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# Priority Setting in Agricultural Biotechnology Research

## *Supporting Public Decisions in Developing Countries with the Analytic Hierarchy Process*

T. Braunschweig

## About ISNAR

*Mission*

The International Service for National Agricultural Research (ISNAR) assists developing countries in improving the performance of their national agricultural research systems and organizations. It does this by promoting appropriate agricultural research policies, sustainable research institutions, and improved research management. ISNAR's services to national research are ultimately intended to benefit producers and consumers in developing countries and to safeguard the natural environment for future generations.

*Impact*

To maximize the impact of its work in developing countries, ISNAR focuses on three objectives:

- enhancing the capacity of agricultural research organizations to respond to their clients' needs and to emerging challenges
- expanding global knowledge on agricultural research policy, organization, and management
- improving developing countries' access to knowledge on agricultural research policy, organization, and management

*Background*

ISNAR was established in 1979 by the Consultative Group on International Agricultural Research (CGIAR), on the basis of recommendations from an international task force. It began operating its headquarters in The Hague, the Netherlands, on September 1, 1980.

ISNAR is a nonprofit autonomous institution, international in character and apolitical in its management, staffing, and operations. It is financially supported by a number of the members of the CGIAR, an informal group of donors that includes countries, development banks, international organizations, and foundations. Of the 16 centers in the CGIAR system of international centers, ISNAR is the only one that focuses specifically on institutional development within national agricultural research systems.

*ISNAR's Research Report series presents the findings of research conducted by the institute and its partners in the areas of agricultural research policy, organization and management.*

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## *Supporting Public Decisions in Developing Countries with the Analytic Hierarchy Process*

T. Braunschweig

*August 2000*

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# Contents

Figures



Tables

# Foreword

Agricultural researchers are continually identifying and applying new methods and techniques that could generate solutions and opportunities to support the development of the agricultural sector. As a result of new developments in biotechnology, the search for new methods and techniques has gained great momentum. The possibility of understanding and modifying the genetic structure of living organisms is paving the way for new economic, ecological, and social contributions to society.

The principles of biotechnology, which are based on the disciplines of genetics, tissue culture, and molecular biology, encompasses biology, medicine, pharmacology, and agriculture. The fields of pharmacology and agriculture, in particular, have propelled the development of biotechnology in agricultural research.

The attempt to apply new biotechnology methods is complicated by several factors. First, heavy investments in equipment and human resources are often required, limiting the use of some techniques. Second, by the very nature of emerging technologies, techniques in biotechnology are difficult to evaluate because they have virtually no track record. Third, given the surge of new technical developments in the field, it is highly probable that the most advanced technique currently available will become obsolete within a very short period of time. Fourth, biotechnology applications represent new ethical and biosecurity dilemmas, such as the introduction of genes from one organism to another, genetically incompatible organism. Decision making in public agricultural research is further complicated by the need to balance the agendas of different interest groups.

In spite of this, biotechnology has assumed a very important role in agricultural research. Research institutes throughout the world must now decide how to integrate biotechnology into their research programs. This is why ISNAR has made new technologies in research management an area of high priority. For the same reason, Chile's national government and its Institute of Agricultural Research (INIA) have decided to reinforce the country's biotechnology capacity.

With support from the Swiss Federal Institute of Technology (ETH) and the ISNAR Biotechnology Service (IBS), INIA and ISNAR embarked on a pilot project to develop methods that support the complex decisions that must be made in biotechnology research. The Analytic Hierarchy Process (AHP), a participatory method that supports the project-selection process, was adopted for this purpose. We hope that this joint effort will benefit other institutes and research systems and help them define their policies and priorities pertaining to agricultural biotechnology.

Stein W. Bie
Director General ISNAR
August 2000

Carlos Muñoz Schick
Director General INIA

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I am greatly indebted to Peter Rieder for giving me the opportunity to conduct this study and for giving me all conceivable liberties. I also thank my colleagues at the Department of Agricultural Economics. They all contributed in various ways to improving the quality of the dissertation on which this research report is based.

Very special and warm thanks go to Willem Janssen of ISNAR for his most valuable guidance and advice at every stage of this study. He gave generously of his time beyond normal limits. Thanks to my other colleagues at ISNAR who provided a lot of constructive input, especially to Cesar Falconi, who assisted with the second workshop in Chile, and to David Bigman, who made many excellent comments on an earlier version of this report. Thanks also to Jan van Dongen, who edited the dissertation on which this report is based, to Claudia Forero, who translated “Annex A” from the original Spanish with great care, and to Oona Paredes, who edited the final version of this research report.

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Thomas Braunschweig

# Abstract

This document introduces an innovative approach to establishing priorities among biotechnology research projects. The procedure has been applied to the national technology program in Chile, for validation as a decision-making tool for public research institutions. Based on the Analytic Hierarchy Process (AHP), this procedure is well-suited for supporting highly complex decision making, involving multiple criteria. The procedure consists of 10 steps, which are discussed in detail. It decomposes the decision-making problem into a hierarchical structure, then compares the elements of the hierarchy in pairs in order to determine their relative importance. The resulting judgments are expressed as a ranking of projects. Pairwise comparisons allow the evaluators to include subjective judgments that are reached through group discussions. This compensates for weaknesses in the information base—a problem frequently encountered in the evaluation of biotechnology research. Special decision-making criteria are selected to accommodate the special features of biotechnology research. The element of uncertainty, which is inherent to the processes of research and technology adoption, is explicitly incorporated into the analysis, through the use of special criteria for estimating a project's chances of success. On the whole, applying this priority setting approach in Chile yielded encouraging results. For future applications, a range of modifications are suggested to further improve its efficiency and accuracy.

