementation, in order to apply more advanced methods of analysis to evaluate the environmental benefits.

Farmers' decisions to adopt new farming practices are complex, as farmers apply a range of decision criteria to meet multiple objectives, subject to their production possibilities and constraints. In low-input farming systems, the adoption decisions of farmers may be heavily influenced by the possibility of negative returns in any year, even though the expected NPV is positive in the long term (Nelson and Cramb, 2001). Access to credit to compensate for negative or low returns in establishment years may be essential for farmers' survival.

Empirical studies to assess the impact of NRM technologies on productivity are often faced with the problem of identification. That is, the pure effect of adoption may be severely correlated with factors that affect the adoption decision. Under such situations there is a potential for 'selection bias', and failure to account for the self-selection bias would result in biased estimates of the productivity gain of adopting the NRM technology.

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10 IWMI. Assessing the Outcome of IWMI's Research and Interventions on Irrigation Management Transfer

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A key recommendation following from the Earth Summit held in Rio de Janeiro in 1992 was that water management should be decentralized and farmers and other stakeholders should play a more important role in the management of natural resources, including water (United Nations, 1992). Even before the Earth Summit, countries with sizeable irrigation sectors were transferring the management of irrigation systems from government agencies to water users' associations (WUAs) or other local non-governmental organizations (NGOs). This phenomenon became known as irrigation management transfer (IMT). IMT entails the partial or complete transfer of irrigation management rights and responsibilities for an irrigation (sub)system from government to farmers' organizations (FOs), WUAs, other non-governmental agencies (including the private sector) or local government agencies. The growing interest in IMT stemmed in part from the assumed efficiency and productivity gains due to farmer participation and decentralized management of irrigation systems. It was also assumed that the transfer of management responsibility to local organizations would improve the accountability of the irrigation service to farmers, improve the cost-effectiveness of service provision, motivate farmers to invest more in maintaining irrigation systems and, ultimately, make irrigation systems and irrigated agriculture more sustainable. In addition, shortfalls in government funds to finance the recurring costs of irrigation and the inability to recover costs from farmers further encouraged many developing countries to adopt IMT reform programmes.

Despite widespread interest in irrigation management turnover, however, there was very little documentation about the processes used and the impact of the transfer in terms of efficiency and productivity gains. Many policy makers, development agencies and WUAs were searching for viable management options, but were constrained by lack of experience and information. Further, there was uncertainty and some scepticism about the effects the changes would have on management performance. As a result, there was an urgent need for a systematic, comparative assessment about the range of approaches being used, constraints to implementation and the impacts on performance of transferring irrigation management to local institutions. There was also a growing demand for information on supportive legal, policy and regulatory frameworks, and about the suitability of different turnover processes in differing political, social and economic settings.

To respond to this need, the International Water Management Institute (IWMI), formerly the International Irrigation Management Institute (IIMI), launched a series of projects at the global, regional and national levels that reviewed and analysed past IMT experiences and impacts. As a research institute, IIMI/IWMI's role was not to advocate IMT but rather to objectively assess the extent to which the institutional innovation enhanced the performance and sustainability of irrigation schemes. Based on its research, IWMI then developed a series of 'products', including policy and operational recommendations to assist governments and local institutions that had decided to pursue IMT. Complementing the country-specific recommendations, IWMI also produced international public goods in the form of generic guidelines for IMT in general and for the establishment of WUAs in particular. We describe IWMI's contributions in each of these areas below.

Overview of IWMI's Irrigation Management Transfer Research Products

The first phase of IWMI's research on IMT focused on the analysis of past experiences and the resultant impacts from irrigation turnover. Although IMT was occurring, there had not been any systematic study of the process and outcomes. Thus, IWMI sought to fill this knowledge gap through in-depth overviews and case studies conducted at the regional scale, beginning with Asia and Latin America and thereafter assessing the implications for Africa. Further work was done at the household scale in terms of examining the gender- and poverty-related impacts of IMT. A summary of the research products from this first phase of IWMI IMT research can be found in Table 10.1.

The results from the various case studies suggested that, in general, the impact of IMT in Asia and Latin America was mixed. Furthermore, IWMI research found that even the success cases may not easily be replicated in Africa without a substantially modified approach. However, despite these uncertainties in terms of the benefits of IMT globally, IMT continued and continues to be a major component of institutional reform programmes worldwide. Accordingly, IWMI moved into a second phase of IMT research at the policy and operational levels, in which the Institute became more actively involved in drawing from past lessons in an effort to promote more effective and sustainable implementation of

Table 10.1. Case studies on irrigation management transfer conducted by the International Water Management Institute.

Case study region/type	Reference
Overviews	Vermillion and Johnson (1995), Vermillion (1997, 1998)
Latin America	Vermillion and Garcés-Restrepo (1996, 1998), Johnson (1997), Kloezen *et al*. (1997)
Asia	Mandal and Parker (1995), Bandaragoda and Memon (1997), Bandaragoda (1999), Brewer *et al*. (1999), Murray-Rust *et al*. (1999), Samad and Vermillion (1999), Vermillion *et al*. (2000), Naik *et al*. (2002)
Africa	Samad *et al*. (1995), Abernethy *et al*. (2000), Shah *et al*. (2001, 2002)
Gender and poverty studies	Athukorale and Zwarteveen (1994), Zwarteveen (1994, 1995a, 1995b, 1995c, 1997), Zwarteveen and Neupane (1996), Jordans and Zwarteveen (1997), Buechler and Zapata (2000), van Koppen (2002), van Koppen *et al*. (2002)

IMT programmes in the future. The most substantial policy-level involvement was in Sri Lanka, through the Irrigation Management Policy Support Activity (IMPSA) in the early 1990s. IMPSA was a pioneering effort to institutionalize IMT. The project was launched in collaboration with the then Ministry of Lands, Irrigation and Mahaweli Development and the US Agency for International Development (USAID), which funded the activity together with IWMI core support. Beyond the IMPSA project, IWMI was also involved in IMT policy development in Nepal, and has offered assistance to the governments of Cambodia and South Africa to support their irrigation management reform programmes.

At the operational level, IWMI participated in two major action-research projects in Pakistan and Sri Lanka to support the implementation of IMT policies. In Pakistan, IWMI launched four pilot studies between 1995 and 2000 to establish FOs in the Punjab and Sindh provinces. In Sri Lanka, the IMPSA project led to the development of a USAID/Government of Sri Lanka-funded watershed management project entitled 'Shared Control of Natural Resources' (SCOR), which promoted stakeholder participation in watershed management. IWMI also worked with the governments of Indonesia and Nepal in the implementation of IMT reform programmes. Unlike Pakistan and Sri Lanka, however, IWMI's role was confined to monitoring and evaluating the transfer processes.

Finally, to capitalize on the lessons learned from past IMT experiences and to make the information more broadly available, IWMI and its partners have developed a series of generic decision-making and operational guidelines for IMT and the establishment of WUAs. In terms of general IMT reform, IWMI and the Food and Agricultural Organization of the United

Nations (FAO) produced a handbook entitled *Transfer of Irrigation Management Services: Guidelines* (Vermillion and Sagardoy, 1999). The publication draws upon IWMI and FAO's worldwide experience with IMT. The manual offers guidance to policy makers, planners, technical assistance experts and other stakeholders as to the conditions under which a country should adopt an IMT programme and the principles and methods for effective design and implementation. More recently IWMI, together with the Scientific Information Centre/Interstate Commission for Water Coordination in Central Asia, with support from the Swiss Agency for Development and Cooperation, published guidelines for establishing WUAs (IWMI/SIC IWC, 2003) and an accompanying manual on social mobilization and institutional development (ul Hassan and Nizamedinkhodjaeva, 2003) for use in Central Asia. Unlike the IWMI/FAO guidelines, which are globally applicable, these publications were prepared to address specific IMT reform issues faced within the Central Asian context.

Study Objectives and Methodology

The objective of IWMI's research on IMT was to improve the global knowledge base on IMT experiences and impacts. Given the results of IWMI's studies and the fact that IMT was continuing despite its mixed track record, IWMI commenced a complementary set of projects to capitalize on the lessons learned from the past to improve IMT reform processes in the future. Through this latter set of projects IWMI developed decision-support tools, guidelines and, in some cases, became involved in on-the-ground implementation. As noted above, IWMI's role was not to advocate irrigation turnover, but to objectively assess the results of past IMT experiences for the benefit of future decision making and action. Thus, the focus of the analysis conducted in this chapter is to measure, to the extent possible, the outcomes of IWMI research on the overall IMT knowledge base and on IMT policy and operations in specific countries where IWMI has played a direct role in shaping or implementing IMT reform.

To carry out this assessment, we have organized our analysis around three hypothesized areas of influence from IWMI IMT-related activities, namely:

- Raised awareness of new research.
- Employment of improved policies.
- Employment of improved techniques.

These three outcomes draw from a larger typology developed by IWMI to assist its researchers and management in tracking and measuring research outcomes and impacts. The typology, schematically represented in Fig. 10.1, focuses on seven broad outcomes that IWMI, together with its partners, can reasonably anticipate, track and measure. A set of vehicles for achieving impact as well as a set of sample indicators and measure-

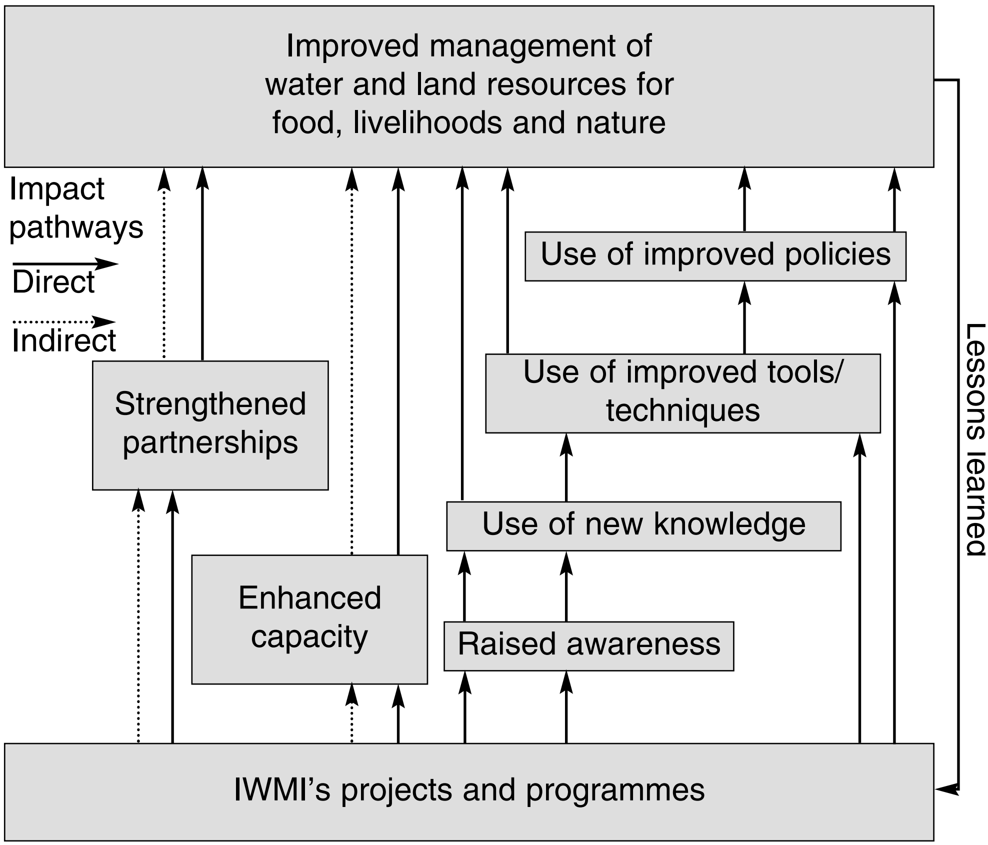

Fig. 10.1. Outcome typology schematic.

ment techniques are included in the typology.

The typology thus serves as a planning and monitoring tool to assess progress along the impact pathway from project outputs towards the achievement of the Institute's overarching mission of improved management of land and water resources for food, livelihoods and nature. The typology, and Fig. 10.1, also distinguishes between direct and indirect pathways. With the former, IWMI research outputs raise awareness about new knowledge and offer policy makers and resource managers better tools to improve their decision making; the latter enables IWMI's stakeholders to draw on partnerships, networks and strengthened capacity which, in turn, may foster broader application of IWMI's research results.

Before describing the specific methodological framework applied in this analysis, we must first emphasize the reasons for focusing on research outcomes rather than impacts, i.e. for not conducting a cost–benefit analysis with a rate of return on IWMI's research investment. First, for research activities in general, there are long and variable time lags between the actual research project and a measurable change in related policies and practices (Alston *et al.*, 1995; Smith, 1998). While IWMI's IMT research began in the early 1990s, most of the key recommendations and interventions date back just 5–7 years. Second, establishing the attribution between IWMI's research and the adoption of their findings by policy makers is difficult (see e.g. Ryan, 2004). Third, an assessment of the economic benefits is limited by the lack of baseline data and resources available to collect them. As discussed in the conclusions below, IWMI is now addressing this latter issue for its research portfolio in general; and, for the past IMT projects in particular, a larger, formal impact study in the future may allow us to overcome this challenge.

Even in advance of a formal cost–benefit analysis, it is none the less useful to hypothesize the counterfactual situation for IWMI's IMT research programme as a whole. As noted above, prior to IWMI's involvement no comprehensive study had been conducted to document the past successes and failures of IMT reform. We posit then that by offering an impartial analysis of past IMT successes and failures at a relatively early stage, followed by informed recommendations and decision support tools, IWMI has helped to reduce the transaction costs associated with IMT planning and implementation and increased the likelihood of longer-term success of IMT reforms. While we are unable to prove this assertion, the outcome analysis below provides some insights on the influences of IWMI's IMT research to date. In the future, once sufficient time has passed since IWMI's interventions, we hope that a more in-depth impact assessment could be conducted to formally test this hypothesis.

The methodology employed for this case study draws on the general IWMI outcome assessment framework described above and utilizes a host of quantitative and qualitative measurement techniques to assess the influence of IWMI's research on IMT knowledge, policies and actions to date. We begin with an internal review of the knowledge generated by IWMI on IMT through research publications, workshop proceedings and paper presentations. We then attempt to measure the demand for, use and estimated implications of IWMI IMT research at various scales and by various users. Proxy indicators, such as bibliometric and web site download (webmetric) analyses, are used to measure the demand for IWMI IMT research products. More direct indicators, such as feedback from structured questionnaire surveys, are used where IWMI's involvement was more explicit through action research or actual project implementation. We summarize in Table 10.2 the techniques employed for each of the three outcome types tested. Specific details of each step in the methodology and the resultant outcomes are provided in the next section.

Results and Discussion

For each of the three outcome types, we describe below the results of our assessment of IWMI contributions to IMT knowledge and application through the projects and related outputs summarized above. For raised

Table 10.2. Summary of techniques employed to test each of the three outcome types.

Outcome type	Target audience	IWMI vehicle to achieve impact	Measurement tool employed
Raised awareness of new IMT research	Academics, policy makers	• IWMI IMT publications	• Bibliometric/webmetric assessments
Employment of improved IMT policies	Policy makers	• IWMI presentations/workshops on IMT • IWMI IMT publications (indirect) • IWMI action-research projects (direct)	• Internal and external source documents • Qualitative feedback • Demand for IWMI assistance on IMT from international organizations and national governments • Feedback via structured survey
Employment of improved IMT techniques/institutions	Canal irrigators, WUAs, local NRM groups	• Pilot studies to establish WUAs • SCOR project implementation • Development of IMT and WUA guidelines	• Adoption of IWMI recommendations through WUA pilot studies • Adoption of SCOR interventions • Feedback via structured survey • Webmetrics and other feedback on IMT/WUA guidelines • Demand for IWMI assistance

IWMI, International Water Management Institute; IMT, irrigation management transfer; WUA, water users' association; NMR, natural resource management; SCOR, Shared Control of Natural Resources (project).

awareness, we utilize proxy indicators to broadly estimate the demand for and usage of IWMI's IMT research products. For the other two categories – employment of improved policies and employment of improved techniques – we limited our assessment to those regions/countries where IWMI has played a relatively large role in IMT policy reform and implementation.

Raised awareness of new research

As described above, IWMI has developed a large body of literature on IMT. The literature ranges from initial assessments of IMT as a method to improve the management of agricultural water resources (e.g. Vermillion, 1997), to gender analysis (e.g. van Koppen, 2002) and the impact of IMT on poverty (e.g. van Koppen *et al.*, 2002), to evaluations and assessments of past IMT experiences and, from that, related implementation and policy recommendations (e.g. Kloezen *et al.*, 1997; Svendsen and Nott, 1997; Vermillion and Garcés-Restrepo, 1998; Vermillion *et al.*, 2000). To assess the extent to which IWMI's IMT literature has resulted in raised awareness within the scientific community, we conducted a bibliometric assessment using Google Scholar™ (Beta) (http://scholar.google.com/), as well as an analysis of web site downloads of IWMI's IMT research outputs. Google Scholar covers a wide variety of publications, from peer-reviewed journal articles to technical reports and other non-peer-reviewed publications. As a relatively new search engine, gaps still remain in availability of articles on Google Scholar. However, as of July 2005, 50% of IWMI's 251 IMT outputs were registered on the site. For these 126 outputs, the Google Scholar search documented 529 total citations, of which 65% were from non-IWMI authors (see Table 10.3). The largest number of citations was of IWMI's Research Report Series and peer-reviewed journal articles. The single most cited publication was IWMI's IMT synthesis report (Vermillion, 1997), which received 25 citations from non-IWMI authors.