## Resumen

Este documento presenta un procedimiento innovador para establecer prioridades entre proyectos de investigación biotecnológica. Ha sido aplicado en el programa nacional de biotecnología en Chile, para evaluar su utilidad como herramienta de apoyo en la toma de decisiones de las instituciones de investigación pública. Basado en el Proceso Jerárquico Analítico (AHP) este método es apropiado para ayudar a la toma de decisiones de alta complejidad usando un criterio multiple. El procedimiento consiste en diez etapas, las cuales se especifican en detalles. El AHP descompone el problema de decisión en una estructura jerárquica y usa una escala relativa para comparar a pares para así poder determinar su importancia relativa. Los resultados de estos juicios son sintetizados para conseguir el rango de los proyectos. La comparación por pares permite a los evaluadores incluir juicios subjetivos alcanzados por medio de reuniones de grupo para poder superar la débil base de información- problema que se presenta con frecuencia en la evaluación de la investigación biotecnológica. Así como también, el uso especial de los criterios para la toma de decisión puede ser adaptados según las características de la investigación biotecnológica. Finalmente, la incertidumbre existente en los procesos de investigación y adopción ha sido incluida en análisis y jerarquías específicas que permitan las estimación de las posibilidades de éxito. En general, la aplicación de procedimiento para establecer prioridades en Chile ha producido resultados prometedores. Para aplicaciones futuras, varias modificaciones son sugeridas a fin de mejorar la eficiencia y precisión del procedimiento.

# Abrégé

Le présent rapport propose une méthode innovatrice de définition des priorités entre des projets de recherche biotechnologique. La méthode a été appliquée au Chili, dans le cadre du programme national de recherches biotechnologiques, afin de la valoriser en tant qu'outil de prise de décision, destiné aux responsables d'institutions publiques de recherche. En effet, fondée sur le procédé d'analyse hiérarchique (AHP), la méthode constitue un excellent outil d'appui pour la prise de décisions complexes et basées sur de multiples critères. La procédure compte dix étapes distinctes, dont le rapport fournit une analyse détaillée. Elle consiste tout d'abord à décomposer un problème de prise de décision selon un modèle hiérarchique. Ensuite, les éléments sont comparés par paires, en vue d'en déterminer l'importance relative. La synthèse des jugements ainsi obtenus permet de classer les projets. La comparaison des éléments groupés en paires permet aux évaluateurs d'inclure des jugements subjectifs, résultats des discussions de groupes, en vue de pallier les insuffisances de la base d'information obstacle fréquemment rencontré dans l'évaluation des projets de recherche biotechnologique. En outre, la méthode prévoit des critères de prise de décision spéciaux pour bien tenir compte des réalités spécifiques du secteur biotechnologique. L'élément d'incertitude - qui est inhérent à la recherche comme au processus d'adoption de technologies nouvelles - est maîtrisé par l'application de critères qui permettent d'estimer les chances de réussite. D'une façon générale, les résultats de la mise en œuvre de la méthode au Chili sont encourageants. En conclusion du rapport, l'auteur propose une série de modifications qui permettront de perfectionner la procédure, en en augmentant l'efficacité et la fiabilité.

# Acronyms

| | |
|---|---|
| AHP | Analytic Hierarchy Process |
| CGIAR | Consultative Group on International Agricultural Research |
| CONICYT | Comisión Nacional de Investigación Científica y Tecnológica (National Committee for Science and Technology Research) |
| CRI | regional research center (centro regional de investigación) |
| DNA | deoxyribonucleic acid |
| ETH | Swiss Federal Institute of Technology |
| FAO | Food and Agriculture Organization of the United Nations |
| IAW | Department of Agricultural Economics |
| IBS | ISNAR Biotechnology Service |
| INDAP | Instituto de Desarrollo Agropecuario (Institute for Agricultural Development) |
| INIA | Instituto Nacional de Investigaciones Agropecuarias de Chile (National Agricultural Research Institute of Chile) |
| IPR | intellectual property rights |
| ISNAR | International Service for National Agricultural Research |
| MINAGRI | Ministerio de Agricultura de Chile (Ministry of Agriculture, Chile) |
| NARS | national agricultural research system(s) |
| NPV | net present value |
| OECD | Organisation for Economic Cooperation and Development |
| PNB | Programa Nacional para el Desarrollo de la Biotecnología Agropecuaria y Forestal (National Program for the Development of Agricultural Biotechnology) |

# Executive Summary

The objective of this report is to assess a priority setting approach to support agricultural research managers in public institutions, especially those in developing countries, through the difficult process of choosing among biotechnology activities. A priority setting approach called the Analytic Hierarchy Process (AHP) was applied to the selection of projects for Chile's National Biotechnology Program. AHP was selected as the methodological basis for this study because it structures multicriteria-decision problems hierarchically and employs pairwise comparisons to determine preferences within a set of alternatives. In this report, AHP is assessed for its validity and viability for priority setting in agricultural biotechnology.

The report begins with the rationale for public-sector research, analyzing the major trends and challenges that will shape the agenda of public agricultural research organizations. A literature review of the potential role of biotechnology in agricultural research in developing countries is also included. The main difficulties in priority setting for public research are identified, including the multicriteria nature of the public decision-making process, measurement and aggregation problems pertaining to different types of research impact, and a poor information base that is due in part to the forward-looking nature of biotechnology research.

The development of the priority setting approach for use in agricultural biotechnology is guided by three working hypotheses: (1) the specific features of biotechnology-based research require that special criteria are defined and incorporated into the priority setting approach, (2) the sources of uncertainty with regard to research success and the rate of adoption of the results by end users must be carefully identified and included in the approach, and (3) the strategic component of biotechnology research, in terms of strengthening research capacity, should be explicitly assessed. In this study, AHP is adjusted to accommodate these hypotheses.

The application of AHP to Chile's biotechnology program involves a 10-step procedure, which is described in detail. This procedure includes the modeling of the specific decision problem, the elicitation of criteria weights by decision makers, and the assessment of research impact based on previously-collected data and the subjective judgments of project leaders and research planners. In the case study, seven biotechnology research projects are prioritized using economic, social, environmental, and institutional criteria. Each project's chances of research success and adoption are evaluated separately, then combined with the impact assessments in order to determine the final ranking of the research projects. To test this ranking, a sensitivity analysis was done, using scenarios with different criteria weights. The sensitivity analysis indicates that AHP produced a fairly stable rank order.

The AHP method proves its potential for coping with multicriteria decision problems. Its flexibility in modeling the problem allows the working hypotheses to be accommodated. AHP also meets the requirements for participation, transparency, and a standardized measurement scale. Because it is simple and intuitive, the application of AHP does not require special analytical skills. The way it structures and visualizes complex decision problems is straightforward and appealing. It uses pairwise comparisons to produce relative preferences among alternatives, which is particularly attractive for assessing qualitative impact.

The Chilean case study produces a favorable assessment of the ability of AHP to support decision making in public research for several additional reasons. A clear, conceptual separation between the evaluation of potential impacts, and the chances of realizing them, permits a detailed analysis of the sources of uncertainty and provides useful information regarding the potential shortcomings of the research. Working with two groups of experts allowed different perspectives to be incorporated into the priority setting exercise. The application also reveals that biotechnology features, such as biosafety regulations and public acceptance, seem to be strongly context-dependent in terms of their relevance. The most important result for the host country was the wide variation in the experts' weighting of the criteria. The exercise also produced sensible project priorities that provide a good basis for resource allocation.

There is still room for improvement in several areas. A major shortcoming of AHP is the large amount of pairwise comparisons required when many alternatives are to be evaluated. The importance of fine-tuning the sequence of steps has been made apparent with regard to information collection and processing. More subject matter experts need to be involved in meeting specific information needs, and, in future applications, more attention must be paid to the communication between the participants. Representatives of end users, especially farmers, should also participate in the process directly. One major difficulty for AHP is evaluating the rate of adoption of the more strategic research projects, because, in this study, the end users are researchers rather than farmers. A better approach for future applications is to develop criteria that are not specific in terms of end users.

Further modifications are needed in order to allow for the uncertainty caused by rapidly changing environments within research organizations. The strategic component of research projects, i.e., capacity building and human resources, is already captured by specific criteria. However, the way in which the costs of the research projects were incorporated into the approach was deficient and needs to be improved. Various ways of dealing with this issue are suggested. Several options are presented, which should be assessed for their time-saving potential and their implications for the quality of decision outcomes. More research is also needed to determine the optimal point at which to stop decomposing the decision problem.

# 1. Introduction

## Background and Objectives

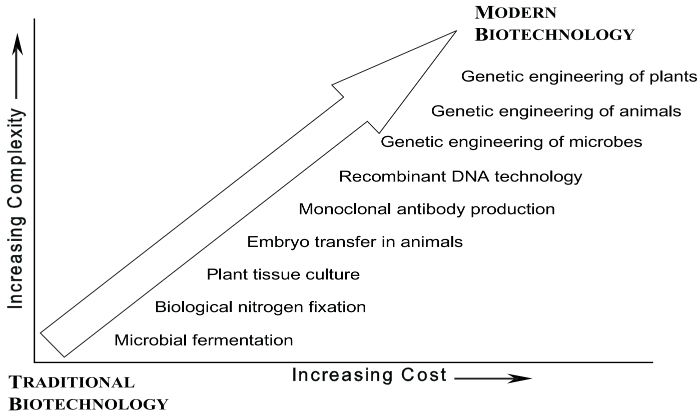
Knowledge is the key strategic resource for economic development. The creation, distribution, and use of knowledge is rapidly gaining importance for development at individual, organizational, national, regional, and global levels (Conceição et al. 1998). As a consequence, new challenges are emerging for policymakers, managers, and researchers. Developing countries, in particular, have to increase their efforts to design policies that can narrow the knowledge gap that separates them from the more developed countries (World Bank 1998). In many developing countries, agriculture is the most important sector of the economy, and this makes growth in agriculture essential to creating employment and alleviating hunger and poverty (CGIAR 1997). This means that investments in agricultural research play a key role in such economies. Because public research institutions form, by far, the greater part of national agricultural research systems (NARS) in developing countries, they are especially challenged in this respect.

Investment in agricultural biotechnology is a good case in point—it is knowledge intensive and has the characteristics of a generic technology. Modern biotechnology includes powerful new techniques and tools for a broad range of applications for agriculture in developing countries (World Bank 1991). Its appeal is that it can address problems that are not solved by conventional means and it can enhance existing research through increased precision and shortened timeframes for producing results. However, resources for agricultural science are scarce to begin with, and introducing biotechnology into an institutional research setting requires new institutional arrangements, special infrastructure, and well-trained professionals (Janssen 1995b).

With scarce resources, managers have to make difficult choices from among many possible biotechnology applications. As depicted in figure 1, different techniques used in agricultural biotechnology involve very different financial commitments and scientific knowledge requirements. For instance, research in plant tissue culture is relatively cheap and simple, while more strategic research in genetic engineering is considerably expensive and knowledge intensive.

A lot of effort has gone into evaluating public agricultural research. This is due in part to the increasing complexity of decision problems, and in part to tight research budgets and the resulting pressure for greater accountability.[1] Allocating resources efficiently and selecting the most promising research activities

1. Horton et al. (1993, 6) define accountability as "the responsibility of an individual or an organization to account for the proper use of resources. Accountability requirements have traditionally been met through periodic reports on resource use and activities; however, there has been a growing demand for more and better evidence of the results and impact of agricultural research."




*Source:* Jones (1990)

*Figure 1. Biotechnology gradient*

are issues of both scarcity and choice—processes that can benefit from the work of economists. It should therefore come as no surprise that the study of research evaluation and priority setting has been dominated by economists. As a consequence, most of these studies place an emphasis on economic efficiency and on costs and benefits that can be expressed in monetary values. This has raised concerns because externalities, distributional effects, and longer-term impacts all tend to be neglected with such a narrow focus (Dahlberg 1988; Thompson 1998).

This study provides a somewhat wider approach to decision making in public agricultural research. The overall objective is to develop and assess a priority-setting approach that is more problem-driven and that can take into account the special features of biotechnology, as well as the need to strengthen scientific capacity in developing countries. Ultimately, this provides a tool that can support research managers who face multicriteria decision problems with a limited amount of information. In particular, the study focuses on the *process* of priority setting, suggesting various procedures to identify and select decision criteria and to elicit subjective judgments. The ultimate objective is the development of a decision support tool that facilitates the participation of stakeholders and allows them to express their preferences.

This report covers three phases. The first phase involves the development of a conceptual framework for priority setting processes in agricultural biotechnology research. This includes an analysis of the key issues for priority setting in public research, and the identification and modification of a suitable decision support method. The second phase tests the usefulness of the approach through a pilot application in the Chilean biotechnology program. The third phase is devoted to assessing the performance of the approach in the pilot application. This includes a discussion of improvements and special issues to be dealt with in future, and some issues that require further research.

## Institutional Setting

The study contained in this report is based on a research project developed jointly by the Department of Agricultural Economics at the Swiss Federal Institute of Technology (IAW/ETH) and ISNAR. Collaboration between an academic research institute and an application-oriented international research center has been very beneficial for the study. In particular, it contributed to achieving a good balance between theoretical rigor and practical feasibility in the application of this priority setting approach. Collaboration with the Instituto de Investigaciones Agropecuarias (INIA) in Chile was also exemplary and proved critical to the successful implementation of the exercise.