An assessment of downloads from the IWMI web site indicated potentially even broader demand for IWMI IMT research. For this analysis, we first reviewed raw statistics of web site downloads[1] from the IWMI web site for the period January 2000 to July 2005 (the period for which web statistics are available from the CGNET[2]). During this period, 18 IIMI/IWMI Research Reports and five IWMI Working Papers on IMT, dating from 1996 to 2003, ranked within the top 50 monthly downloads from the IWMI website, with more than 29,000 downloads of these 23 publications in total during the period.

[1]Publications on IWMI's website are stored as Adobe™ Portable Document Format (PDF) files. The number of downloads indicates the number of times the file was successfully copied by a user. If an error occurred during the transfer, that transfer is not counted.

[2]CGIAR (Consultative Group on International Agricultural Research) Network Services International (CGNET), a privately held company that provides Internet, e-mail and other web services to the CGIAR Centres and others.

Table 10.3. Summary of Google Scholar™ citations of irrigation management transfer (IMT) publications of the International Water Management Institute (IWMI).

Publication category	IWMI IMT outputs			Citations		
	Total	Registered in Google	% Registered	Total	By non-IWMI authors	By non-IWMI authors (%)
IWMI research reports	21	19	91	141	107	76
Journal articles (peer-reviewed)	24	22	92	114	81	71
Workshop papers and proceedings	79	29	37	88	49	56
IWMI Short Report Series	15	15	100	50	24	48
Other IWMI Research/Policy Brief Series	69	23	33	59	30	51
Books and book chapters	16	9	38	36	22	61
Monographs, technical reports, case studies	12	7	58	36	29	81
IWMI project reports and unpublished reports	12	2	16	5	3	60
Journal articles (non-peer reviewed)	3	0	0	0	0	0
Total	251	126	50	529	345	65

A more detailed analysis of web site downloads was conducted for the period October to December 2003. For this time period the CGNET was able to provide ISP addresses, country and city information of IWMI's web users. During this 3-month period, over 1100 downloads[3] of IWMI IMT Research Reports (853) and Working Papers (283) were recorded from institutions and individuals in developed countries (70%) and developing countries/countries in transition (30%). Although most of the ISP addresses were generic (e.g. commercial search engines or state telecom lines), we were able to document over 170 downloads from universities and research organizations, approximately one-third of which were from developing countries/countries in transition.

While there are a number of caveats associated with webmetrics, it can serve as an indication of current and potential 'usage impact' (Brody *et al.*, 2006). In fact, recent research suggests a correlation between downloads of academic articles and subsequent citations. For example, in an analysis of physics and mathematics literature, Brody *et al.* (2006) found a significant correlation (0.4) between citations and article downloads. A positive correlation between citations and downloads was also found in two studies of papers published in the *British Medical Journal* (Perneger, 2004) and the *Journal of Finance* (Pinkowitz, 2002). A further benefit of webmetrics is that it can capture (albeit imperfectly) other forms of usage apart from publications, such as use by practitioners (Pinkowitz, 2002; Brody *et al.*, 2006). While more research is clearly required to determine whether these findings can be translated to the field of natural resource management (NRM), webmetrics coupled with feedback from the actual downloaders themselves may serve as useful early indicators NRM research impact.

Employment of improved policies

To test the influence of IWMI's IMT research on the employment of improved policies in Sri Lanka and Nepal,[4] we utilized both direct and indirect measurement techniques. In Sri Lanka, we examined the outcomes of the IMPSA project, which was implemented in the early 1990s. According to IWMI sources, following the IMPSA project, the government amended the Agrarian Services Act to provide legal recognition to FOs. The government also amended the Irrigation Ordinance to legalize the role of FOs in all major government-owned irrigation schemes. Further, IWMI project documentation and later follow-up studies indicate that specific policy reforms proposed by the IMPSA project have been gradually applied over the past decade. For instance, the IMPSA recommendation to restructure the Mahaweli Authority of Sri Lanka, which manages

[3] All downloads from IWMI are excluded from this figure.

[4] We focus here on IWMI's policy interventions in Sri Lanka and Nepal only as it is too early to assess the outcomes of IWMI's more recent IMT policy projects in Cambodia and South Africa.

the country's largest multi-purpose water resources development project, is currently being implemented. More importantly, in 2000 the government took action to implement a major IMPSA recommendation to establish a National Water Resources Council to formulate 'a comprehensive water policy that looks at water in a holistic way, to put water to the most beneficial use at the least cost, so as to conserve it without degrading the environment, sustaining it for future generations as well' (IIMI, 1992; Nanayakkara, 2003).

IWMI's other major policy-level intervention was in Nepal, where the Institute assisted with the country's IMT reform programme. Since IWMI's involvement in the mid-1990s, many of IWMI's recommendations have been incorporated into Nepal's new Irrigation Regulation 2056. Specific references to IWMI recommendations within the Regulation include (IWMI, 2000):

- Government support for building capacity of WUAs (Clause 5, Section 2).
- Promotion of record-keeping by WUAs (Clause 5 and 6).
- Government assistance in regulating water quality control, environmental protection and security of water rights (Clause 5, 12, 16, 21, 24, 39, 40, 43 and 45).
- Retention of significant resource contributions to invest in operation and maintenance (O&M) (Clause 9).
- Provisions for forming joint committees (WUAs and government agency) to fix irrigation service fees in irrigation systems (Clause 26).
- Establishing user fees that take into account O&M costs (Clause 28).
- Applying variable rather than constant flat rate fee systems (Clause 28).

Additionally, on the basis of IWMI and others' research findings related to gender and IMT, Nepal's national irrigation policy now officially supports the role of women farmers in water management by stipulating that female farmers constitute at least one-third of WUA membership (IWMI, 2000).

Employment of improved techniques

To assess the adoption of IWMI-supported IMT techniques by canal irrigators, WUAs and community resource organizations, we examined the outcomes of IWMI-led action-research projects in Pakistan, Sri Lanka and Indonesia. We also reviewed the demand for and use of global and regional IMT guidelines to which IWMI has contributed. Measurement tools for this outcome category included qualitative feedback, structured questionnaire surveys and webmetrics.

Outcomes from IWMI pilot studies on water users' associations in Pakistan

For the Pakistan study, we examined the progression of WUAs in two provinces following IWMI's pilot interventions. According to IWMI researchers in Pakistan, since IWMI's pilot FO programmes in Sindh, the provincial government has adopted the IWMI model in the three study canals. Furthermore, the lessons from the pilot study have helped in the formation of IMT policy elsewhere in the province (W.A. Jehangir, Senior Agricultural Economist, IWMI, Lahore, Pakistan, personal communication, 2004; Y. Memon, Community Development Specialist, Hyderabad, Sindh Province, Pakistan, personal communication, 2005). Developments in this area are now continuing as part of a larger IMT reform process in the entire Sindh irrigation system that began in late 1995 with the support of the World Bank. As part of this, the Sindh Assembly approved an Act which shifted responsibilities for management of the irrigation and drainage infrastructure from the centralized provincial Irrigation and Power Department to the Sindh Irrigation and Drainage Authority (SIDA), area water boards and to FOs. To carry forward the reform process, the Sindh Government has set a goal of establishing over 1300 FOs in 14 canal systems. As of April 2004, SIDA had registered 196 FOs and management responsibilities had been transferred for 154 of these. As these FOs are established, IWMI has been asked to assist SIDA in related capacity-building activities (W.A. Jehangir, personal communication, 2004).

In the case of Punjab, following IWMI's intervention and the actual transfer of irrigation management responsibilities in May 2000, the Punjab Irrigation and Drainage Authority (PIDA) announced the Pilot Area Water Board in Lower Chenab Canal East. As a result, work is now in progress to transfer irrigation management responsibilities to 22 FOs. As in Sindh, IWMI has again been approached to assist PIDA in the capacity building of these FOs (W.A. Jehangir, personal communication, 2004). While we cannot directly attribute the developments in Sindh and Punjab to IWMI interventions, the direction of change is consistent with IWMI recommendations. Further, the fact that IWMI is again being asked to assist in future IMT activities is a strong indication of the use of IWMI's research findings by policy makers.

Outcomes of institutional interventions in the Shared Control of Natural Resources project

While not a specific IMT project per se, the SCOR project was a complementary research effort that drew on IWMI's IMT knowledge products. Through its IMT research, IWMI focused extensively on collective action by farmers for irrigation management. A key institutional innovation under the SCOR project was to extend that concept to community/user participation in other areas of NRM. The specific institutional interventions promoted in the SCOR project were:

- Strengthening the capacity of resource groups to participate in NRM.
- Improving tenure arrangements for land and other resources to achieve both increased production and conservation of the natural resource base.

- Strengthening the capacities of government agencies, NGOs and private sector organizations in NRM.
- Improving the coordination and linkages between state agencies, NGOs and other stakeholders involved in the management of natural resources.

To test the outcomes of the SCOR institutional interventions, we utilized key informant interviews, focus group discussions, informal interviews with farmers and a structured questionnaire survey involving 187 farmers. In contrast with the Pakistan pilot project, the SCOR institutional interventions, which as in Pakistan were aimed to promote greater local control over NRM, appear to have been much less successful following the conclusion of project activities. Based on the comments received from the interviewees, with the exception of a few sites, the sustainability of the SCOR institutional interventions was negligible. For example, while two-thirds of the survey respondents are currently members of resource user groups, only 4% are members of the resource user groups established by the SCOR project. The reasons given are manifold but related more to implementation deficiencies than to a lack of intrinsic worth of the institutions themselves. Many of the interviewed SCOR farmers claimed for instance that they did not have the right understanding of the objectives of the project from the very beginning, and considered the project more of a short-term aid operation than a longer-term participatory research and extension project. A second reason given for the lack of continuity of the SCOR-created institutions was the drastic change in the administration of FOs following the change in government in 2001. Finally, several farmers explained that the longer-term goals (and potential benefits) of the SCOR project were difficult to balance with short-term household subsistence needs.

The study found that the villages that have continued to implement the SCOR institutional innovations are largely characterized by severe water shortages and, perhaps as a result, tend to have strong leaders of the local FO. Benefits in terms of farmer credit and other institutional gains appear to have continued for these villages. However, it must be noted that in these villages the organizations are not performing according to the original planned or stated functions of SCOR.

One notable success recorded in the interviews relates to the role of the resource user organizations in one of the project study watersheds. Prior to the SCOR project, the farmers in this region had no legal right to use water from the Mahaweli system. The results of the field survey suggest, however, that following the establishment of the SCOR-sponsored resource user organizations, the farmers were able to lobby and become the legal users of the Mahaweli irrigation system. As a result, the survey respondents indicated that the cropping pattern and intensity have changed, the cultivated area has increased and the demand for shifting cultivation has significantly declined. Hence, this may be a case where the knowledge generated by IWMI’s IMT research may have indirectly led to improved water productivity and a more equitable access to resources. However, no quantification or economic valuation of these effects could be carried out in the context of this study.

Results from IWMI's irrigation management transfer interventions in Indonesia

As noted above, IWMI's involvement in Indonesia at the operational level was largely limited to monitoring and evaluating the transfer process. IWMI was specifically involved in four pilot projects in two provinces through a technical assistance programme funded by the Asian Development Bank. To assess the outcomes from IWMI's interventions, we circulated a structured questionnaire survey to ten government agencies, research organizations and WUAs involved in the pilot projects. Of the eight respondents, five indicated that the recommendations made by IWMI during the pilot studies had influenced subsequent implementation of IMT policy in Indonesia. Specifically, the respondents highlighted the influence of IWMI recommendations concerning the involvement of farmers in IMT planning and implementation, the need for continued agency support for WUAs and FOs following irrigation turnover and the importance of supporting legal frameworks to strengthen and empower WUAs.

Employment of IWMI guidelines on water users' associations

A final test of IWMI influence at the operational level involved an assessment of the demand for and use of IWMI-authored guidelines on IMT and the establishment of WUAs. We focused this analysis on the IWMI/FAO IMT guidelines (Vermillion and Sagardoy, 1999) and the two reference documents on the establishment of WUAs in Central Asia (IWMI/SIC IWC, 2003; ul Hassan and Nizamedinkhodjaeva, 2003). To gauge the influence of these guidelines we utilized FAO publication statistics, web downloads of the Central Asia guidelines, and circulated a structured questionnaire survey on the use of both the FAO/IWMI and WUA guidelines for Central Asia.

According to FAO statistics, a total of 5700 copies of the IWMI/FAO guidelines have been produced and distributed since 1999. This includes 4100 in English with an additional 1600 in Spanish, French and Russian (G. Munoz, Water Resources Development and Management Service, FAO, personal communication, 2005). Further information on the use of these guidelines is provided below.

In contrast with the IWMI/FAO guidelines, IWMI's guidelines on the establishment of WUAs in Central Asia were disseminated primarily through the IWMI web site. The results of our web site analysis indicate that, since the release of the guidelines in March 2004, they have consistently ranked in the top ten downloads each month, with downloads of the English language version averaging around 475 per month.[5] We

[5]The WUA guidelines have also been translated into Russian, Tajik, Uzbek and Kyrgyz.

understand that the popularity of the English language version, as opposed to the local language translations, stems from the fact that many international NGOs are now utilizing the guidelines with their local partners. For example, the IWMI/Central Asia office has been contacted by several NGOs and other development agencies, including the Agency for Technical Cooperation and Development (ACTED), Mercy Corps and the German Agency for Technical Cooperation, who have confirmed their application of the guidelines in Tajikistan, Uzbekistan and Azerbaijan (M. ul Hassan, Office Director, IWMI, Tashkent, Uzbekistan, personal communication, 2004). ACTED in particular noted their appreciation of the ease with which the guidelines can be understood and applied and the utility of local language translations (I. Gulomjanov, Deputy Coordinator, ACTED Ferghana Valley, Tajikistan, personal communication, 2005). In addition, the Asian Development Bank has drawn from IWMI's WUA guidelines to prepare WUA training manuals and has further recommended IWMI guidelines to the Agha Khan Foundation's Microfinance and Social Development Support Project and to CARE/Tajikistan (M. Shafique, Consultant, Asian Development Bank, personal communication, 2005). A recent external review of the project also highlighted the Social Mobilization and Institutional Development guidelines as one of the major achievements of project 'for establishing WUAs and CWCs, for conflict resolution, and for addressing legal issues' (PA Government Services, 2005, p. v).

As both sets of guidelines are practical in nature we also circulated a structured questionnaire survey to government agencies, universities and NGOs in eight countries[6] in South, Central and South-east Asia where IWMI has undertaken IMT research activities to assess awareness and application of the IMT and WUA guidelines. Specifically, the questionnaire recipients were asked about their awareness of IWMI's guidelines and whether they had used the guidelines for implementing IMT programmes in their respective countries. A total of 44 questionnaires were distributed with 26 respondents from seven countries. Half of the respondents were aware of the IWMI/FAO IMT guidelines and nearly all respondents in Central Asia were aware of the WUA and Social Mobilization and Institutional Development guidelines.

The survey results indicated that the guidelines were particularly popular in Central Asia, where IMT is a more recent policy intervention in helping transition from state-dominated to more participatory forms of irrigation management. For these seven respondents, all but one had utilized one or more of the guidelines for training, operational and/or reference purposes. Further, the respondents indicated that they had used the guidelines to establish over 250 WUAs themselves and had recommended the guidelines to nearly 55 other institutions, basin authorities and individuals. The specific benefits of the guidelines as noted by the

[6]The eight countries are Sri Lanka, India, Nepal, Pakistan, Indonesia, Uzbekistan, Tajikistan and the Philippines.

respondents from Central Asia and elsewhere include:

- Improved understanding of institutional reform and farmer participation in irrigation management (66.7%).
- Improved project design and management (50%).
- Improved quality of work (50%).
- Facilitation of the establishment of effective WUAs (33.3%).
- Enhancement of the effectiveness of the project implementation (33.3%).
- Reduced operational cost (16.7%).

Although the results draw from a small sample size, this feedback suggests that the use of and benefits from the guidelines have not been insignificant.

Conclusion and Lessons from IWMI Research on Irrigation Management Transfer

During the last two decades many governments have taken steps to transfer irrigation management responsibility to farmer or other local organizations. This action has been based on the premise that involving farmers in irrigation management decisions will improve the accountability of the irrigation service to farmers, result in more effective service provision, motivate farmers to invest more in maintaining irrigation systems and, ultimately, make irrigation systems and irrigated agriculture more sustainable. Since the early 1990s, IWMI has tried to inform this process by documenting past experiences and impacts of IMT in a number of countries throughout the world and, based on the results of this research, offering guidelines, policy advice and technical support for future IMT decision making and application.

In this chapter, we have described both the background of IWMI's IMT research and related interventions and attempted to assess the outcomes from these contributions. The analysis did not focus on the overall success of IMT, as that was indeed the objective of the first phase of IWMI's IMT research programme. Instead, the chapter concentrated on IWMI's influence on the global IMT knowledge base as well as on IMT policy and operational decisions. More specifically, the analysis focused on three hypothesized outcomes of IWMI IMT research; namely, raised awareness, improved policies and improved techniques. The methodology applied in this task drew from a broader conceptual framework and typology developed by IWMI for NRM outcome assessment and utilized a range of direct and indirect measurement tools.