## Structure of the Study

This report reflects the different phases of the priority setting exercise. Chapter 2 addresses the issues that are important for research evaluation in biotechnology. It begins with general thoughts on public agricultural research and later focuses on the difficulties that are often confronted in priority setting. It is followed by an overview of biotechnology in developing countries, from which specific problems for research evaluation are derived. The chapter concludes with a set of working hypotheses and a discussion of the requirements that must be met by the priority setting process.

Chapter 3 provides the methodological background of the study. There is a brief review of the methods used for ex ante evaluation of research, followed by a discussion of formal priority setting and its necessity. The priority setting approach used in this study, which is based on the Analytic Hierarchy Process (AHP), is described in detail in this chapter.

Chapter 4 is devoted to a step-by-step description of the pilot application in Chile. First, background information is provided for Chile, with particular attention given to this country's activities in the field of biotechnology research. This is followed by a detailed discussion of how AHP was applied to establish priorities for Chile's National Biotechnology Program (PNB), and a discussion of the sensitivity analysis that was carried out to help assess the results. The results of this exercise are then discussed, and a first assessment of some procedural issues is also given.

Chapter 5 is an assessment of the priority setting approach, based on the working hypotheses that were formulated in Chapter 2. This assessment focuses on methodological issues and includes some important modifications to improve future applications. The chapter concludes with a discussion of other issues that require further research.

Chapter 6 concludes the report by summarizing the conceptual, methodological, and procedural issues that emerged in the course of the pilot application. The principal strengths and weaknesses of AHP are discussed as they pertain to evaluating research in agricultural biotechnology.

## Definitions

There is no general agreement as to what constitutes a ***national agricultural research system*** (NARS). The term can be synonymous with a nation's main public research institute (NARI), but, in this study, a broader definition is used. "A national agricultural research system includes state and parastatal research institutions, academic institutions, and private sector research entities" (Purcell and Anderson 1997, 161). For a detailed discussion of the NARS concept, see Craig et al. (1991), who attempt to operationalize the term for statistical purposes.

The term ***biotechnology*** is defined as "any technology that uses living organisms, or substances from those organisms, to make or modify a product, to improve plants, animals, or to develop micro-organisms for specific uses" (OTA 1986, 31). However, one must distinguish between traditional and modern[2] biotechnology. The former involves, among many things, the use of bacterial cultures to ferment and preserve food (e.g., cheese) and to make alcoholic beverages. The scientific disciplines behind modern biotechnology, on the other hand, are molecular, micro-, and cell biology, in combination with biochemistry (Bhagavan 1997a). In this study, the term biotechnology is synonymous with modern biotechnology. It includes all the techniques depicted in figure 1, except microbial fermentation and biological nitrogen fixation.

***Research evaluation*** refers to assessing the societal costs and benefits of research activities. Horton et al. (1993, 6) offer the following definition: "Evaluation is judging, appraising, or determining the worth, value, or quality of research, whether it is proposed, on-going, or completed. This is done in terms of its relevance, effectiveness, efficiency, and impact." Evaluation stems from the word 'value' and can be done ex ante (before the research activity) or ex post (after the research activity).

***Priority setting*** in research is the process of ranking different research alternatives. It is a common part of planning and helps define a research portfolio in line with the mission of the organization or the agricultural policy of the country (ISNAR 1998). According to Stewart, a priority is, literally, something one does first. "If A has priority over B, all A's claims are met before any of B's are considered" (1995, 117).

***Decision making*** is the process of choosing among a set of alternatives. According to Saaty (1994), there are several basic elements necessary for making decisions: (1) details of the problem to be decided, (2) the people or actors involved, (3) their objectives and policies, (4) the influences affecting the outcome, and (5) the time horizons, scenarios, and constraints.

***Resource allocation*** is the activity of funding research according to a few objectives that are maximized, subject to certain constraints on the available resources. In order to determine the optimal allocation of resources among a set of alternatives, information about the outputs and outcomes of the alternatives is required.

2. Instead of *modern*, the terms *new* and *second-generation* are also used in the literature.

Finally, the relationships between research evaluation, priority setting, decision making, and resource allocation should be clarified. For the purposes of the study, these terms represent increasingly concrete stages of ascertaining the value of the societal alternatives, depicted in figure 2.

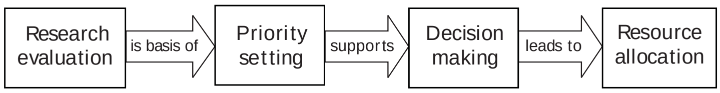



*Figure 2. Increasingly concrete stages of research planning*

Some kind of research evaluation is necessary in order to set priorities among alternatives. However, the evaluation may not yield clear priorities if multiple objectives are involved. For this reason, priority setting includes determining the relative importance of these objectives, which results in a ranking of research alternatives that takes into account the weights attached to each objective. The priorities are used as aids in decision making. Consultations with stakeholders can lead to adjustments, as part of consensus building. Scenarios using different weights for the objectives might also be discussed, and new alternatives or ongoing research activities might be considered. The outcome of decision making may be a bundle of research activities to be implemented.

However, the allocation of research resources still involves further considerations, such as the definition of an optimal portfolio under the given budget constraints, the possibility of funding some research on a partial basis, or locating additional financial sources. In this sense, priority setting differs from resource allocation. However, priority ranks can provide additional information for the allocation of resources, but only if the ranking reflects the actual relationship between the preferences of the alternatives, rather than a mere arrangement of the alternatives.

# 2. Issues in Biotechnology Research Evaluation

This chapter identifies the factors critical to the design of priority setting processes for biotechnology research. First, public agricultural research in developing countries is described, and the role of biotechnology in such systems is summarized. The potential problems of priority setting in biotechnology research are then discussed, and three working hypotheses are formulated to adequately address them. Finally, requirements for the procedure and the methodological tools to be used are determined. The requirements serve as guidelines for developing a systematic approach to support decision making in public biotechnology research.

There are three sections in this chapter. The first section outlines the rationale for public-sector research and some of the trends and challenges that may shape NARS agendas in the future. This is followed by a discussion of the principal difficulties in priority setting. In the second section, agricultural biotechnology is described insofar as it concerns research in developing countries. The potential of biotechnology to contribute to agricultural research in the developing world is explored, and the consequences of this particular technology for priority setting are detailed. In the final section, three working hypotheses are defined specifically for evaluating research in agricultural biotechnology. The chapter concludes by explaining the requirements that must be met by priority setting procedures: participation, transparency, and a standardized measurement procedure.

## Public Agricultural Research

### *Rationales for Public-Sector Research*

As stated earlier, NARS consist of both public and private institutions. Given the costs involved in agricultural research, why should a country engage in public research, and not simply leave it to the private sector? Economic theory suggests that the primary justification for public-sector investment is a "market failure" by the private sector in the production and funding of research. Market failure in agricultural research appears to be largely taken for granted (Alston et al. 1997). The reason is that much of the new knowledge produced from research displays *nonrivalness* and *nonexcludability*, two essential characteristics of a public good. Nonrivalness means that the use of the research output by any agent has no effect on the amount available for use by others. Nonexcludability means that it is neither feasible nor cost-efficient to exclude those who do not pay for the good.[1]

1. See Ostrom and Ostrom (1977) for details on the nature of public goods.

Because firms can appropriate research benefits without incurring the actual costs of research, this leads to the “free-rider” problem (Pray and Echeverría 1991).

The consequence of this factor is that private firms are often unable to capture all of the benefits resulting from such a research investment. That is, benefits to an investor are less than the social benefits, and therefore, from society’s point of view, the private sector tends to underinvest in agricultural research. Consider, for example, the generation of knowledge to improve water management in irrigated agriculture. Once this knowledge is released, no one can be excluded from using it at zero cost. As a result, there is no incentive for private firms (including both industry and farmers) to produce the socially optimal level of such a good. By the same token, if the expected social rate of return exceeds the expected private rate of return, there is a strong case for government intervention.[2] To put it another way, when it comes to public goods, allocation decisions are made primarily by political processes and not by market mechanisms.

Distortions due to externalities are another market failure that can justify public sector involvement in agricultural research (Alston et al. 1997). Externalities are closely related to the concept of a public good. They arise when one person’s production or consumption activities involve effects on others that are not being considered. External effects can be positive or negative and are usually the unintended consequences of legitimate activities. Some examples are spillover benefits from research activities undertaken in one region that are found to be applicable in other regions (positive externality), or the pollution of groundwater through the runoff of plant nutrients and pesticides (negative externality). The existence of externalities means that marginal social values differ from private values, i.e., market prices cannot be used as socially optimal indicators of costs and benefits.[3]

Alston et al. (1997) claim that government intervention is justified because research activities are often long term, large scale, and risky, which makes it unprofitable and impractical for the typical agricultural enterprise (i.e., the small-scale farm) to conduct research. In addition, the cost of collective action for organizing research may be too high. Economies of scale and scope in terms of research can therefore threaten the competitive structure of markets in the production, input, and marketing sectors. The complementarity of research and education has been put forward as another argument in favor of public involvement (Ruttan 1982).

In sum, three economic reasons justify government intervention: (1) the failure of markets to produce the socially optimal amount of research, (2) the need to enhance or maintain the competitive structure of markets, and (3) the existence of opportunities for exploiting the complementarity of research and education (Alston et al. 1995). Government intervention takes various forms. The most direct method is to allocate resources for agricultural research. Other types of intervention include improving and enforcing property rights legislation such as

2. Griliches (1958) argues that the difference between social and private rates of return is not a sufficient reason for public intervention since the private returns may still be high enough to attract research investments from private firms.
3. Zilberman and Marra (1993) provide a thorough discussion of the economics of externalities in agriculture.

patents, creating an enabling environment that includes a consistent policy framework and investments in human resources, and enhancing other incentives for private sector research (Beynon 1995).

Public and private research activities also take different forms.[4] Basic research and most strategic research generally display the characteristics of public goods and are therefore more appropriately attributed to the public sector. Applied research and adaptive research tend to be more in the private domain (Pray and Echeverría 1991), and surveys of actual investments partially confirm this conception (Umali 1992). However, the boundary between public and private research is influenced significantly by institutional and technical factors that determine the amenability of knowledge to exclusion mechanisms. Such mechanisms help overcome the free-rider problem and enable the appropriation of returns to research investments. When these mechanisms do not exist, governments need to finance more applied research (Beynon 1995). For instance, studies of Latin America and the Caribbean indicate that there are significant public sector investments in applied and adaptive research in these regions (Falconi and Elliott 1995). This is consistent with the observation that, in most developing countries, the scale of private research activities is typically small, accounting for only 10% to 15% of total agricultural research expenditures (compared to 50% in industrialized countries). Moreover, most of this private-sector investment is concentrated in a few large countries in Asia and Latin America (Byerlee and Alex 1998).

## *Trends and Challenges*

As rightly argued by Byerlee and Alex (1998), the changing research environment calls for institutional innovation in the organization and management of public research systems. In this section, the factors in this changing environment that are pertinent to priority setting issues—the scale and sources of research funding, the globalization of research, trade liberalization, and the need to broaden the research agenda—are considered.

Alston et al. (1997) provide an overview of global trends in the public funding of agricultural research.[5] Over the past two decades, annual investments in agricultural research by national governments almost doubled in real terms—from US$7.3 billion in 1971, to nearly US$15 billion in 1991 (in 1985 international dollars). In 1971, research expenditures from developing countries accounted for 41% of total spending, and by 1991, this share had grown to 54%. However, when these are expressed in terms of expenditures per agricultural GDP, investments by developing countries in agricultural research were only at 0.5% in 1991, remaining nearly unchanged since the late 1970s. This level is also far below the average investment of developed countries (2.39%) and the target for developing countries (2%) recommended by the World Bank in the early 1980s

4. The research classifications used in this study are based on those of the Consultative Group on International Agricultural Research (CGIAR, 1981), which distinguishes four types of research: basic, strategic, applied, and adaptive. Basic research generates new scientific knowledge but has no direct commercial application. Strategic research addresses issues that normally influence the efficiency with which other research further downstream can be carried out. Applied research creates technology with commercial applications. Adaptive research adjusts technology to the specific needs of a particular set of environmental conditions. In reality, however, there are no clear-cut boundaries between these types. Instead, research activities should be seen as a part of a continuum from more basic to more adaptive.
5. For figures on regional and country trends in financing public agricultural research, see chapters 15 to 17 in Tabor et al. (1998).