While we did not apply cost–benefit analysis to quantify IWMI's impact, for the reasons noted above, the application of a range of direct and indirect measurement techniques suggests an overall positive contribution from IWMI to the IMT concept and its application. The results of the bibliometric and webmetric analyses suggest a large and continuing demand for IWMI research products on IMT. Direct and indirect data sources also indicate that IWMI policy and operational-level interventions have, in general, contributed positively to IMT decision making and action both nationally, through action-research projects, as well as regionally and globally, through the development of generic IMT guidelines. Finally, continued demand for IWMI involvement in IMT action research serves as an important indicator of IWMI's past contributions. Requests for IWMI IMT and participatory irrigation management research and training activities were already noted above with regard to Cambodia and Pakistan. In addition, the state governments of Andhra Pradesh and Maharashtra in India recently requested IWMI to help address certain second-generation problems associated with IMT. In South Africa as well, IWMI, at the request of the national government, is providing policy-level support as the country reforms its water laws and institutions.

Finally, in addition to analysing the contributions of IWMI's IMT research, this case study has also highlighted important programmatic and operational lessons. Programmatically, the results of the SCOR outcome assessment suggested a need for IWMI to better clarify its position *vis-à-vis* its partners on the research–development continuum. While the assessment of SCOR's technical interventions yielded somewhat more positive results, the overall performance of the SCOR project was substantially lower than the standards IWMI set out to achieve. The interviews carried out as part of the outcome assessment suggested that some of the reasons behind the poor uptake of the SCOR interventions included a need for stronger capacity building for the newly created institutions and a clearer understanding of the overall goals and objectives of the project. As mentioned above, IWMI played a somewhat unusual role in this particular project, focusing more on knowledge application than its traditional knowledge-generation function. Since the SCOR project, and as part of the IWMI Strategic Plan 2004–2008, IWMI has endeavoured to define more clearly the roles for itself and the complementary roles of NGOs and other development organizations with whom it partners. Specifically, the Strategic Plan sets out a plan for the Institute to develop stronger relationships with appropriate development partners (national agricultural research and extension systems, local NGOs, international NGOs) who can draw from the knowledge generated by IWMI and its partners and better enable its application.

Operationally, the chapter offers important insights for future outcome and impact studies. One key lesson is that proper *ex post* evaluation requires careful planning and monitoring before, during and after the project life cycle. The difficulties encountered in the case study in accessing baseline information have thus reinforced IWMI's decision to promote more informed outcome and impact planning and monitoring as part of its project management system. Second, this evaluation has attempted to demonstrate the value of outcome analysis as an intermediary step towards impact assessment. As noted above, there are inherently long and variable time lags between research and broader uptake. Tracking project outcomes through a variety of qualitative and quantitative means, however, allows research organizations to assess at a much earlier stage the general direction of project influence, which in turn can be used to inform future programmatic decision making long before adoption studies are possible. This chapter has demonstrated several techniques that may be applied in future outcome studies, and has suggested additional tools worthy of further examination including webmetrics and Internet surveys. While formal impact assessments may not be feasible for each and every project, some level of outcome analysis in every project supplemented by a representative sample of impact assessments will allow research institutes, such as IWMI, to more effectively monitor the influence of their past projects and programmes and, from that, more effectively design future projects and programmes for the benefit of their stakeholders.

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11 CIFOR. The Sustainability of Forest Management: Assessing the Impact of CIFOR Criteria and Indicators Research

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International and popular concern about the wide-scale loss and degradation of forest areas, especially in tropical countries, emerged in the 1980s and, coupled with the Brundtland Commission's calls for 'sustainable development', resulted in forest issues receiving considerable attention at the 1992 Rio Earth Summit (the United Nations Conference on Environment and Development, UNCED).

UNCED precipitated a plethora of national and international and regional initiatives aiming to promote sustainable forest management (SFM). SFM, criteria and indicators (C&I) and forest certification became issues commanding great attention at national and international levels and were a prominent topic for the United Nations Intergovernmental Panel on Forests (IPF), which followed on from UNCED. The IPF agreed on several proposals to promote C&I development and diffusion, and called for more research on the topic.

Furthermore, in the early 1990s, there was a great surge of interest in timber certification as a potentially effective market-driven incentive to improve forest management. In simple terms, the concept was to provide a guarantee to retailers and consumers that timber and wood products had been produced from enterprises that managed their forests in a sustainable way. It was anticipated that wood and timber products produced from independently certified sources could later be sold at premium prices.

The Centre for International Forestry Research (CIFOR) Criteria and Indicators (C&I) research project responded to this international demand for scientific standards in this field of natural resource management (NRM) policy to help clarify the assessment of SFM. C&I help define standards for SFM and are used by many different groups. Governments use

C&I to help them regulate the practices of forest users and report on the status of their forests to international processes and forums. Forest certification bodies depend on C&I to assess whether forest management companies or groups are managing their forests in a sustainable manner. Forest managers themselves often use C&I to improve the quality of their management.

Although the numerous C&I development efforts reflected global concerns for the sustainability of forest management, they lacked rigorous scientific testing. There was ‘a need to harmonize the different standards, to test them with respect to their relevance to sustainability and effectiveness as criteria thereof’. There was a need to develop and define criteria relevant to the different forest conditions prevailing within each country. This process, it was argued, would benefit from systematic testing and a standardized methodology (Prabhu *et al.*, 1998).

While there was adequate research capacity to undertake research on C&I available among advanced forestry research organizations of the North, CIFOR was the organization that had the skill sets in combination with the practical, forest-based management experience to complete the work. There were few if any credible alternative sources of supply, especially for the development of C&I relevant to the developing tropics.

Thus the CIFOR C&I research project entitled ‘Assessing the Sustainability of Forest Management: Developing Criteria and Indicators’ had global relevance, was timely and represented a direct response to international discussions on the validity of using C&I for evaluating the sustainability of forest management at the forest management unit (FMU) level. CIFOR’s research was the first international effort that sought to test and compare the effectiveness of C&I for SFM ‘on the ground’ at the FMU level.

This case study shows that the C&I research achieved widespread influence and was adopted across many different types of organizations. This uptake has led to the generation of significant international public good (IPG) through the improved management of forests.

CIFOR Criteria and Indicators Research

The usefulness of the CIFOR C&I research was thought to go well beyond incorporation in forest certification systems; it was anticipated that findings would play an important role as general guidelines for improving forest management practices globally – i.e. research on C&I for SFM would have multiple uses, at multiple levels and would generate benefits across regions, national borders, generations and population groups. Such C&I would be useful in:

- Evaluating the implementation of UNCED forest principles.
- Negotiating international financial support for SFM.
- Informing standards applied in timber certification schemes.

- Helping provide a basis for comparing country performances in SFM.
- Creating and stimulating debate on SFM.

The first phase of the research involved C&I field tests in five countries and seven locations: Austria, Germany, Indonesia, Côte d'Ivoire (Mengin-Lecreulx *et al.*, 1995) and Brazil (Zweede *et al.*, 1995). The research findings clearly showed that there could be no universal set of C&I. Forest conditions vary substantially, and the C&I used to guide management towards the desired objectives (which themselves may vary) must be appropriately matched to the prevailing ecological, economic and social conditions. The work also showed that there was, generally, a greater site-specific nature of 'social' C&I compared with ecological or 'production systems' C&I. Phase I field tests consistently showed that C&I for biodiversity and social sustainability were weak and, consequently, Phase II research devoted special attention to their development, and further field tests were conducted, including those in Cameroon (Prabhu *et al.*, 1998), Gabon (Nasi *et al.*, 1999) and the USA. Research efforts were also directed towards the design and production of the basic tools necessary for C&I development.

The team identified a 'generic C&I template' in 1998, comprising six basic principles and about 25 criteria related to policy, ecology, social conditions and production embedded in a hierarchical framework from broad principles to verifiers. They were not intended to be an 'ideal and universally applicable' set of C&I, but a 'point of departure' for adaptation of C&I to local conditions, and they were the foundation of the C&I 'Toolbox'. The CIFOR work also provided 'tools' and methods to assist C&I development and adaptation processes. Phase II also specifically included a field-based test of the CIFOR generic C&I template led by a team of certification auditors from SmartWood (the certification arm of the Rainforest Alliance) and SGS. The findings were documented in a research report.[1]

The 'Criteria and Indicators Toolbox Series' (CIFOR, 1999) was a comprehensive series of eight manuals and decision-support software which guided users through the complexities of assessing the sustainability of natural and planted forests, enabling them to decide which assessment tools and decision-making methods were appropriate for a given overall management situation. Of key importance to certifiers was the CIFOR work on the social C&I for SFM. The C&I Toolbox was produced in English, Indonesian, French, Portuguese, Chinese and Spanish. Over 1000 copies were distributed in English alone.

The total costs of the C&I research are estimated to be approximately US$3.3 million from inception in 1994 to completion of Phase II of the project in 1999. Donors included the German Agency for Technical

[1]Blakeney, J., Donovan, R.Z., Higman, S. and Nussbaum, R. (1998) Certifier Evaluation and Field Test of CIFOR C&I. CIFOR C&I Toolbox. Centre for International Forestry Research, Bogor, Indonesia, unpublished.

Cooperation (GTZ), the US Agency for International Development and the European Commission.

Criteria and Indicators Research Uptake and Impact Pathways

In general terms, the impact of research is more readily appraised in situations where new science-based innovations are clearly defined and where their adoption directly affects patterns of production, consumption and/or human welfare. Nevertheless, impact from science may also be achieved indirectly, for example through influencing policies, decision-making processes, management assessment processes or development assistance interventions. Where new technologies are developed for use 'on the ground' directly by land mangers (farmers/forest managers), the magnitude of the impact is often dependent on the number of adopters of a particular research innovation and the land areas over which the research innovation yields an 'improvement'. However, there are other types of 'impact pathway' where a small number of adoption events (or a single event) can change the way a 'system' or a process functions; for example, national governance processes or a regulatory system (such as forest certification).

The CIFOR C&I research generated information rather than 'finished' technologies. However, the utilization of information from research (to a greater degree than with 'finished' technologies) is not a binary phenomenon: new research-based information may be only partially applied, further increasing the difficulties of determining the level of 'adoption' and concomitant linkages and attribution to any changes 'on the ground'.

The CIFOR C&I research was intended to be of relevance for application at individual FMUs to improve forest management across a wide range of countries and settings. The C&I were also intended to have relevance for broader C&I initiatives at both national and regional levels. Achieving the widespread improvement in forest management at the FMU level through a series of independent, direct (cumulative) adoption events among multiple forest managers was thought less likely than widespread impact achieved through the use of C&I in regulatory processes (i.e. 'systemic' impact through national legislation and regulation and/or voluntary certification).

It was anticipated that the work would be used in the following ways:

- By independent forest auditors or certifiers as the basis for standards for certification assessment at the FMU or community level.
- By groups assigned the task of developing regional or national certification standards.
- By governments as the basis for development of national guidelines for SFM which might be incorporated into national laws, administrative requirements, etc.

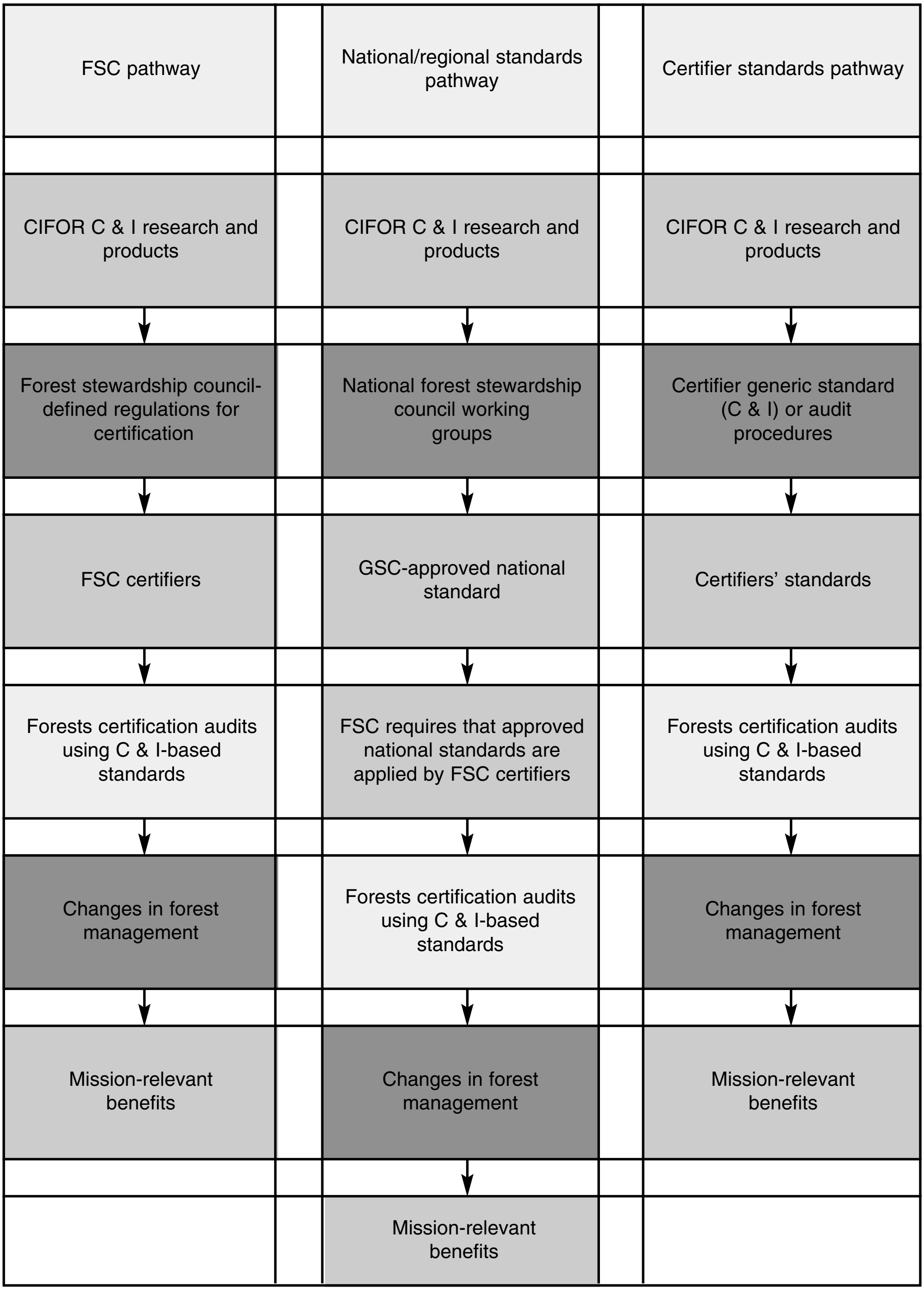

Fig. 11.1. Major impact pathways through the Forest Stewardship Council's (FSC) certification processes (CIFOR, Centre for International Forestry Research; C&I, criteria and indicators).

- By forest managers to understand, implement and/or monitor the sustainability of their forest management.

This case study focuses on three specific impact pathways and examines the extent to which certification bodies, the Forest Stewardship Council (FSC) and national standards development processes made use of the CIFOR C&I research. This is followed by an analysis showing the consequent patterns of improvement in the management of FSC-certified forests in developing countries of the South.

The general impact of certification on forests (an attempt to compare outcomes 'with/without' certification) is summarized from recently published literature on certification in these forest settings.

Figure 11.1 shows a schematic diagram of three related impact pathways, those associated with: (i) FSC certification; (ii) the national FSC working groups; and (iii) certifier generic standards (C&I) or audit procedures. A critical element in all three pathways is that C&I research is used to inform, shape or influence the performance standards for certification of forest management. Performance standards link directly to improved forest management practices on the ground through the regulatory framework of the certification process.

Forest certification includes a process by which the performance of 'on-the-ground' forestry operations is assessed against a predetermined set of standards (that make use of C&I). The vast majority of certified forests are currently located in temperate and boreal regions of the North. The largest and most significant forest certification system operating globally and including developing countries is that of the Forest Stewardship Council. The FSC is an international organization offering independent third-party verification of forest management and timber products. The FSC's principles and criteria (P&C) that apply to tropical, temperate and boreal forests are analogous to an international agreement to which FSC members, certification bodies, forest managers and FSC working groups are all committed. The performance-based P&C underpin FSC certification, but they do not represent standards against which forestry management operations can be directly assessed.

The FSC accredits independent certification bodies to conduct impartial, detailed assessments of forest operations at the request of landowners. Assessments make use of FSC-approved forest management standards. It should be stressed that in conducting forest audits, FSC-accredited certification companies only certify that FSC-approved standards of forest management have been met. Nevertheless, these standards are widely accepted as being consistent with the principles of good forest stewardship and sustainability.

The global total of FSC-endorsed certified forest in 2004 was 47 million ha (see Fig. 11.2). The area of FSC-certified forests has risen rapidly since 1996 and continues to increase. The area of forests certified in Asia, Africa and Latin America represents only 18% of the total FSC-certified area; the area of the FSC-certified forests that occurs within

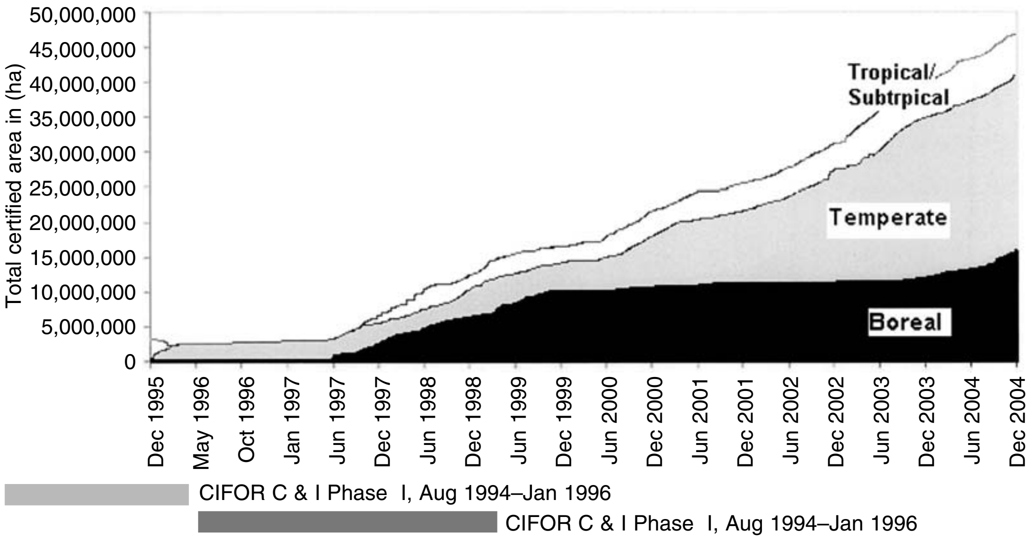

Fig. 11.2. The rate of increase in Forest Stewardship Council-certified forests, 1995–2004 (CIFOR, Centre for International Forestry Research; C&I, criteria and indicators). (From UNEP-WCMC, WWF, FSC & GTZ, 2004.)