(Byerlee and Alex 1998). Inadequate funding of public agricultural research institutes is the most serious challenge facing NARS (Purcell and Anderson 1997). In developing countries, investment in agricultural research grew by 6.4% annually from 1971 to 1981, but slowed down to 3.8% annually from 1981 to 1991. This slowdown in research spending was particularly severe in Africa and Latin America, with the latter recording a decline in absolute terms (Alston et al. 1997). This downward trend was accompanied by an increase in the number of scientists, resulting in a drop both in spending per researcher and in operating budgets.

Aside from the deterioration of public-sector spending, three additional trends in research funding are important to the analysis of priority setting issues. First, a shift in the funding mode can be observed, from institutional budget assignment toward project-based funding. This is due in part to a demand for increased efficiency and greater client orientation. Despite the substantial administrative costs they involve, competitive grant schemes have become popular in many NARS.[6] Competitive grants are useful for coordinating research across different agencies in line with national priorities. The selection of grants for funding is based on predefined criteria that take into account research priorities and scientific merit (Byerlee and Alex 1998; Janssen 1998).

Second, donor funding represents a substantial portion of public research expenditures in developing countries.[7] Pardey et al. (1991) estimate the share of donor funding at 16% for the period of 1981 to 1985, but with significant regional differences. The highest proportion of external support (grants and loans) is reported for sub-Saharan Africa (35%), followed by Asia and the Pacific (excluding China) with 26%, West Asia and North Africa with 11%, and Latin America and the Caribbean with 7%. However, these regional averages mask intraregional diversity. For developing countries, particularly in Africa, external support can easily constitute half (and sometimes even more than 60%) of agricultural research spending (Alston et al. 1995). More recent figures on external contributions to African NARS indicate a notable increase in the donor share of total agricultural research expenditures, from 34% to 43% for the period of 1986 to 1991 (based on a sample of 13 countries, Pardey and Roseboom 1998). This evidence points to the increasing dependence of some countries on donor funds, which has a potentially negative impact on the sustainability of public agricultural research financing and on autonomy in research priority setting.

Third, research conducted by the private sector is growing rapidly in developing countries. As mentioned earlier, the role of the private sector in agricultural research remains relatively small, when compared to that of the public sector. However, in some larger countries in Latin America and Asia, private-sector involvement in applied and adaptive research can be substantial. Data from three country studies in Latin America suggest that, on average, the private sector accounts for 40% of research expenditures (Falconi and Elliott 1995). The widespread adoption of economic policies aimed at improving and enforcing intellec-

6. In Chile, competitive grants have been in use since 1981 and have become the dominant practice in research resource allocation.
7. The single largest donor is the World Bank, which has loaned nearly US$4 billion for agricultural research since 1981 (Byerlee and Alex 1998).

tual property protection, eliminating import restrictions on agricultural technology, and reducing the size of the public sector, together create an enabling environment by alleviating some of the constraints on private-sector research. Figures in Alston et al. (1997) show that privately funded research is a prominent feature of contemporary agricultural research in developed countries. If this indicates a future trend in developing countries (or at the least, in some of the more advanced developing countries), the private sector will become a major player in agricultural research operations in the near future.

Globalization—the increasing economic, political, cultural, and social integration of sovereign states—is another factor to consider. It encompasses growing international trade, cross-border investment activity, and the harmonization and coordination of domestic policies, laws, and institutions. The driving forces of globalization include advances in information, communication, and transportation technologies; regional and global free trade agreements; and policy changes such as deregulation and privatization (Bonte-Friedheim et al. 1997). Increasing linkages between and the growing interdependence of national economies have two critical impacts on NARS. One direct impact is the emergence of international markets for science, which gives developing countries access to a broader and more diverse range of scientific service providers. This means that,

> globalization will create new market-based opportunities for cross-border generation and exchange of agricultural technology. (...) Science policy leaders will need to learn (...) to redefine what technology development services are supplied locally and what is produced from international sources (Bonte-Friedheim et al. 1997, 11).

These new international sources of technology, together with the high cost of research and the limits on available resources, have led to a growing number of global research initiatives, such as the “Global Plan of Action” launched by the CGIAR (CGIAR 1996). At the same time, a trend toward regionalization in agricultural research can be observed, especially in Africa and Latin America. It goes without saying that this development has an impact on decision making in public research institutions.

Because countries are also reducing tariffs and non-tariff protective measures, liberalization is opening new opportunities for the agricultural sector and is compelling developing countries to compete effectively in international markets, as well as in domestic markets. Trade liberalization has far-reaching implications for the research agendas of NARS, because improved technologies will come to play an increasingly important role in every country’s exploitation of its agricultural sector (Byerlee and Alex 1998).

The final item for consideration concerns two challenges that require a substantial broadening of the research agenda—the growing concern over environmental problems associated with agricultural activities, and the decline of research capacity. Regarding environmental concerns, there is no doubt that NARS need to integrate the implications of new technologies on the natural resource base and the environment into their research agendas (e.g., CGIAR 1997; Crosson and Anderson 1993; Graham-Tomasi 1991; Ruttan 1991). Agricultural production often has negative impacts on natural resources and the environment, as well as adverse effects on human health. However, it may also have positive consequences, such as farm management practices that preserve the landscape and provide recreation opportunities for the public. The point is that many of these consequences show the characteristics of a public good, making a strong case for supporting public research to deal with these environmental issues. Regarding capacity building, Schuh and Norton state that

> Another serious issue in many less-developed countries is that both the capacity to train agricultural scientists and the capacity for research itself appear to have declined in the 1980s as a consequence of severe economic crises (1991, 59).

This observation is consistent with the state of INIA in Chile. Noncompetitive salary scales—due to a slowdown in the growth rate of research funding, combined with the extension of staff—and management weaknesses have already led to a decline in the quality of scientists in many countries, and any number of institutional and organizational problems can erode institutional capacity in public research institutions (Nickel 1997). When the growing need to generate knowledge and improved technologies (in order to compete successfully in a more liberalized market) are considered, the relevance of institutional and human-resource capacity building becomes obvious.

### *Difficulties in Priority Setting*

A major difficulty for public research is the multicriteria nature of their priority-setting processes. Using a multicriteria framework carries methodological implications for research in terms of increased cost, consideration of noneconomic factors and consequences, coping with measurement problems due to the incompatible standards of individual criteria, and the quality and quantity of information on which decisions are based.

To establish priorities is to rank a set of alternatives in a way that is most consistent with the objectives from which the employed decision criteria have been derived. Some economists have persistently argued in favor of a single objective based on economic efficiency (Alston et al. 1995, 1997; Alston and Pardey 1995; Norton et al. 1992). They claim that

> the use of public-sector agricultural research to pursue nonefficiency objectives can be questioned on two grounds. First, considering more than one objective adds greatly to the cost of decision-making, and second, there are usually better instruments for pursuing nonefficiency goals (Alston et al. 1995, 15).

No doubt the first argument raises an important point, that research evaluation should be efficient. But it should also be effective. In other words, in order to guide research decisions, research evaluation should address the most important objectives and assess their achievement. Although research is intended mainly to contribute to increasing efficiency, society often wants to pursue other objectives through agricultural research. Distribution and food security concerns are often mentioned as nonefficiency objectives that also guide research decisions (e.g., Collion and Kissi 1995; Janssen 1995a). Given that many NARS receive substantial funding from donors who sometimes make their support conditional upon the incorporation of nonefficiency objectives into the decision-making process, economists and other analysts must bear in mind this political reality.

The second argument, that there are better means of pursuing nonefficiency goals, is misleading. Agricultural research results do affect objectives other than economic efficiency (Schuh and Tollini 1979). The claim that there are better policies is no excuse for ignoring noneconomic impacts in agricultural research evaluation. Antle and Wagenet (1995, 12) rightly criticize this omission in a study for the American Agricultural Economics Association:

> The research evaluation literature has developed increasingly refined models and estimates of economic impacts, but has virtually ignored all other social, environmental, or health impacts. It appears that agricultural economics has suffered from its own disciplinary isolation, and has failed to apply economic principles in designing its own research. Indeed, an 'economically optimal' allocation of research effort would devote suitable effort to all potentially important impacts.

Much more can be said about the narrow focus and the restrictive value assumptions of the economic-efficiency criterion (e.g., Bromley 1990; Madden 1986; Thompson 1998, chapters 1-3), but Amartya Sen, 1999 Nobel Laureate in economics, sums up the argument nicely:

> The criterion of Pareto optimality [sometimes also called "economic efficiency"] is an extremely limited way of assessing social achievement ... (1987, 35).

The multicriteria framework for research evaluation has two major implications. First, since multiple objectives usually involve significant trade-offs (i.e., more of one can be attained only at the expense of another), priority setting requires attaching weights to each objective. The relative importance of any single objective varies per country and depends on the policies pursued by each government and each country's stage of development (Schuh and Tollini 1979). This means that specifying weights is the responsibility of policymakers and senior research managers. Their participation in the decision-making process is therefore critical. In addition, pooling subjective judgments helps to balance the potential biases of individual value judgments. Therefore, appropriate procedures are needed for eliciting the preferences of decision makers and for facilitating interaction between them.

Second, the contributions of research activities towards different objectives must be aggregated in order to attain a final score for each alternative. This poses a measurement problem because such contributions are generally measured according to different standards that may not be compatible. For instance, how can the reduction in yield losses (measured in monetary values) be aggregated with the increase in employment opportunities (measured in number of jobs created)? In evaluations using a single criterion such as economic efficiency, all research contributions are converted into monetary values. But even this economic solution causes substantial difficulties because no markets exist for many research outputs—such as food security. This is certainly the case for noncommodity research that produces environmental benefits.

Measurement problems have great bearing on the evaluation of more strategic research because it does not change productivity or production costs directly (as opposed to applied research), an issue that has received relatively little attention in research evaluation (Norton et al. 1992). As noted earlier, public-sector research may involve a wide range of activities along the basic-adaptive research continuum, and sometimes research managers must evaluate strategic and applied research simultaneously. Traditional priority setting approaches tend to have a bias towards applied research because its benefits are more tangible and thus more amenable to financial evaluation. However, new knowledge generated by the research process, even if it may not be directly applicable in the productive sector, may still have substantial value in terms of strengthening a country's scientific capacity.

Finally, information is the key factor in priority setting. However, analysts are often faced with a very poor information base. Relevant secondary data may not be available, and the collection of primary data may be too expensive. The problem of data availability is usually more pronounced in developing countries due to insufficient institutional capacity. This situation pushes analysts to rely on subjective judgments in order to generate the necessary information. This brings the problem of determining suitable elicitation techniques and identifying experts who can provide reliable subjective judgments on the likely costs, benefits, and other variables of alternative research activities. The use of subjective judgments is not unique to agricultural research, and, as Shumway puts it:

> All ex ante research evaluation procedures are inherently subjective. The only difference is where subjectivity enters and how it is processed. (...) Consequently, the legitimate role of subjectivity in ex ante evaluation needs to be recognized clearly and respected (1981, 171).

An even more serious information problem is the forward-looking nature of priority setting. Because the future is, by definition, unknown, there is a great deal of uncertainty regarding how far the potential contributions of research will be realized. Anderson (1991) identifies two broad areas of uncertainty surrounding agricultural research—the uncertainty present in agriculture, and the uncertainty affecting the research and adoption process itself.

The first type of uncertainty concerns variability in natural, economic, and political environments that have an effect on research impact. There is a broad range of human, institutional, technological, and economic factors that contribute to uncertainty. The other, arguably more critical type of uncertainty concerns the chances of research success and the chances that the end users will adopt[8] the results.[9] In priority setting, it is important to consider the possibility of research failure. Measures for the chances of success have to be defined and correctly

8. "Rate of adoption" would be the more appropriate term since this is not a (0;1) event.
9. For instance, the success of national research processes will increasingly be influenced by the emerging international markets of science, as well as by the country's response.

combined with estimates of potential impact in order to obtain a final performance assessment for each research alternative. This task is not straightforward, because the relevant factors must be carefully identified, and their potential influence on success must be determined. Priority setting processes cannot be expected to accommodate an exhaustive list of such factors, but a sufficient attempt must be made to incorporate the most relevant ones. Again, the subjective judgments of knowledgeable individuals will play a dominant role in such an analysis.

## Agricultural Biotechnology and Developing Countries

There is an extensive body of literature on agricultural biotechnology in developing countries. This section aims to highlight issues in agricultural biotechnology that are important for successfully planning and executing public research. In this section, an overview of agricultural biotechnology and its special features relevant to developing countries is presented, followed by a discussion of the consequences these features may have for priority setting processes in public research organizations.