CIFOR 'mandate countries' exceeds 5.84 million ha. Whilst FSC has formally accredited 13 forest certification companies, analysis of the area of FSC-certified forests globally and in CIFOR 'mandate' countries shows that the certification agencies SmartWood, the Soil Association and the SGS Qualifor programme, and to a lesser extent Scientific Certification Systems (SCS), dominate FSC forest certification globally. Official statistics from the United Nations Environment Programme (UNEP) and the FSC show that these four certification companies are responsible for auditing over 96% of the world's current FSC-certified forest operations. These FSC-accredited certification agencies are also far more important than other certification agencies in auditing forests certified in the South.

Figure 11.2 shows the rapid increase in FSC-approved certified forest areas since 1995. The graph also shows the timing of the main phases of the CIFOR C&I research: a period during which the major certification companies were engaged with the CIFOR C&I work and during which the generic certification standards used by these companies were developing rapidly. In this regard, the CIFOR C&I work was both relevant and timely; any research influence on standards being likely to have direct practical application.

The regulatory nature of the certification process means that if CIFOR research helped to improve the standards used by certification bodies, these improvements are then applied over large areas of forest. The certification process provides a regulatory link to 'on-the-ground' changes in management practice and an independently verified assurance that improvements in forest management are sustained during the period that

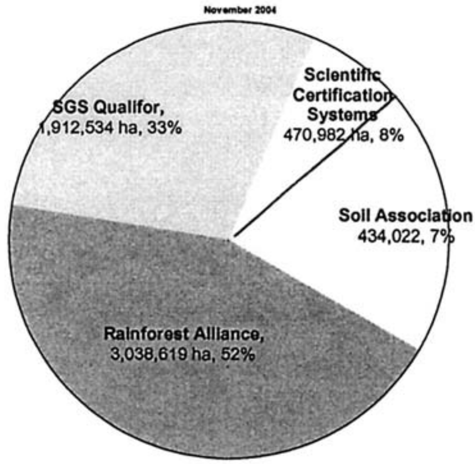

Fig. 11.3. Forest Stewardship Council-certified forest in countries targeted by the Centre for International Forestry Research (CIFOR) by certification company, November 2004. Target countries are defined in CIFOR's strategic plan and focus on developing countries in tropical and subtropical regions.

the certification holds. Figure 11.3 shows that two certification companies service more than 80% of the certified forest, while SCS service less than 10%.

Forest management standards

Standards are pivotal to certification and to the implications for 'on-the-ground' changes in forest management. Standards provide the basis for the quality of any certification scheme and are the frame of reference for any claims made in relation to it. Forests vary enormously in their biology, climates, soils and their social and economic contexts. Definitions of 'sustainable forest management' vary, and involve a balance of economic, environmental and social requirements. The development of forest certification standards is often a process involving a variety of information sources and a range of interest groups. In this context, research and science-based information is often only one source of information among many other competing sources that contribute to the development of certification standards.

Certifier standards pathway – uptake by Forest Stewardship Council-accredited certifiers

Only a few companies have been responsible for the bulk of FSC-certified forests. Standards development within these certification companies progressed rapidly between 1994 and 2000. However, there were relatively few individuals within these certification companies responsible for the refinement of such standards.

Key staff of certification agencies employed at the time certifier standards development took place were canvassed for their perspectives on whether or not the CIFOR C&I research played any role in the development of those standards and, if so, what the likely outcome would have been in the absence of the CIFOR work. In addition, project documentation (reports, meeting minutes and e-mails), published documents and Internet resources were examined for evidence of FSC certifiers making use of CIFOR's C&I research.

Evidence of adoption of CIFOR's criteria and indicators research by SmartWood/Rainforest Alliance

SmartWood pioneered the concept of forest and forest-products certification that has since taken hold around the world. SmartWood was a prime mover in promoting forest certification globally and is currently the world's leading non-profit forestry certifier, with 14.8 million ha of forest in approximately 50 countries. In 1998 SmartWood revised its criteria for assessing forest management in both natural forests and tree plantations. These 'Generic Guidelines' were reviewed and approved by the FSC. Richard Donovan, SmartWood's Chief Forester, a key figure in certification since its inception, made the following comments regarding the utility and impact of the CIFOR C&I research:

> The [CIFOR C&I] field tests helped to change the way people looked at sustainable forest management … they helped to inject realism into a debate that was often very theoretical … CIFOR and its partners went into the field and looked at what worked and what didn't work. That made a big difference.

According to Donovan, SmartWood has continued to make occasional use of the CIFOR C&I Toolbox in periodic review and update of its indicator sets. In developing its standards it is clear that SmartWood made use of CIFOR C&I research. This is acknowledged on its official web site and appears in the text of its current generic standards set (SmartWood, 2000). Significantly, the SmartWood generic standards form the basis of the interim standard sets that are adapted for certification audits of forest management in a range of different countries, as indicated by the following statement:

> We believe these criteria are in accord with the intent of relevant forest management and biological conservation guidelines issued by the International Union for the Conservation of Nature (IUCN) and the International Tropical Timber Organization (ITTO). We have also drawn on work by the Centre for International Forestry (CIFOR), World Rainforest Movement, International Labour Organization (ILO), and FSC regional standards working groups. (SmartWood, 2000).

Interim standards are used by SmartWood where there are no FSC-approved national/regional standards. Some SmartWood interim stan-

Table 11.1. SmartWood certification interim national standards for assessing forest management. (From SmartWood, 2002–2003; data from UNEP-WCMC, WWF, FSC and GTZ, 2004.)

Country/region	Current certified area (ha)	Year standard produced/revised	Specific reference to CIFOR in standard
China	6,177	2003	Yes
Lao PDR	–	2003	Yes
Indonesia[a]	90,240[a]	2003	No[a]
Thailand	–	2003	Yes
Ecuador	1,341	2002	Yes
Chile	64,570	2002	Yes
Australia	509,716	2002	Yes
Japan	148,600	2002	Yes
New Zealand	109,329	2002	Yes
Portugal	–	2003	Yes
Russia	812,849	2003	Yes
Southern USA	No data	2003	Yes

[a]The Joint Certification Protocol between the Forest Stewardship Council and Lembaga Ekolabel Indonesia (LEI) certification bodies (2001) specifies that the LEI criteria and indicators (C&I) will be used for natural forest management certification by all certification bodies operating in Indonesia. LEI was a key collaborator in the Centre for International Forestry Research's C&I project, and the C&I research was used extensively by LEI, especially in the development of their social C&I.

dards refer specifically to CIFOR C&I research in similar terms to that quoted in the generic SmartWood standard. Table 11.1 shows published SmartWood interim standards that are derived from the generic SmartWood standard, and highlights which of them contain a formal acknowledgement of the CIFOR research. The areas currently certified by SmartWood using these interim standard sets are also shown where data are available. SmartWood interim standards for Costa Rica, Guatemala/Belize, Honduras, Mexico, Nicaragua, Panama, Uruguay, Spain, Argentina and Venezuela are all modified from the generic standard but do not contain a specific acknowledgement of the CIFOR research contribution.

CIFOR project staff also received a personal communication in 1997 from Mr Tasso Rezende de Azevedo, Director of Imaflora (SmartWood's affiliate organization in Latin America) on the utility of the C&I developed during the CIFOR Brazil test as forming the template for the development of a set of C&I used in the certification of Precious Woods (Mil Madereira) in Manaus, one of the earliest forests to receive FSC certification status in Brazil (De Camino and Alfaro, 1998; De Azevedo *et al.*, 2001).

Without the CIFOR, research certification standards would have developed less rapidly and possibly less effectively (e.g. with regard to social C&I and effective methods for stakeholder consultation). The utility of the CIFOR C&I tests in this regard is acknowledged by SmartWood.

Research uptake by SGS Qualifor

SGS is an international inspection, verification, testing and certification company active in forest certification with the 'Qualifor' certification programme. SGS Qualifor develops 'checklists' based on an endorsed FSC national standard if it exists. Otherwise SGS develops a set of C&I based on the generic SGS Qualifor checklist together with any draft local FSC standard, local requirements or codes of practice. There is no direct reference to CIFOR (or any other research or information source) evident in the published standards. However, evidence from key informants suggests that the CIFOR research had a positive influence on SGS forest certification standards and audit procedures. This includes unsolicited written comment from SGS staff involved in the key standards development work in 1998 sent to the CIFOR research team and verified in a key informant interview with the Director of SGS Qualifor (see Box 11.1). The CIFOR work was of use in helping SGS to develop their stakeholder consultation processes and helped to inform their standards development process, particularly with regard to social issues and 'intergenerational access to resources' in SFM. However, there was no 'wholesale adoption' of CIFOR's generic C&I.

Without the CIFOR research it is likely that audit processes for stakeholder consultation and indicators relevant to local stakeholder interests would have developed more slowly; therefore it is likely that outcomes in the field would have been less consultative and less responsive to local stakeholders and risked greater conflicts of interests with local communities.

There is a strong and plausible case that certification standards and audit processes were improved, especially with regard to their treatment

Box 11.1. Research influence on SGS standards and audit processes.

'The whole area of defining and judging or certifying sustainable forest management is one which is fraught with practical, political and scientific problems … [The Centre for International Forestry Resources (CIFOR)] team managed to pull together policy makers, foresters and academics and not only get them to discuss the issues but also to test things out in practice, which pushed the whole debate forward in a constructive and practical way.

One particular feature of the project is that CIFOR was perhaps one of the only organizations which could do this. I feel that it is a perfect example of what CIFOR as an international, non-aligned entity can do. Research on forests themselves will always have to be done through local projects, but research into international policy issues with very significant local implications fits perfectly within the mandate of an organization such as CIFOR … in particular the work done by Carol Colfer and her associates (1997) on social issues in forestry – in many ways the most difficult area to tackle. Her work on ranking the importance of stakeholder requirements, published in a CIFOR paper, has formed the basis for our stakeholder consultation programme which is increasingly successful … as a way of tackling the need to involve a wider range of interested parties in forest management.'

R. Nussbaum, Director SGS Qualifor, 1998.

of social issues relating to forest-dependent communities. Broad stakeholder acceptance of Qualifor standards may have also been enhanced by the credibility afforded to them by the independent CIFOR field tests.

Research uptake by the Soil Association–Woodmark

The Soil Association is an environmental non-governmental organization (NGO) with a non-profit status. The Soil Association entered the forestry realm with the production of the Responsible Forestry Standards in 1992, and launched the 'Woodmark' scheme in March 1994. The Soil Association Woodmark generic standards reflect FSC P&C, have been through several revisions and were last updated in 2004.

Key informant interviews with both current and former employees (K. Jones, I. Rowland and M. Wenban-Smith, personal communication, 2004) suggested that CIFOR C&I research was important in the development of Woodmark standards. Rowland and Wenban-Smith commented that the CIFOR C&I work was important because it highlighted potential C&I and possible audit approaches to tackle key elements of the FSC P&C dealing with tenure and use rights, indigenous people's rights and community relations (e.g. stakeholder consultation tools and processes). CIFOR C&I were not used directly in the Woodmark standard; however, the CIFOR Toolbox was used as an important reference text during the standards development process and helped focus the Soil Association's attention on aspects of SFM that had not been adequately dealt with in earlier standard sets. For example, the C&I dealing with biodiversity in the generic CIFOR C&I highlighted the importance of developing C&I to capture ecological processes that are important for the retention and maintenance of biodiversity. However, the specific biodiversity C&I presented by CIFOR were regarded as being too 'academic', too costly and impractical for direct application in forest certification audits.

The CIFOR C&I research was acknowledged by Soil Association staff as having been useful and important during the early years of certification standards development. The effect of research on those standards was difficult to quantify. Again, it is likely that without the CIFOR research the focus on biodiversity and social issues would have received less attention and taken longer to refine within certification standards.

Broad acceptance of the Woodmark standard may possibly have been aided by the credibility afforded by the independent CIFOR field tests of their standard sets. Presumably, without the CIFOR work such acceptance may have taken longer.

Research uptake by Scientific Certification Systems

SCS is an FSC-accredited company based in the USA. SCS first developed its Forest Conservation Program in 1991, and operational guidelines were developed in 1994 and published in 1995, before the inception of the CIFOR project. SCS entered the certification scene with a focus on forest certification in North America. The most recent SCS *Generic Interim*

Standards for Natural Forest and Plantation Forest Management Certification were published in early 2002. These follow the structure of the FSC P&C. SCS were not involved in the CIFOR research project as collaborators, nor were the SCS standards included in the original base sets of C&I that were tested. Evidence of direct uptake and indirect influence of CIFOR research on SCS standards is lacking, and the senior SCS forestry representative indicated that SCS did not consider the CIFOR research to have been influential in their standards development processes. The main reasons for this were SCS's predominant focus on North American commercial forests and CIFOR's focus on forests in tropical developing countries of the South.

Forest Stewardship Council certifier uptake summary

Since the CIFOR study was completed, large areas of forests have been certified using generic standards to which the CIFOR work contributed. The global total of FSC-endorsed certified forest is currently over 47 million ha. Over 79% or 37.1 million ha of forest have been certified by companies that acknowledge some use of CIFOR's C&I research in their certification standards or audit processes. Since generic certifier standards are used to derive the standards used in a specific FMU, the 'domain of application' of such standards is very widespread. Spillover effects are very large because the bulk of the world's certified forests are located in the developed countries of the North – outside the countries that are central to the mission of the Consultative Group on International Agricultural Research (CGIAR).

It is therefore reasonable to attribute the development and use of generic standards by globally important FSC certifiers, in part, to CIFOR's C&I research. The CIFOR work tested indicator sets for assessing forest management at the FMU level in multiple field settings, providing independent feedback on which C&I were broadly applicable and thus speeding the development and refinement of FSC certification bodies' standards. This testing process, coupled with CIFOR's perceived status as an independent international research organization, helped improve the legitimacy and credibility afforded to FSC certifier standards for forest management across a wide range of stakeholders in government, industry and environmental NGOs.

Assessing the 'on-the-ground' Impact of Certification on Forest Management

Standards applied through audit processes by certification bodies should lead to 'on-the ground' changes in the management of forests. This section addresses whether it is possible and practical to make field-based comparisons of 'with/without' certification situations. Comparing the wide range of 'sustainability attributes' in forests is extremely challenging. Sheil *et al.* (2004) raise a large number of methodological problems in interpreting field-based comparisons of forests using C&I for assessing biodiversity. These challenges are relevant to the application of C&I in general, but especially to evaluation methods attempting to compare forest management situations ‘with/without’ certification.

Difficulties arise in making comparisons between certified and uncertified planted forests or between communities living in and around certified and uncertified forests. Observed differences can only be ascribed to certification if detailed site-specific knowledge and time-series information are available.

Additionally, there are trade-offs in the impact of certification. Positive impacts at the FMU scale may be negative at another scale. Plantation management operations may improve locally to satisfy certifier standards; yet, at the landscape level, expansion of plantation forestry might imply a reduction in biodiversity and other environmental services and/or possibly negative consequences to the livelihood options available to local communities than was formerly the case. The reverse may also be true: certification may act to increase costs and reduce revenues at the FMU scale, e.g. by enforcing labour standards wages increase and reducing short-term annual timber yields at the scale of the management unit, but may offer positive impacts at larger spatial scales and/or over longer temporal scales. For example, certified and sustainable managed forests may reduce runoff and erosion, maintain connectivity between habitats for threatened species or may even reduce social conflicts surrounding forest resource management in the longer term.

Assessing the impacts of forest certification using Corrective Action Requests

The FSC forest certification audit process requires independent third-party certifiers (e.g. SmartWood, SGS, Soil Association, SCS) to assess forest management against consistent C&I-based standards, and publicly document which management aspects are in compliance and, critically, where standards are not met. Non-compliance with the certifier standard results in issuance of a Corrective Action Request (CAR). CARs are given when the certification standard’s forest management performance criteria are not adequately met; they outline what needs to be improved to bring the operation into compliance. CARs are specified in publicly available Certification Assessment Reports (for public certification summaries, see reference citations needed for SmartWood, 2004, SGS, 2004, SCS, 2004) and define which aspects of forest production, environmental, social and economic issues, etc. the operation is required to address to become certified. The certification regulatory system (which includes follow-up audits) ensures that forest management entities must improve their management with regard to these CARs to become ‘compliant’ and receive or retain their official certified status. CARs are therefore a reasonable proxy for ‘before’/‘after’ situations in certified forests. They are independent observations made by third-party accredited forest certifiers within a common (FSC) assessment framework.

It is therefore reasonable to attribute the development and use of generic standards by globally important FSC certifiers, in part, to CIFOR's C&I research. The approach used builds on those developed and applied by Thornber (1999) and Gullison (2003), and in particular follows more recent work by Newsom (2004).

Using this approach to determine certification-mediated outcomes assumes that, if formal certification had not been pursued by the enterprise, management procedures would have proceeded with little change and, therefore, the management responses required to comply with standards for SFM express the certification-related improvements.

It needs to be recognized however that CARs will tend systematically to underestimate certification-related improvements in forest management. Potential non-conformities are routinely communicated informally to the forest managers by the certifiers through confidential pre-certification assessments in advance of the final certification audit. Forest managers normally implement many improvements in forest management procedures and practices prior to a certification audit. The public certification documents record only the remaining non-compliant aspects within the management unit at the time of the final audit.

Classifying Corrective Action Requests

Newsom (2004) presents a method to examine the thematic focus and language used in CARs and how these relate to required changes in forest management 'on the ground'. Following Newsom (2004), we examined the CARs in public FSC Certification Assessment Reports and recorded: (i) which thematic areas were addressed; (ii) whether the condition required a procedural or substantive change (or a combination thereof); and (iii) whether or not the condition contained results-based language.

First, CARs were categorized into detailed 'operational themes' classified under three broad categories: (i) forest management; (ii) environmental issues; and (iii) social and cultural issues (see Spilsbury, 2005 for more details). This enabled classification of the wide range of management recommendations occurring in public CARs into a number of commonly occurring themes.

Second, CARs were classified as 'procedural', 'substantive – direct' or 'substantive – indirect' (Newsom, 2004). These three categories are described in detail in Table 11.2.

Finally, for each CAR we identified whether results-based language was present. Results-based language was considered to be present when operations were given a specific 'indicator' or 'goal' towards which they must work, and considered absent if the operation was required simply to 'address' or 'consider' a broad issue.

Table 11.2. Performance- and systems-based classification for Corrective Action Requests. (Adapted from Newsom, 2004.)

Category	Definition	Example
Substantive – direct	Operations are required to make on-the-ground changes to forest practices	'Surround special cultural sites with a buffer during harvesting'
Substantive – indirect	Operations are required to implement a procedure whose outcome will directly impact on-the-ground forest practices	'Modify management plan to ensure that natural forest features are incorporated into plantations'
Procedural	Operations are required to implement a procedure that may or may not directly impact on-the-ground forest practices	'Provide a summary of the forest management plan to community groups'
		'Conduct an inventory of threatened and endangered species'

'On-the-ground changes' from certification

CIFOR research can be assumed to have some influence on the certification standards of SGS, the Soil Association and SmartWood. A total of 59 public Certification Assessment Reports from forests certified by these auditors have been analysed (Table 11.3). The changes in forest management required in the certification process have been appraised through examination and classification of 916 CARs within these reports.

The public certification reports from the survey sample represent an aggregate forest area of 3,283,352 ha across 59 certified sites. Trends in the CARs for these forests were examined in detail (Spilsbury, 2005) and the findings are summarized here. Table 11.4 shows commonly occurring categories for CARs.

Thematic categories and sub-categories were used for classifying CARs. Within these, CARs were additionally classified for their 'action orientation' in terms of the required management responses (Fig. 11.4). The link between forest certification and changes in the management of forests was further explored by examining the use of 'results-based language' in CARs. Figure 11.4 shows a fairly even distribution of results-based language across all CARs and within the three major themes.

Examining the classification of CARs by 'action orientation' in combination with the presence of 'results-based language' showed that a large number of CARs are 'procedural' in nature; 62% of these CARs contain some results-based language, with 27% featuring 'strong' results-based requirements. A CAR classified as requiring a 'substantive direct' management response that additionally contains 'strong' results-based language defines the clearest linkages to direct change in forest management

Table 11.3. Public Certification Assessment Reports examined in countries targeted by the Centre for International Forestry Research.

Country	Number of public Certification Assessment Reports examined	Area of certified forest covered by public certification documents examined (ha)	Share of total area of FSC-certified forest in country (%)
Bolivia	1	119,200	68
Brazil	13	752,919	85
Costa Rica	3	19,524	46
Ecuador	1	20,000	94
Guatemala	2	9,281	88
Indonesia	1	90,240	100
Malaysia	3	77,242	100
Namibia	1	61,130	100
Nicaragua	1	3,500	97
Papua New Guinea	1	4,310	100
Solomon Island	1	39,402	100
South Africa	17	1,062,932	70
Sri Lanka	4	16,251	100
Swaziland	1	17,010	100
Thailand	1	921	100
Uganda	2	35,000	100
Zambia	2	827,005	100
Zimbabwe	4	127,485	100
Total	59	3,283,352	100

FSC, Forest Stewardship Council.

Table 11.4. The most commonly occurring categories for Corrective Action Requests in certified forests in countries targeted by the Centre for International Forestry Research.

Forest management	Environmental issues	Social, cultural and economic issues
'Plantation/forest-stand management'	Protected areas	Social impacts (lack of social impact assessment, negative impacts from forest operations)
Clear cut use/size of felling coupes	Threatened and endangered species	Information provision (public access to information)
Chemical use and disposal (storage and application)	Environmental impact (lack of EIAs or lack of consideration of wider environmental impact of forest operations)	Communications and conflict resolution with local stakeholders
Improvements to roads and skid trails	Aquatic and riparian areas	Worker safety and worker welfare
	Soil conservation and erosion	Compliance with laws and regulations

EIA, Environmental Impact Assessment.

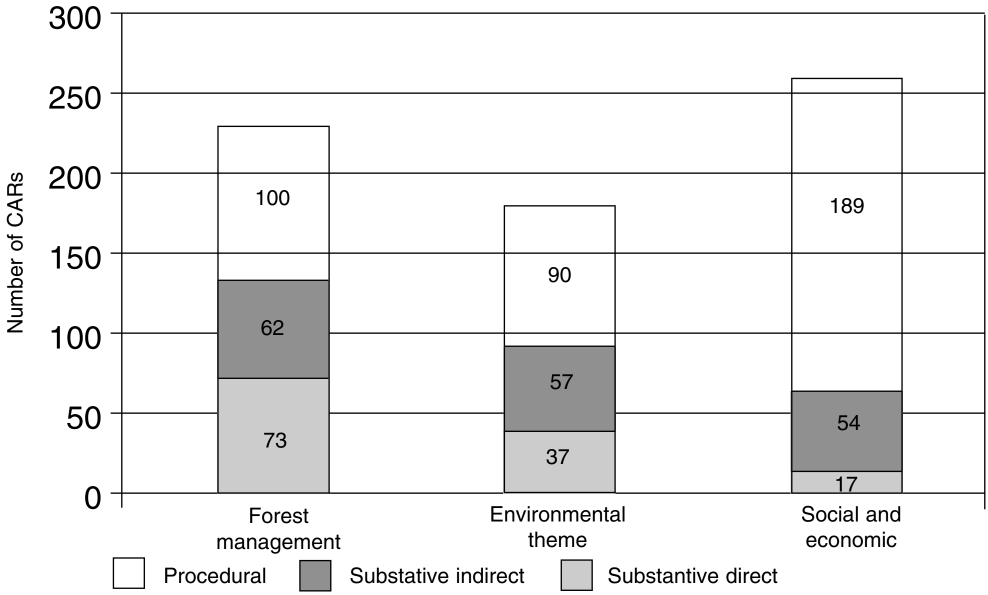

Fig. 11.4. Corrective Action Requests (CARs) from certification documents classified by thematic focus and 'action orientation'.

practices 'on the ground' in response to certification. CARs falling within both of these categories occur more frequently in association with the 'forest management' theme. By contrast, CARs that have the highest levels of uncertainty with regard to forest management practices 'on the ground' are categorized as 'procedural' and contain no results-based language.

Approximately 200 CARs fall into the combined category 'procedural' and 'no results-based language'; 'forest management' and 'environmental' themes each have approximately 25% of this total, while approximately 50% of the CARs classified as such fall within the 'social and economic' theme.

Figure 11.5 shows the frequency of CARs classified within the 'social and economic' theme. The corrective issues most closely linked with CIFOR research contributions are highlighted and include: communication and conflict resolution issues with local stakeholders, and social impacts including the need for social impact assessment by forest managers. In addition, the CIFOR research was linked to issues dealing with the adequate provision of local stakeholder interests, recognition of sites of cultural importance and long-term land tenure/land use and usufruct rights. CARs on these issues are classified under four sub-themes in the analysis of CARs (Table 11.5).

It is clear that many of the 'changes on the ground' in certified forest are consistent with the CGIAR mission of protecting the environment; less certain is how these outcomes translate into livelihood benefits. However, given the assumed counterfactual of forest management without certification failing to make these improvements (a reasonable assumption for forest management practices often prevailing in the

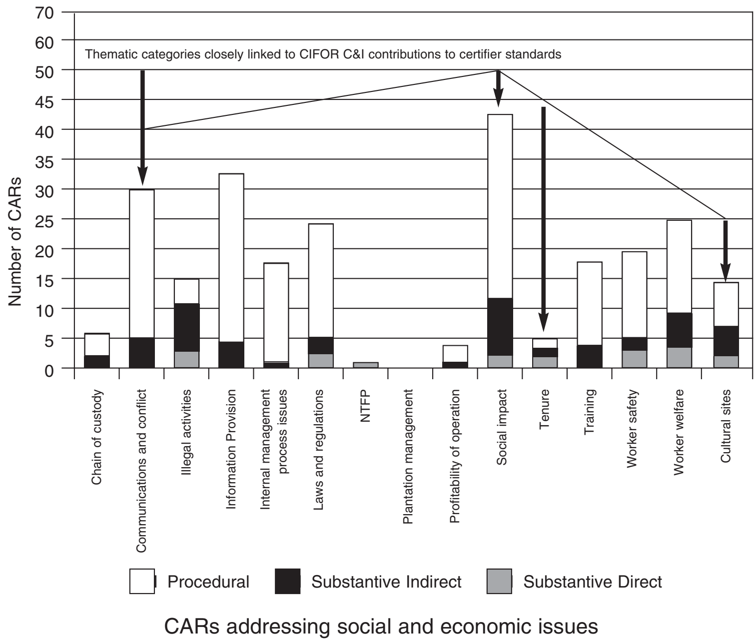

Fig. 11.5. 'Social and economic' Corrective Action Requests (CARS) classified by sub-theme (type of 'on-the-ground' response required) and 'action orientation' (CIFOR, Centre for International Forestry Research; C&I, criteria and indicators).

South), it is realistic to assert that the consideration of local stakeholder interests is generally higher in certified forest than it would otherwise have been.

Quantitative attribution of CIFOR's research contribution to certification standards proved problematic, although it is clear that CIFOR research helped to improve the standards and audit processes applied, especially with regard to 'social' issues in developing country settings. Substantial areas of forests have been certified, and the issues most closely associated with CIFOR research contributions to certification standards commonly feature in CARs, resulting in causally linked improvements to management practices over several million hectares of forests.

The global area of FSC-certified forest continues to increase. Large areas of FSC-certified forest (over 40 million ha) occur in temperate and boreal forests in industrialized countries of the North. These forests are assessed by certification bodies against management standards that, in part, made use of CIFOR research. However, many of the social issues closely associated with specific CIFOR research contributions to certifier standards (e.g. land tenure, conflict with local communities and stakeholders) tend to feature less frequently in CARs of certified forests in temperate and boreal regions. Nevertheless, relatively small improvements to certification standards are significant because they apply over very large areas of forest.

Table 11.5. Number of Corrective Action Requests (CARs) listed in the public Certification Assessment Reports that correspond to sub-themes where research by the Centre for International Forestry Research (CIFOR) contributed to certifier standards.

CAR sub-theme categories most corresponding with CIFOR research contributions	Number of CARs occurring in SA-, SGS- and SmartWood-certified forests in CIFOR target countries	Number of certified sites listing a CAR within a category at least once	Hectares of certified forest in CIFOT target countries required to comply with CARs
Communications and conflict resolution	33	23	2,325,061
Social impacts – lack of social impact assessment and negative impacts from forest operations	44	23	1,968,852
Tenure and land use rights	5	4	217,269
Cultural sites	15	12	474,707
Total	97	62	Not applicable[a]

SA, Soil Alliance.
[a]Total is not meaningful in this instance because some forests have more than one CAR in the categories listed; hence the total would be 'double counting'.

In addition, there is a broad set of evidence that documents examples of research uptake from the CIFOR C&I research, including uptake by key policy audiences and influence on international and national forest C&I-related processes and initiatives. This evidence is presented in detail in Spilsbury (2005).

Additional spillovers may also result from new certification initiatives. There are several nascent certification initiatives emerging in the oil palm industry, as well as in coffee, soybean, banana and citrus production. These are drawing upon the experiences gained with forest certification and, in the case of oil palm, are currently developing C&I for sustainable production using the FSC P&C as a model. CIFOR's work on C&I may yet spill over into standards for the sustainable production of oil palm, and possibly other plantation crops, with potentially very large impacts.

Published studies on the impact of certification on forest management

The literature on the impact of certification on forest management (e.g. Thornber, 1999; Bass *et al.*, 2001; Mayers *et al.*, 2001; Gullison, 2003) has shown that specific certification outcomes vary significantly from one forest location to another. Common trends emerging from the published literature were:

- Environmental services were secured or improved in certified forests,

with greater attention paid to environmental impact assessments and environmental guidelines.
- Certification led to improved worker conditions (health and safety) within managed forests.
- Certification processes often acted to reduce social conflict in and around certified forests, with greater attention paid to social impact evaluations and local consultation.
- Certification helped in securing land tenure and usufruct rights (in certified community forests).
- Certification improved the image of the forest management enterprise locally and in associated markets.
- Certification provided greater access to premium timber markets (where they exist).
- Certification helped promote SFM more generally through dialogue between the private sector, government bodies, NGOs and civil society. In short, certification had positive influences of policies and regulations affecting forests.

A detailed treatment of the literature on certification costs and benefits can be found in Spilsbury (2005).

Break-even Analysis of Monetary Benefits Required to Offset Research Costs

The cost-effectiveness of the CIFOR C&I research can be illustrated through a simple break-even analysis based on aggregate areas of C&I research influence combined with an examination of the plausibility of attaining such levels of benefit. The minimum levels of average per hectare monetary benefits required to justify investment in the research are shown for different sets of aggregated outcomes. The figures for areas of forest under FSC certification are drawn from UNEP-WCMC, WWF, FSC & GTZ (2004), and are available on the World Wide Web and for the US Forest Service (USFS) LUCID project (USDA, 2002). Table 11.6 gives an assessment of SFM outcomes linked to CIFOR research and the corresponding forest areas under Forest Stewardship Certificates. The total investment in the C&I research was approximately US$3.3 million from inception in 1994 to completion in 1999.

Assume that the CIFOR research advanced the development of C&I by between 1 and 5 years more than would otherwise have been the case (counterfactual situation). The break-even benefits range from US$0.02 to US$0.57 per hectare depending on the reference area and the strengths of CIFOR's influence, as shown in Table 11.6. The assumption that the CIFOR research moved the development of C&I forward, especially on social issues, by at least 3 years is conservative; thus the breakeven benefits range from US$0.03 to US$0.24 per ha.[2] Given the frequency with

[2]No discounting was applied in this calculation.

which social issues appear in the CARs of FSC-certified forest areas more generally, it is reasonable to assert that the actual benefits derived from improvements in C&I applied by certifiers and manifested in the consequent management responses would far exceed these modest levels.

Table 11.6. Assessment of sustainable forest management outcomes linked to research by the Centre for International Forestry Research (CIFOR).

1. FSC-certified forests: SmartWood, SGS, SA (global; 37,100,000 ha)	Influence of CIFOR research on certified standards via FSC accreditation – very low. Influence of CIFOR research on certifier generic standards evident – reasonable likelihood that research led to widespread but marginal improvements in forest management
2. FSC total certified forest in Asia, Africa and Latin America (8,460,000 ha)	As above but figures relate to Asia, Africa and Latin America – reasonable likelihood that research led to widespread but marginal improvements in forest management
3. USFS LUCID project. Piloted in State Forests in the USA and Canada (7,500,000 ha)	Area of national forest utilizing monitoring approaches directly derived from CIFOR research methods (see Spilsbury, 2005 for details)
4. FSC total forest certified by SmartWood, SGS, SA (in CIFOR target countries; 5,800,000 ha)	As in 1 above but figures relate only to certified forests in CIFOR target countries – reasonable likelihood that research led to widespread but marginal improvements in forest management
5. SmartWood, SGS, SA (forests in CIFOR target countries with CARs showing non-conformance on social issues; 4,500,000 ha)*	As in 1 above but figures relate only to certified forests in CIFOR target countries that have CARs closely linked to CIFOR research contributions on social issues – high likelihood that research led to widespread but marginal improvements in forest management

FSC, Forest Stewardship Council; SA, Soil Alliance; USFS, US Forest Service; CAR, Corrective Action Request.
*Areas are conservative estimates.

In reality much of the benefit derived from the use and application of the CIFOR C&I research is of a non-monetary nature and is unevenly distributed by area. For example, an important contribution of the CIFOR C&I research relates to stakeholder consultation processes, 'intergenerational access to resources'– land tenure and rights of local and indigenous communities. Benefits accruing from the application of such C&I might include avoidance of conflicts, securing of tenurial rights and improved communication between communities and forest managers, etc. Such outcomes are not readily converted to a per-hectare monetary value.

Nevertheless, the low levels of monetary benefit required per hectare to justify the research investment suggest, with a high degree of plausibility, that the research has generated mission-relevant benefits that far exceed the costs. In this regard, the CIFOR research had been completed and had had influence on certifier standards at a time when global totals of certified forest were still low but rising rapidly (see Fig. 11.3).

Additionally, this analysis addresses only a limited set of outcomes; other documented research uptake and use events – e.g. the influence of forest policy in India or South Africa, or monitoring in Brazil and Mexico (see Spilsbury, 2005 for further documented examples) – are excluded and thus the areas over which the C&I research has had some significant influence are grossly underestimated.

Conclusions

The CIFOR C&I research responded to an international demand for science in the area of NRM policy to help clarify the assessment of SFM through development and improvement of C&I. C&I help define standards for SFM and are now being used by many different groups. The case study shows that the research achieved widespread influence and uptake across many different types of organizations. This uptake has led to the generation of significant IPG.

The global total of FSC-endorsed certified forest is steadily increasing and currently stands at over 47 million ha. The area of forests certified in Asia, Africa and Latin America represents 18% of the total certified area. Within this, the area of certified forests that occurs within CIFOR 'mandate countries' exceeds 5.84 million ha. Official statistics from UNEP and the FSC show that the most active certification companies globally in terms of the areas of forest certified have been SGS, Rainforest Alliance, SCS and the Soil Association. These four companies are responsible for auditing over 96% of the world's current FSC-certified forest operations and are far more important than other certification agencies with regard to tropical forests and forests certified in the South.

Three of the four key FSC certification bodies acknowledge benefiting from the CIFOR work on C&I in developing their generic certification standards or auditing processes. Therefore, over 79% of the global total of certified forest, or 37.1 million ha of forest, has been certified by companies that acknowledge some use of CIFOR's C&I research in their certification standards or audit processes. Spillover effects are therefore large, because the bulk of the world's certified forests are located in the developed countries of the North – outside the countries that are central to the CGIAR mission.

The standards developed and used by certification bodies did not adopt CIFOR's C&I in a 'wholesale' manner, and quantitative attribution of CIFOR's research contribution to certification standards proved problematic. Nevertheless, there was broad agreement among three of the four major FSC certification bodies that CIFOR C&I research highlighted general areas of weakness and inconsistency in SFM standards and showed that it is not practicably possible to have a single set of globally applicable C&I.

Prior to the CIFOR research effort, C&I dealing with 'social sustainability' issues were relatively weak in the standards used by FSC certification bodies. The CIFOR work helped bring credibility and legitimacy to social sustainability issues that were initially regarded as very difficult to incorporate in assessments of SFM and forest certification processes.

The CIFOR research helped focus the attention of certifiers on social sustainability issues and helped speed the development of certification standards in this regard. CIFOR's contribution in the realm of 'social' C&I was associated with stakeholder consultation methods, mitigation of conflicts with indigenous or local communities and consideration of their tenurial and land use/usufruct rights. The research also helped draw increased attention to biodiversity issues, although the C&I developed by CIFOR lacked practical utility for certification field audits.

The case study shows, through examination of public assessment reports, that certification in turn has led to large improvements in SFM on the ground. Substantial areas of forests have been certified, and the issues most closely associated with CIFOR research contributions to certification standards commonly feature in documented changes in forest management practice. These commonly occurring improvements in forest management involve stakeholder consultation processes and 'intergenerational access to resources' – land tenure and rights of local and indigenous communities – and result from research-related improvements to management practices. The 'on-the-ground changes' occur in more than 3.2 million ha of forests in CIFOR target countries.

The analysis of public Certification Assessment Reports, coupled with a review of findings published in recent literature, show that certification in developing countries has:

- Helped secure or improve environmental services in certified forests.
- Improved worker conditions within certified forests.
- Acted to reduce social conflict in and around certified forests.
- Helped in securing land tenure and usufruct rights (in certified community forests).
- Improved the image of the forest management enterprise locally and in associated markets.
- Provided greater access to premium timber markets.
- Helped promote SFM more generally through dialogue between the private sector, government bodies, NGOs and civil society.

Such improvements clearly contribute to CGIAR goals over large areas, but the magnitude and the distribution of benefits remain difficult to quantify and compare.

The CIFOR research effort was timely because certification in general and FSC certifier indicator sets in particular were developing quickly during the life of the CIFOR research project. In the period since completion of the CIFOR C&I research, large areas of forests have been certified under the FSC system using C&I-based standard sets and audit process.

The FSC itself has made limited use of the CIFOR C&I, yet key documents such as *FSC Guidelines for Certifiers* encourage certifiers and national working groups to refer to CIFOR research regarding financial C&I for SFM:

> Certification bodies and FSC National Initiatives are encouraged to study the CIFOR paper, especially Table 11.5 'Recommended Criteria and Indicators', with a view to improving the certification bodies' 'generic standards', and FSC Regional Standards. (FSC, 2002a)

Regional/national FSC standards development processes are iterative, participatory and accommodate a wide range of stakeholder interests – consequently direct research influence on such processes is challenging and requires research organizations to remain engaged in the long term or succeed in achieving 'first-mover advantage'. There are examples of CIFOR research influencing national/regional FSC standards development processes through the CIFOR C&I field tests in Brazil and Cameroon; these tests were conducted when certification processes were nascent in these countries. In the case of Brazil, CIFOR played a key role early in the process of developing standards for *terra firma* forests. Substantial forest areas have come under FSC-certified management in Brazil; however, much of it is outside the Brazilian Amazon, where the CIFOR work had its greatest relevance and influence.

There is evidence of influence on FSC national standards development processes in Nicaragua, Honduras, Costa Rica, Guyana and Guatemala through application of C&I selection methods developed by CIFOR and Centro Agronómico Tropical de Investigación y Enseñanza (CATIE). More indirect and less attributable influence has resulted from the use of the CIFOR research outputs as a general information resource for standard-setting processes, and through use of the research by national working groups in Chile and Cameroon. Generally, research uptake in FSC working groups has been patchy, and many FSC national standards development processes have yet to be completed in developing countries.

In addition to certification-related uptake and impact, Spilsbury (2005) highlights a number of uptake events across a wide range of organizations at international regional, national and sub-national levels. In some cases these events have led to significant outcomes and impacts.

CIFOR research from the Cameroon C&I test was extensively used in the development of C&I by the African Timber Organization (ATO). These C&I were later harmonized with those of ITTO for use in ATO countries.

Thorough examination of a large number of key policy documents produced by major donors supporting forest-related initiatives showed that CIFOR C&I research was frequently cited (Spilsbury and Bose, 2005). Notable examples included: World Bank Forest Policy, the Global Environment Facility's Roundtable on Forests, the report of the Convention of Biological Diversity's Subsidiary Body on Scientific, Technical and Technological Advice to the Conference of Parties to the United Nations Framework Convention on Climate Change, in guidelines for best practice in integrating biodiversity into national forest planning, and in the IPF/United Nations Forum on Forests decisions. In general, the CIFOR C&I research has been highly regarded at the international level, and has been acknowledged in key documents that have helped to shape the international forestry agenda.

CIFOR C&I research played an important role in shaping national and state policies in India. CIFOR experience with multi-stakeholder processes and method for selection of C&I was important in the formulation of national forest management standards in South Africa. In Brazil, IBAMA enforces compliance with the Forest Code through its regional offices in each state, and has made use of the CIFOR C&I, and especially the CIFOR C&I Brazil test findings, to revise guidelines to audit the activities of companies involved in the timber business in the state of Para (Spilsbury, 2005).

The USFS tested the CIFOR C&I in the state of Idaho and developed a standard framework for the monitoring of the sustainability of the US Federal Forests. This framework draws extensively on CIFOR research and has been applied in test areas that cover more than 7.5 million ha of forest in the USA. The USFS initiative has also been influential in standards development for forest management in Canada and Mexico (Spilsbury, 2005).

There is potential for additional spillovers in coming years from new certification initiatives emerging in the oil palm industry and in coffee, soybean, banana and citrus production. Development of C&I for resource management is an area that remains of strategic importance for CIFOR and the CGIAR more generally.

The variety of cases of research uptake and widespread research influence highlight the strategic relevance of CIFOR C&I research and the range of 'pathways' through which outcomes can result. The variety and number of positive outcomes serve to highlight the IPG nature of the CIFOR C&I research.

Enhancing research uptake and impact: lessons learned

The experience gained from the CIFOR C&I research, coupled with findings from the literature on effective means of promoting research uptake, has been used to help formulate best practice guidelines for research practitioners and managers. Empirical findings from the C&I research were distilled (Spilsbury and Nasi, 2006) and the general conclusions are summarized below.

In general terms, research approaches that seek direct engagement with the intended users (e.g. participatory approaches and 'action' research) reduce the gap between innovation suppliers and innovation users by making them a part of the same process and allowing two-way communications in the development of research-based solutions. The C&I project actively engaged key users through its advisory panels, and this helped to enhance research uptake, especially among certification bodies and the FSC.

Important strategies to enhance the use of research-based innovations and their influence/impact are highlighted in Bero *et al.* (1998), Tabor and Faber (1998), Sizer (2001) and Douthwaite (2002) and include:

- Seek out powerful or influential alliances/partnerships for uptake and ‘promotion’ from the outset, selecting a strong and credible lead agency.
- Ensure that the innovation has a volunteer ‘champion’ in key ‘impact pathways’, through the entire process from initiation of research to eventual impact.
- Adopt a pluralistic attitude to the research process and encourage multi-institutional ownership of insights and innovations.
- Invest in ‘market research’ and learn from the audience through advisory groups, planning workshops, partnerships and networks.
- Build the intended audience into the research process and seek feedback at all stages.
- Translate research into ‘operational’ language’, e.g. management suggestions or policy decision options.
- Embed research within influential ‘change processes’ (e.g. policy change processes or development initiatives).
- Invest in outreach processes and make use of a combination of approaches to enhance uptake, such as holding ‘launch events’ for key products and findings; use the mass media to reach large but important constituencies; develop good interpersonal channels of communication with key influential individuals (or make use of partners who can do this); use Internet and e-mail list servers as communication tools, not as a dissemination strategy; send frequent reminders or conduct repeated demonstrations to intended users about the innovation; and invest in interactive ‘educational’ meetings (e.g. ‘best practice’ discussion forums) that involve researchers and users/practitioners.

Clearly, in NRM policy research, producing research outputs and relying on passive dissemination approaches is not sufficient to maximize uptake and impact. Processes for policy (and often technology as well) adoption are complex and iterative. Because passive dissemination of information is generally ineffective, greater emphasis on building ‘ownership’ of research innovations or policy recommendations is required. This implies understanding user or ‘target audience’ needs and the use of networks or the formation of alliances or partnerships to help communicate and promote research-based innovations.

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12 The Major Lessons from the Case Studies

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The case studies described in the previous chapters are illustrative of the state of impact assessment of natural resource management research (NRMR) in the Consultative Group on International Agricultural Research (CGIAR). Their results have shown that the benefits of successful NRMR may include productivity enhancement, risk reduction and resource conservation, improved environmental services, and more reliable information for facilitation of water and land management policies, all of which contribute to both the Millennium Development Goals and to the mission of the CGIAR to 'contribute, through its research, to promoting sustainable agriculture for food security in the developing countries'. While the case studies have documented the range of actual and expected benefits that derive from improved natural resource management (NRM) technologies resulting from well-focused research, they also suggest avenues for improving impact assessment methodology for NRMR.

Overall, the case studies provide examples of investments in NRMR projects that have paid off. Yet, the case studies represent only a small fraction of the NRMR portfolio of the CGIAR and thus they should not be mistaken as a parallel for the kind of meta-analyses that exist in the germplasm improvement (GPI) research area (Evenson and Gollin, 2003). Hence, conclusions about aggregate CGIAR investments in NRMR cannot be drawn at this point. In spite of this limitation, the results of these studies provide indicators of the potential value of NRMR, and are also helpful in designing future impact studies. Below, we summarize the results related to two dimensions of NRMR outcomes: adoption and investment efficiency. We conclude the chapter with a summary of lessons learned.

Adoption

The innovation literature suggests that rates of adoption of innovation are affected by the effectiveness of transfer of knowledge and marketing efforts (Sunding and Zilberman, 2001). Applied research programmes consist of outreach and interaction with potential adopters to refine the technology and identify barriers for adoption. Software producers cooperate with likely users to debug their product and refine their user manuals. Plant breeding research includes field trials in farmers' fields, and adaptive research is emphasized in other lines of agricultural research. Initial outreach efforts generating knowledge to ease marketing and to enhance adoption are especially important for NRMR, since it frequently results in new products or management strategies without a dedicated marketing network.

The case studies indicate that some of the projects included a significant outreach component for NRMR, resulting in either embodied or disembodied innovations. The work at the International Maize and Wheat Improvement Centre (CIMMYT) (seeding machine), the World Agroforestry Centre (planting material), the WorldFish Centre (fish) and the International Centre for Agricultural Research in the Dry Areas (ICARDA) (vegetation) have resulted in embodied technologies, and the Centres generated outreach packages and collaborated with private companies, non-governmental organizations (NGOs) and government agencies in scaling up and diffusing the technology. Similarly, in the case of the International Centre for Tropical Agriculture (CIAT) (seeds and vegetation), the development of the technology and an outreach strategy – although limited to the original project sites – were part of the project concept.

In cases where the NRM technologies are not embodied, i.e. where the research product is knowledge (designs, decision rules, procedures), the marketing leading to their diffusion is more complex. In some cases, a network of private consultants may exist or may emerge. When the disembodied technologies lead to the purchase of physical inputs the sellers of the inputs may provide consultant services or collaborate with consultants. An example is fingerling producers in aquaculture, who often provide advice to grow-out fish producers. However, if the new NRM technology reduces input use, the sellers of inputs may suppress spread of the new knowledge and, unless a viable source of information emerges, adoption will suffer (Wiebers *et al.*, 2002). A major problem for the diffusion of disembodied technologies is that smallholders in developing countries have limited access to private extension services (although they are becoming increasingly abundant in some developing countries, like India) and thus are less likely to adopt disembodied NRM technologies unless effective public sector agencies or NGOs provide the knowledge.

In the case of macro NRMR, the adopters are not farmers but governments, cooperatives, NGOs and firms. These innovations are disembodied and, for example in the case of the International Water Management

Institute (IWMI), are incorporated in larger policy packages. The results of macro NRMR may be disseminated through formal channels like printed publications or informally, through contact with policy makers.

The case studies' findings are in line with the adoption literature showing that adoption rates of micro NRM innovation increase in response to an increase in expected gains and a perceived reduction in risks. The cases also confirm that key socio-economic factors affect the rate of adoption, including human capital, farm size, land quality and climatic conditions, among others. An outstanding example of large-scale adoption is the zero/reduced tillage technology. This technology applied to field crops has been adopted in many parts of the world. To introduce the technology in India, CIMMYT provided standards for technology testing and local adaptation, which can be regarded as the establishment of a kind of informal technology certification procedure. The NRMR relied on an existing embodied innovation, and CIMMYT contributed to large-scale adoption by: (i) providing the additional knowledge required before implementation could be achieved; and (ii) playing the role of an 'honest broker' for standardizing the technology assessment procedure, including methodologies and designs of supportive research such as appropriate on-farm experiments and the publication of results.

The World Agroforestry Centre case is another example of substantial diffusion of a technology. To achieve adoption of simultaneous intercropping of leguminous trees in maize by some 77,000 farmers in Zambia (see Table 12.1), the Centre linked up with World Vision, an NGO, to establish a network of nurseries that provided planting material at low costs to farmers. However, the cost-effectiveness and the merit of these investments are not clear. The latter example again raises the question of the International Centres' relative advantage in becoming involved in extension. Centres may have to temporarily provide this support in situations where the national extension systems are dysfunctional, in emergency situations following a tsunami or other natural disaster, or in post-conflict situations like Afghanistan.

As established in Chapter 3, adoption of NRM technologies is induced by incentives provided by markets and policies. This has been shown in the case of the cactus/*Atriplex* alley-cropping technology of the ICARDA project in Morocco and Tunisia. Results of the research allowed for increasing and stabilizing fodder reserves, thereby providing an effective risk-hedging strategy for the dry areas. By reducing soil erosion at the same time, it also generates environmental benefits. Morocco and Tunisia provided subsidies to internalize the latter benefits, which helped the diffusion of the cactus/*Atriplex* alley-cropping technology in the ecologically sensitive dry land areas of the Magrheb/Mashref region. It is not clear how the subsidy amounts compare with the marginal value of the social benefit generated.

In the CIAT case, the NRMR was conducted on outreach methods. The researchers did not develop a new farming technology, but instead interacted with farmers and helped them to select the appropriate

Table 12.1. Adoption of natural resource management research projects.

Centre	Scale of adoption, actual (A)[a] and predicted (P)[b]	Unit of adoption	Adoption model	Limitations
CIAT	8 (A); 22,400 (A)	Villages; tonnes of cassava per year	Field survey in project villages	Factors that determine up-scaling remain unknown
CIFOR	45 million (P)	Hectares of forest under certification	Intuitive model: interviewing key informants, assessment of certification documents	Causality difficult to establish
CIMMYT	0.82 million (A); 3.4 million (P)	Hectares; hectares	Predicted adoption area based on sales of drill machines	Indirect adoption measurement
ICARDA	Tunisia: 470 (A); 96,000 (P) Morocco: 1,650 (A); 350,000 ha (P)	No. of adopters (Tunisia); area of adoption in hectares (Morocco); prediction of secondary effects (e.g. herd size)	Farm household survey; extension records; Logit model	Small sample size in adoption survey
IWMI	50,000 (A); 7,500 (A)	Number of downloads; copies of IMT guidelines distributed	Bibliometric assessment using the Web of Science® and Google Scholar™	Attribution to policy adoption not possible
World Agroforestry Centre	About 77,000 (A)	No. of farmers	Informal field surveys	Results of formal adoption models ambiguous
WorldFish Centre	1,000 (A); 15,000 (P)[c]	Tonnes of fish per year	Trend analysis of fish production	Only indirect adoption indicator

[a]A refers to *ex post* evidence of adoption in the project intervention area by the end of the data collection of the study, i.e. around 2002/2003.
[b]P refers to the predicted adoption on national level outside the project intervention area.
[c]Calculated on the basis of the observed annual growth rate up to 2016.

technologies for each location. These technologies included new varieties, intercropping, fertilization, etc. To some extent, this type of research is similar to marketing research on new techniques for managing outreach and product introduction strategies, so it has potential as a public good if it results in generalized principles that are useful elsewhere. For example, the methods of participatory research developed by CIAT could be adopted by national agricultural research systems and other groups in the public sector, and even by the private sector (like consultants). As we will see later, the participatory research process itself generated a decent rate of return, as farmers followed the advice given by the researchers. However, we do not have good evidence to determine whether the general knowledge generated by this case has been adopted elsewhere.

Generally, measurements of adoption and attribution are far more complex for macro NRMR than micro NRMR. It can be difficult to identify direct indicators of uptake of an NRMR product, but indirect measures of its use through citations and feedback can be used. As shown in Table 12.1, while many policy makers have sought IWMI information, it is not clear how many have actually applied it and how. IWMI's research on evaluating irrigation management transfer experiences provides policy makers with better information regarding the introduction of market-based incentives for the management of water resources. The exact polices are likely to vary across locations. The implementation of these incentives can lead to adoption of water-conserving technologies and other changes in resource allocation. Hence, the impact of the IWMI research project can, in principle, be derived from observed changes on the ground. However, attribution is a problem since the changes may have happened anyway and the IWMI results may just have augmented the implementation process, rather than ultimately triggering it. The evidence provided by IWMI for adoption of its water policy-related research products is derived from web-based measurement of demand for information. However, it was not possible to establish the ultimate link to policy adoption, nor was there information that would establish the on-farm benefits of the policy change.

Similarly, the Centre for International Forestry Research (CIFOR) case is constrained by a lack of empirically established attribution, although the adoption data were rather concrete in terms of the area of forest certified. In this case there are indications that the research shaped the formulation of forest product certification standards that may have influenced forest production on a large scale (45 million ha). Again net benefits of certification, which can be measured in principle on the supply side (change in producer behaviour) and the demand side (change in consumer behaviour), were not calculated.

There is a minimal tradition of impact assessment of NRMR, and the case studies had to rely on limited data and use indirect indicators (e.g. sales of specialized drills in the CIMMYT study to estimate acreage; citations in Google Scholar™ in the IWMI case) of adoption and impacts. Some technologies were introduced recently and therefore estimation of actual and predicted adoption based on trajectories was introduced, as seen in Table 12.1. Such projections are common in technology assessment studies, but they introduce another element of uncertainty into the results.

One of the problems is that national agricultural statistical agencies rarely collect data on adoption of NRM technologies, while data collection on the use of seeds, fertilizer or machinery is more likely to exist. Therefore, studies of NRM almost always require primary data collection and related assessment approaches. A significant problem in these case studies is that a conscious impact assessment scheme was not part of the initial design of the NRMR projects. All the case studies were thus an add-on activity. Therefore, in most of the studies, the data were based on recall and the impact assessment researchers used best available and multiple impact indicators – some of them clearly suboptimal (see Table 12.1). Hence, in some cases data collection had to use sampling schemes that made the establishment of treatment and control groups problematic. Furthermore, some studies conducted the empirical analysis without relying on a formal conceptual framework for data collection and deriving hypotheses, and some of the conclusions were based on intuition and informal analysis. These deficiencies are not unique to these case studies. What all this suggests is the need: (i) to strengthen tracking of the uptake and embedding of CGIAR NRMR outputs into improved technologies; and (ii) for more systematic and rigorous measuring of adoption – where, by whom and to what effect.

Investment Efficiency and Impact

All five micro-level NRM case studies applied the partial equilibrium surplus analysis. It assumes that the new technologies expand supply, resulting in increased quantities and lower prices of homogeneous products (see upper part of Fig. 12.1).

However, none of the five projects dealt with innovations that improve quality of outputs, reflected in a shift of demand. The conceptual framework recognizes that technologies affect environmental quality in several possible ways. In the lower part of Fig. 12.1, environmental goods and services are assumed to be complements of the economic goods. For these cases, the NRM technology both increases output (from q_0 to q_1) and improves environmental quality (from B_0 to B_1). Some of the case studies (e.g. CIMMYT, CIAT, ICARDA) demonstrated such complementarity, but these impacts were not always quantified and monetized. Some studies estimated the impact on a range of other objectives, including improving environmental quality, conserving natural resources and reducing human health risks, but these were not formally included in the welfare measures. As shown in Table 4.3 (Chapter 4), two of the five case studies had calculated producer and consumer surplus with the latter exceeding the former, suggesting inelastic demand, which is reasonable for basic food

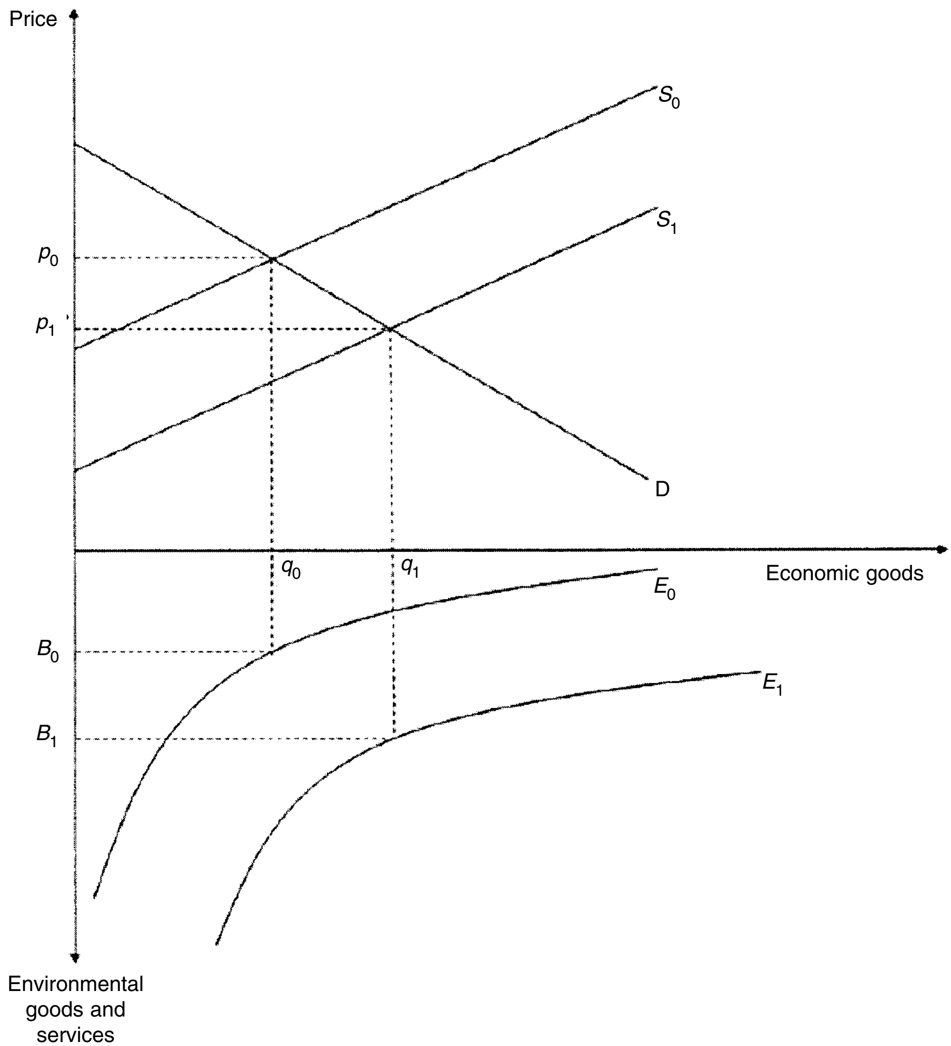

Fig. 12.1. The economic and environmental effects of a new natural resource management technology.

products. In the CIAT case, only producer surplus was calculated because of the limited scale, resulting in minimal price effects. In the World Agroforestry Centre study, no economic surplus measure has been calculated. None of the studies considered the welfare of the input manufacturers. This omission might be especially significant in the case of CIMMYT, where the NRM technology included machines produced by private suppliers. However, it could also have been important in some of the other cases.

The conceptual analysis, and sometimes the empirical analysis, recognized that the research projects were likely to affect other dimensions besides yield and cost. For example, the analysis of the projects of CIAT, the World Agroforestry Centre and the WorldFish Centre have recognized that these NRM innovations were likely to increase farmer knowledge and their understanding of ecosystem functions, i.e. deepening of human capital asset, leading to higher efficiency of existing technologies and other benefits in the future.

Practically none of the cases applied formal methods of economic valuation of non-market effects, including environmental effects on natural resources and human health effects. Some of these effects may be internalized by the adopters of the technology and are, at least partially, included in farmer surplus: e.g. the reduction of soil erosion in the CIAT and ICARDA cases. On the other hand, due to the non-rival character and the non-exclusiveness of some of these NRM outputs (off-site and off-time externalities), true non-market effects exist. While these were identified by the case studies, they were not quantified in monetary terms. However, it was shown that most of the identified non-market effects are cost-reducing instead of output-increasing. For example, the *Atriplex* alley cropping of the ICARDA NRM project in Morocco has a positive impact on the level of pollution by reducing the level of sedimentation in water bodies, caused by soil erosion of the conventional barley-cropping system in the dry areas of the Mashreq/Maghreb region. Likewise, both the World Agroforestry Centre and the CIMMYT projects have positive longer-term effects on the climate, while the latter especially has demonstrated water conservation effects. Monetization of these effects, except for the ICARDA Morocco case, using simple environmental accounting approaches, was not attempted. In some of the cases the valuation of environmental and resource benefits requires additional studies using solid theoretical frameworks. For example, in the CIMMYT case, water savings effects were established. Determining the economic price of water would require a resource economic model to quantify user costs. Given the resource limitations, emphasis was placed on estimating the direct effects of the technologies. However, none of the cases seem to have generated environmental amenities like aesthetic values, improved ecological conditions or environmental losses (loss of biodiversity) that may necessitate the use of contingent valuation or similar techniques.

As environmental effects have not been measured, the rates of return calculated by the five case studies of micro NRMR projects are incomplete. Since obtaining this component of impact is costly, some policy makers may elect to ignore it if the economic rate of return is sufficient. However, ignoring these environmental factors in the calculation of the internal rate of return (IRR) provides only a partial measure of the relative merits of the NRMR projects.

A similar measurement problem was observed on the cost side. The full costs of the respective NRMR projects (especially the fixed costs) turned out to be difficult to measure, because some activities deemed crucial for a successful outcome of the NRM projects were jointly done with other projects and the share of costs attributed to the NRM effort was not fully estimated. These underestimations of costs may possibly offset the under-valuations of environmental benefits. The costs presented in Table 4.3 include the direct Research Centre costs and, in some cases, the cost of farmer experimentation of the technology and the costs of outreach. The projects are rather modest in size, since the reported costs range from around US$1 million to a maximum of US$4 million, with most of the projects costing around US$3 million.

Based on the estimated costs and benefits of the micro NRMR, the rates of return (IRR) are all above 10%, which is a respectable rate of return. However, rates vary considerably from about 12% to almost 60% (see Fig. 12.2; see also Table 4.3 in Chapter 4). On the other hand, the IRRs may not reach the levels reported for investments in GPI research. Some of the reasons for this difference have been made clear through these case studies and through the theoretical discussion in Chapter 3.

It must be recognized that there are external factors not attributable to the research investment, and therefore not quantified, which also affect the IRR. Among these factors are network externalities, social capital, prior knowledge, institutional arrangements and social, cultural and policy conditions. These factors, in some cases, may be partially embedded in the costs and benefits of technology adoption and, therefore, should be reflected in adoption rates, but they rarely are explicitly revealed. In conventional cost–benefit analysis, their costs are treated as

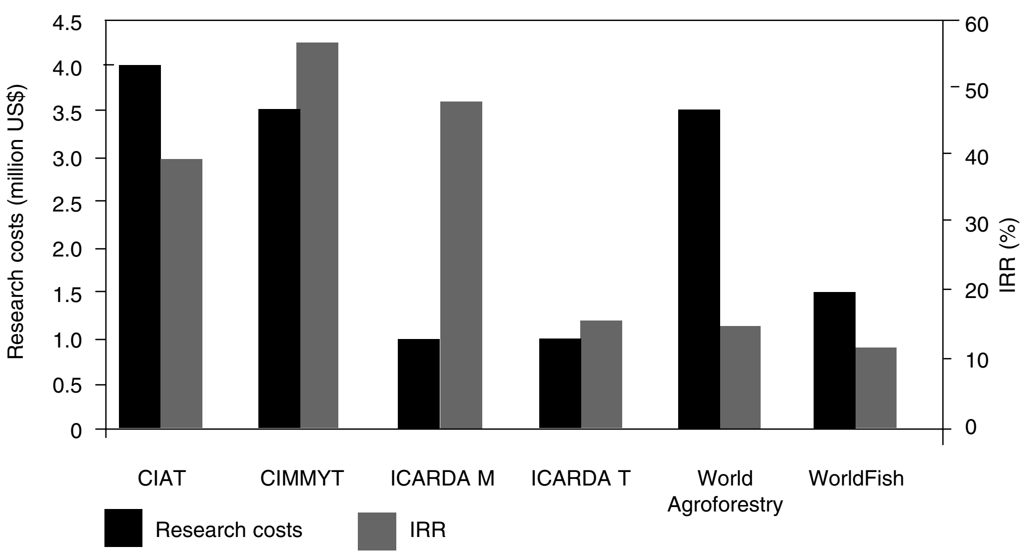

Fig. 12.2. Research costs and internal rates of return (IRRs) of the case studies.

sunk costs and hence are ignored. However, it is nevertheless important to describe those conditions, as they can be indicators of the potential augmenting effects or constraints of the adoption of NRMR products. In the latter case, policy shifts or social change processes can reduce impact.

The micro case studies are good examples of how NRM projects do not usually enjoy the benefits of both private and public marketing infrastructures which exist for seeds and effectively help to diffuse new varieties at low cost. In addition, although not shown in the case studies, NRM projects sometimes have to overcome existing path dependencies and vested interests. For example, in the case of integrated pest management, it has been shown that adoption can be inhibited and the impact of the technology limited even when the technology being promoted is economically attractive (e.g. Cowan and Gunby, 1996). Thus, external factors can introduce uncertainty to the rate of return, as erstwhile conducive conditions can also turn negative. That is why, for example in the case of the ICARDA project, the randomness of the IRR has been made explicit using stochastic simulation techniques, thus accounting for uncertainty in feed prices.

Summary of Lessons

Summarizing the seven case studies of impact assessment of NRMR and analysing concepts and methods from the literature, it becomes clear that assessing the impact of NRMR remains challenging. Combining the theoretical analysis of Chapter 3 with the findings of the seven NRMR impact case studies yields a number of lessons, but also raises new questions.

First, the NRMR impact studies demonstrate that, at least in cases where benefits can be quantified, CGIAR investment in these NRMR projects has paid off. However, the IRRs do not, in general, reach the levels achieved for crop GPI research. At the same time, NRMR is often likely to have additional positive net environmental benefits that, if quantified, would most likely raise the rates of return for this research. More efforts are needed to quantify such effects in future studies. This may require collecting baseline information or additional matching of treatment and control groups. Investment in such efforts should be done selectively, so that incremental benefits are expected to exceed the extra costs.

It has been shown in this chapter that the tools of welfare economics can be applied to quantitatively assess the impact of NRM projects. Especially for the micro-level projects, an assessment of expected net benefits (discounted), distribution of benefits among groups and impacts on income distribution provide useful information and can be derived with reasonable effort. The major challenge is to organize research projects from the start with an eye on assessment of impacts, and to document costs, as well as benefits, as part of the ongoing activities of the projects. The improvement of information technology can reduce the cost of data collection efforts, so with a modest allocation of resources the quality of assessment can be dramatically improved.

The two areas of assessment that require extra effort and provide intellectual and administrative challenges are: (i) measurement of effects on the environment, human health and knowledge; and (ii) attribution of benefits (and costs) to individual projects and research groups, especially in the case of macro-level projects, when inputs may come from a myriad of sources and policy making may be affected by many sources of information other than the project being assessed. Ongoing research in environmental economics and improvements in information technologies, particularly computerized geographic information systems, are likely to improve the ability to assess environmental impacts. Further creative analytical thinking and research on this subject are needed to develop better methods of attribution and to improve quantification of the impacts of micro-level projects.

As Pardey and Smith (2004) also have concluded, the impact assessment case studies presented in this book have shown that quantitative assessment of the benefits of macro NRMR projects is challenging because of methodological and data difficulties. While the two policy projects were able to document dissemination of results, they were not able to quantify net social benefits. Future policy studies should facilitate data collection that will enable quantitative impact assessment, particularly if such assessment needs are built into projects right from the start. To measure reductions in transactions costs, losses avoided, increases in productivity, gains in time, and fewer misguided policy interventions in a multi-agent setting requires a dynamic model that includes learning and adaptation. Some of the variables have been pointed out in the models described in Chapter 3.

While policy research in NRM is most challenging, farm-level NRM technologies are more amenable to assessment with well-developed adoption models and economic surplus techniques. Nevertheless, what seems plainly obvious is the pressing need to undertake a much wider range of NRMR impact assessments. Thereafter, what remains to be done is to investigate empirically the extent of, and reasons for, differences in the rates of return between micro NRM and crop-breeding projects. The analyses presented in this book cannot answer this question. However, some suggestions can be offered.

1. One reason for the high rate of return for crop genetic improvement (CGI) projects relative to NRMR is that dissemination of results can benefit from existing – often private – extension and marketing networks, including seed companies and national agricultural research systems. NRM projects are diverse in nature and frequently require establishing a dissemination mechanism as part of the project. This deficiency in effective extension services can reduce the project benefits and increase the costs, thus lowering the rate of return. Further, the national responsibility for such dissemination often falls between the normal responsibilities of agricultural and environmental or natural resource agencies, such as in the case of introduction of agroforestry technologies.

2. The environmental impacts of both genetic improvement and NRMR projects have not been adequately identified, documented and computed. Both types of projects have environmental benefits[1] (and costs), but it is plausible to suggest that the positive environmental benefits, including genetic resource conservation and prevention or slowing down of environmental decay such as soil loss, play a more important role in NRMR projects than in genetic improvement projects; and thus the exclusion of net positive environmental benefits from calculations of rates of return has a stronger downside impact on NRMR projects.

3. There is plausible concern that rates of return fail to adequately attribute all the contributions of NRMR activities (especially in cases where they affect or help facilitate positive outcomes related to CGI), because of the complexity of the natural resource systems they affect. While there have been some attempts to partition out such contributions (see Bell *et al.*, 1995), in general there is inadequate evidence to robustly address them.

4. Research outcomes are always uncertain, and thus only a fraction of research projects have substantial effects. Many hundreds of CGIAR adoption and impact studies have focused on CGI; and commodity-oriented Centres such as CIMMYT have invested much more in impact assessment than have NRM or policy-oriented Centres. Thus, one would expect more uncertainty about the impacts of the NRMR projects. It is imperative to strengthen data collection efforts focused on adoption of improved NRM technologies and to plan for impact assessment needs in NRM project design and implementation, in order to better assess them.

In conclusion, the fact that the seven cases followed different approaches to the assessment of impacts has provided a wide range of insights on the reality of impact assessment of NRMR, and has provided useful lessons to further develop a relevant and practical set of guidelines for impact assessment in the CGIAR system. They suggest that, with the expanded categories of new innovations, assessment of research productivity requires modelling, data collection and analysis to accommodate the uniqueness of the research categories. This may include assessing non-market impacts and impacts on natural resources and the environment. It is also evident that any advance in impact assessment methodology will have to deal explicitly with the classic problems of: (i) developing acceptable counterfactuals; (ii) attribution of benefits; and (iii) collection of baseline data. Most importantly, it also must pay attention to other real-world issues such as credibility, plausibility and transparency.

[1]Yield-increasing seed varieties can reduce the acreage allocated to agriculture and may slow deforestation, although such causality will depend on institutional conditions.

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13 The Way Ahead – Impact Assessment of Natural Resource Management Research

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Fifty years ago, two seminal studies by Griliches (1957, 1958) on hybrid maize established state-of-the-art methods to assess the diffusion and social rate of return of new agricultural innovations. These methods spawned a large body of literature, documented and summarized by Evenson and Rosegrant (2003), that quantified the successes of the Green Revolution and the significant economic benefits of germplasm improvement research to poor developing countries and emerging market economies. These methods provide a foundation for analysis of natural resource management research (NRMR). The need to incorporate environmental side-effects, the impact on natural resources, learning and other considerations into assessments of NRMR poses methodological challenges and requires new and innovative approaches. The methodologies developed in Chapter 3 and in the case studies, and the assessments thereof, provide direction for future NRMR impact studies. Future studies will have to develop integrated modelling of physical, biological and sociological phenomena into economic welfare evaluation frameworks and analyse the dynamics of natural resources, environmental indicators and indicators of distribution and human well-being. The studies in this book also provide lessons that go beyond the need to expand the research evaluation methodology. They suggest changes in the way NRMR is organized and managed, and the role and extent of involvement of researchers in Centres of the Consultative Group on International Agricultural Research (CGIAR) in the innovation chain. Thus, we envision several new directions that improve NRMR and its assessment. These changes can also apply to other areas of research.

Impact assessment is part of a system of accountability that must be incorporated into research, development and extension activities associated with new technologies. For NRMR and other research investments, the CGIAR may consider introducing cost accounting to attribute costs to various projects, as well as ongoing documentation and the assessment of adoption, use and benefits to provide the most important input for impact evaluation: reliable data. With the declining cost of information technology, enhancing data collection and monitoring is becoming increasingly affordable. The CGIAR should consider extra benefits and costs as it upgrades its documentation and monitoring infrastructures. There is no substitution for background effort and pre-design. Impact assessment needs to rely on a strong foundation of conceptualization and data, which includes modelling, baseline measurements of key variables and distinction between treatment and control populations. This is especially true with NRMR, where the data collection is not only for economic behaviour, but for natural and biological phenomena as well. With new multidimensional geographic information systems, sometimes the selection of an exact experiment location should be dependent on data availability, and sometimes launching new projects will be accompanied by the build-up of data sources. The background work should emphasize identifying and building data indicators for adoption, productivity, economic welfare, status of the environment, health and poverty.

Since NRMR leads to changes in stocks of natural resources and human capital, it is essential to develop benchmarks that document the initial conditions that, in turn, allow for measurement of changes associated with the application of knowledge generated by the NRMR on the various stocks. It is not sufficient to measure changes in physical quantities; it is essential also to monetize these changes. Most of the NRMR projects included in the Standing Panel on Impact Assessment's (SPIA) impact assessment initiative have emphasized improvements of environmental quality and reduction of resource management problems. For example, the International Maize and Wheat Improvement Centre (CIMMYT) project showed a reduction in fuel required per hectare (resulting in less carbon released into the atmosphere) which might have contributed to sequestering atmospheric carbon, but these impacts have not been quantified in physical or monetary terms. The International Centre for Tropical Agriculture (CIAT) project showed reduced soil erosion and improved water quality, but the quantification of the benefits, which are measured by the losses avoided, was only partial. The same is true for the other micro- and macro-oriented projects. Development of effective indicators of benefits that can be monetized is a priority in developing a more comprehensive assessment framework of the value of natural resource management (NRM) projects.

Measuring the contribution of NRMR to farmer knowledge in the context of farmer participatory research (FPR), and assessing the impact of knowledge on productivity, requires an appropriate sampling design and the collection of specific data. The CIAT case study has shown that, unless data on knowledge are collected e.g. through knowledge tests, for participants and non-participants before and after project implementation, even advanced econometric methods do not allow for clear separation of the effects of knowledge from the effects of the technology on productivity. Thus, in this case, the long-term productivity effects of increased knowledge remain unaccounted for. Hence, in FPR projects, conducting baseline surveys is essential. Such surveys can provide the means to develop a better understanding of the mechanisms through which FPR can change behaviour and increase productivity in the short, medium and long term (see e.g. Godtland *et al.*, 2004; Tripp *et al.*, 2005).

Assessing the evolution of stocks of physical and human capital requires having counterfactuals, i.e. assessments of the evolution of the stocks that do not receive the treatment. A critical dimension of benchmarking efforts is the establishment of treatment and control groups, and parallel measurement of changes in indicators within and across groups. Chapter 3 has provided the conceptual framework for doing this, while the lesson from the impact assessment case studies is simple: unless impacts are explicitly measured in the pathways right from the start, the necessary efforts (and costs) to incorporate them in *ex post* studies will be high. One of the major limitations of the case studies was that they did not completely incorporate changes in key stocks resulting from the NRMR-derived intervention. Future impact assessment studies should conduct the background work that will allow more complete assessment of changes in stocks and the value of these changes.

Impact assessment cannot be avoided. As we have seen in this book, impact assessment studies are costly, challenging and imperfect, but they are essential for ensuring accountability and improved resource allocation. Scientists spend donors' money and are accountable in many ways. Assessment measures should adhere to and meet multiple criteria. On the one hand, they must be rigorous, taking into account recent scientific developments and addressing multiple dimensions of NRMR. On the other hand, impact assessment results need to be easily accessible to a non-technical audience. To be effective, impact assessment studies need to take a parsimonious approach that will result in several indicators: internal rates of return, measurements of impacts on the environment and on poverty, changes in knowledge and institutions, and citations in the literature. Quantitative impacts measures are essential to have and, when supplemented with personal accounts and testimonials, satisfy accountability demands and provide thorough evidence for evaluation investments in agricultural research.

NRMR projects have variable internal rates of return (IRRs). As demonstrated throughout the book, the IRR depends on factors such as the characteristics of the innovation, socio-economic conditions and the effectiveness/existence of extension and appropriate marketing networks associated with its introduction. Furthermore, the environmental and natural resource impacts, as well as the distributional effects, may not be fully captured in a monetized IRR. Attempting to find an IRR (or IRRs if several parties are invested in a technology) is an important element for impact assessment of NRMR. However, IRRs are only partial indicators, and it is important to analyse why they are high or low. Lower than expected IRRs may be indicators of a weak project, they may indicate underdeveloped outreach or extension efforts, or they could simply be the result of insufficient recognition of environmental and other impacts.

The building up of skills and networks is essential for NRMR projects. These factors are important at various levels. The success of NRM projects is frequently dependent on adaptation to local conditions and an ability to develop mechanisms that result in ongoing learning. This suggests that, in certain circumstances, investment in building farmers' knowledge and participatory research efforts are essential. Because of the interdisciplinary nature of NRMR, communication across disciplines and the ability of scientists to internalize the knowledge of other disciplines are crucial to the productivity of NRMR.

The case studies, especially those with significant FPR, suggest that applied NRMR may include significant elements of extension in order to establish 'proof of concept', fine-tune the technology or identify barriers to adoption. The equivalent of FPR in the business world is market research that allows the supplier of a product to better understand the needs of different client groups. Thus far, Centres have rarely developed marketing strategies. The discussion of this aspect in Chapter 3 provides a basis for implementing a strategy of scaling up NRM technologies. Given the heterogeneity of potential adopters of NRM technologies, testing and adaptation of technologies through FPR requires the establishment of formal arrangements with public and private extension organizations, consultants, public–private partnerships and non-governmental organizations. Such arrangements must be further developed to include joint strategies for large-scale implementation with quantitative programme targets and time plans. Much can be learned here from past failures of public programmes (such as integrated pest management (IPM) by the CGIAR; see e.g. CGIAR, 2003) and recent successes of the private sector in rapidly marketing new biotechnologies that include a knowledge component in embodied technology (e.g. Bt crops).

NRMR projects are diverse, and result in different types of technologies. Some are farm-level innovations embodied in new equipment, others are farm-level decision rules and still others are policy decision rules. They are less standardized than crop genetic improvement (CGI), and thus their impacts may be less certain. In many cases, they do not have a dedicated extension channel or marketing network. Thus, the uncertainty of impacts and the distributional challenges are barriers to adoption, so they may require significant investment in outreach. High outreach costs may lead to strategic dilemmas. The pursuit of high rates of return may, in some cases, lead to targeting of development of innovations for regions that have sufficient scale of potential gains, to warrant the extra outreach costs. In other cases, it may lead to selection of NRMR projects in regions where farmers have significant levels of human capital, reducing the level of training and therefore the cost of the FPR effort. This may restrict the value of NRMR projects as tools of poverty alleviation, because of human capital constraints in poor regions. Thus, IRRs and poverty alleviation goals must be balanced in targeting NRMR efforts.

Investment in technologies arising from NRMR that may result in new types of products requires a strategic understanding of marketing channels. Increased reliance on market forces in the developing world also provides opportunities to engage the private sector in taking advantage of opportunities to introduce and market new technologies. The CGIAR may consider the possible benefits of research on marketing channels for innovations that go beyond estimation of adoption patterns or analysis of FPR. Such research may allow for more efficient design and evaluation of outreach strategies that are part of NRMR and other efforts of the CGIAR. The capacity to develop effective marketing strategies for new products is especially important for the future of the CGIAR, especially if it wishes to develop technologies that take advantage of new capabilities for information processing, data transfer and miniaturization that will make production more precise and environmentally sound. Some of these technologies seem too expensive to apply for developing countries, but the large-scale success of wireless telephones in the developing world suggests that there are opportunities to introduce modern information and communication technologies to agriculture in poor countries.

When the implementation of NRMR results into new technologies requires significant local adaptation and FPR, it is not clear that success in the CGIAR pilot studies will result in successful large-scale adoption of the technologies. For example, the respectable rate of return from the CIAT pilot project in Vietnam and Thailand may be insufficient for recommending that extension services in these countries should adopt the FPR approach on a broad scale in order to speed up the diffusion of cassava technologies (especially since the diffusion of the CGI component, which contributes to much of the benefit, may be achieved through cheaper outreach methods). As Feder *et al.* (2004) and Praneetvatakul and Waibel (2006) suggest, a critical factor for success of FPR (in the case of IPM) is maintaining the quality of farmer training, which may be very costly. Thus, consideration of investments by the CGIAR in NRMR projects with significant FPR and marketing components require careful analysis of returns and poverty outcomes, as well as establishing partnerships with other groups, which will allow the CGIAR to focus its efforts towards the generation of research as an international public good.

The impact assessments of the NRMR projects presented in this book did not account for their general equilibrium effects. NRM technologies that increase productivity and reduce negative environmental effects may have secondary effects through macroeconomic multipliers, and may have an impact on employment levels as well as health. These issues have hardly been addressed in the case studies, except in the case of the WorldFish project providing some indicators of nutritional and health benefits beyond the direct impacts. It is useful to provide both measures of economic surplus that will allow direct evaluation of efficiency and distributional effects and secondary impacts to obtain overall effects, relying on computable general equilibrium or social accounting metrics (Dixon and Parmenter, 1996). Assessment of secondary effects may be especially important when it comes to the macro NRMR projects, which may have economy-wide effects and large-scale impacts on variables such as employment or even overall gross national product.

An advanced toolbox for NRMR impact assessment has to include poverty reduction impacts. Most of the projects reported in this book failed to sketch out the pathways for such impacts. The Millennium Development Goals introduce a poverty focus for all development projects including research and, thus, put emphasis on the distributional effects of projects. Traditional measures include changes in the share of the population below the poverty line (Foster, 1984) and changes in the GINI coefficient. The analyses presented in this book found some indication that the micro-level projects are beneficial to poor stakeholders. For example, the WorldFish project seems to have a significant poverty alleviation effect. Similar to the environmental valuation questions, the case studies illustrate the importance also of quantifying the distributional impacts of NRMR in future impact assessment studies, if poverty alleviation impacts are of concern. The studies presented in this book were unable to do this because it became clear that the prime focus of past NRMR in the CGIAR did not necessarily have an explicit pro-poor focus; at the time when the research was initiated the priority benefit paradigms were different. As a first step, it may be useful to break the distributional measure down across regions to overcome heterogeneity and identify regions that are strongly affected by the technology. However, recent thinking on poverty treats poverty as a dynamic phenomenon and makes the important distinction between chronic and transient poverty (Murdoch, 1994; Kanbur and Squire, 2001). Hence, the impact of new NRM technologies in reducing people's vulnerability to poverty (e.g. Hoddinott and Quisumbing, 2003) is a more relevant measure that can overcome some of the weaknesses inherent in static poverty indicators. The SPIA-sponsored study on the poverty impacts of CGIAR research (Adato and Meinzen-Dick, 2005) has indicated some first steps in this direction. It can be expected that as more studies on the impact of NRMR in the CGIAR are conducted, using an advanced impact assessment toolbox and applying models as outlined in Chapter 3, the importance of such investments for poverty reduction and natural resource stock sustainability will become more clear.

The studies reported in this book present an early stage in studies on the impacts of NRMR conducted by CGIAR and other institutions. While it documents many achievements and raises important questions, it also sets several challenges for future research. Some of these challenges are unique to NRMR, and others are common to research on the impacts of other technologies. These challenges include the following.

1. *Conceptual analysis of technological impact pathways*. NRM technologies are diverse. Rigorous, relevant and practical modelling of their evolution and impacts is crucial for establishing an empirical strategy for the development of meaningful indicators, information gathering and impact assessment. Chapter 3 provides many alternative avenues to model the impact of several NRM technologies, but new technologies will require continuous efforts and better conceptual understanding, which is crucial for correct analysis.
2. *Survey design and data collection*. Determining the essential data to be collected, in a cost-effective manner. Identifying benchmarks of key stock variables and strategies to monitor them over time. Establishing counterfactuals that allow for effective statistical measurement of impacts. Developing a dynamic monitoring strategy that allows follow-up surveys and tracking the dissemination and evolution of new technologies over time.
3. *Attribution*. Careful description and documentation of the role the NRMR in the CGIAR has played in generating the new technologies. Development of procedures to assess the value of these contributions.
4. *Communication*. Presenting meaningful quantitative measures of impact and narratives that will convey the results to policy makers and to the public.
5. *Outreach*. The CGIAR Centres and other public research organizations are dynamic institutions with limited budgets and changing agendas. They are challenged to develop criteria to determine when, how and how much to invest in NRMR. Selection of NRMR strategies have to take into account their potential impacts, as well as the constraints on, and opportunities for, transferring the knowledge and extending the results from the Centres' field plots to the farmers' fields. Improvements in educational and communications infrastructure may affect the value of NRMR, and strategies for its implementation.

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