### *The Potential Role of Biotechnology in Agricultural Research*

Modern biotechnology is based on three major developments: recombinant DNA technology, monoclonal antibody production, and cell and tissue culture. A combination of these three processes forms the basis of genetic engineering.[10] In terms of agriculture, biotechnology is concerned with the following (Persley 1992):

1. agricultural microbiology, to produce micro-organisms beneficial to crop agriculture;
2. cell and tissue culture, which includes the rapid propagation of useful micro-organisms and plant species;
3. new diagnostics, based on the use of monoclonal antibodies and nucleic acid probes, to detect pests and diseases, and foreign chemicals in food;
4. genetic engineering, to introduce new traits into microbes, plants, and animals; and
5. new genetic mapping techniques, as an aid to conventional plant and animal breeding programs.

The great appeal of biotechnology is that it has the potential to address problems not resolved by conventional research, to speed up research processes, and to increase research precision. Biotechnology has seen major advances in recent years that have opened up a wide range of opportunities for applications in agriculture. These advances include: improved tolerance of crops and livestock to stresses, pests, and pathogens; quality enhancement; increased efficiency in the use of nutrients; and removing biological constraints to achieving higher yields through increased photosynthetic activity and achieving nitrogen fixation in non-leguminous crops. Now, there are prospects for increased agricultural production, improved comparative advantage in countries where the new tech-

10. An introduction to the subject for non-specialists, with an excellent description of the basic techniques, can be found in Persley and Peacock (1990).

nologies are applied, new opportunities for the use of marginal land, and mitigating environmental and pollution problems (Barker 1990; World Bank 1991).

Recent achievements and current research efforts are reported in Kendall et al. (1997), although the rapid pace of technological innovations makes it difficult to establish the state-of-the-art in agricultural biotechnology. However, it is now generally acknowledged that early breakthroughs in biotechnology have led to exaggerated expectations of their positive impact on agriculture, particularly for developing countries (Bhagavan 1997b; Brenner 1996; Komen and Persley 1993; World Bank 1991). At the same time, much literature points to the potential threats posed by these new technologies to developing countries (Buttel et al. 1985; Fowler et al. 1988; Hobbelink 1991; Juma 1989; Walgate 1990). There is concern that biotechnology may further marginalize small-scale farmers, compromise the competitive positions of poorer countries, and lead to negative environmental effects. Such criticism is fuelled in part by biotechnology developments that have led to production shifts from developing to industrialized countries. Two examples are often cited: the artificial production of vanilla flavor, which could eliminate the cultivation of the vanilla bean (FAO 1995) and the substitution of sugar through an enzymatic process that transforms cereal starch into high fructose corn syrups (HFCS), with adverse employment and income effects for sugar-cane producing countries (Galhardi 1996). The "double-edged" impact of biotechnology on developing countries is summarized by Persley as follows:

> The likely socioeconomic effects of biotechnology are positive in terms of increasing the productivity of tropical commodities, opening up new opportunities for the use of marginal lands, and reducing use of agrochemicals. They are also potentially negative, in that they offer the possibility of producing high-value products in tissue culture in industrialised countries, and thus displacing crops presently grown for export in the Third World (1990, 46).

To obtain a realistic picture of the role that biotechnology might someday play in agricultural research in developing countries, a range of specific issues associated with biotechnology needs to be considered. The remainder of this section will deal with these issues.

The bulk of biotechnology research is conducted in industrialized countries, and at least half of all current funding worldwide comes from the private sector. The increasing dominance of the private sector and its growing partnerships with universities may lead to higher costs for access to advances in science and technology that were once freely available as public goods (Persley 1990). The emerging pattern of technology development in the area of agricultural biotechnology is raising fears that the technology gap between industrialized and developing countries is widening. The critical change in the institutional structure of agricultural research is that many of the processes and products of biotechnology are now patentable. There is concern that the growing importance of private sector research is fuelling a tendency toward secrecy and confidentiality, which, in turn, could slow down the dissemination of knowledge that is critical for developing countries (UNCTAD 1991).

Given that knowledge is the key strategic resource for economic development, and that most of the advances in basic research and technology development are likely to occur in the industrialized countries, North-South technology transfer is clearly of great importance. Accordingly, a growing number of international initiatives are being undertaken in support of agricultural biotechnology in developing countries. Brenner and Komen (1994) surveyed these initiatives, which involve various research, information, and advisory activities facilitated by different international organizations. They found that the public sector has been playing the key role in a majority of the technology transfer mechanisms identified by the survey. There is little doubt that the private sector should play a major role in biotechnology transfer to developing countries, but, at present, its role is marginal at best.

In some developing countries, an awareness of the enormous potential of biotechnology has led to the creation of national research programs that give high priority to this new technology. In contrast to industrialized countries, however, the activities in such national research programs are funded and executed predominantly by the public sector, with marginal involvement from the private sector. Moreover, in many biotechnology programs, clearly defined biotechnology policies and strategies are non-existent, and there is a serious lack of focus. This has been confirmed by several country reviews on the opportunities and constraints of agricultural biotechnology in the developing world (Brenner 1996; FAO 1995; Komen and Persley 1993).

Developing countries must address three basic issues in order to effectively absorb imported biotechnology, conduct their own research, and develop technologies appropriate for their needs: intellectual property rights (IPR) regarding biotechnological innovations, biosafety regulations, and capacity building in research and development. The question of ownership needs to be dealt with in order to facilitate technology transfer and to attract private sector investment in national research and development. Having legislation to protect IPR for the products and processes of biotechnology entails resolving many issues, such as the types of protection and their respective exemption clauses, the appropriateness of using IPR for living material, harmonizing international IPR regulations, and the likely impact of harmonization on international trade and development (van Wijk et al. 1993). Two IPR mechanisms, in particular, are important for agricultural biotechnology—patents and plant breeders' rights. Both grant inventors the right to exclude others from commercializing a specific invention for a limited period of time. The latter is confined to plant varieties and is less restrictive, allowing some exemptions for breeders and farmers. Developing countries are often reluctant to extend IPR regulations to the products of biotechnology research and, in particular, refuse the patenting of products (but not the patenting of processes). Meanwhile, in many industrialized countries, the protection of living material is a controversial issue, and its implications for the creation and dissemination of biotechnology innovations are still poorly understood.

IPR were the subject of intense discussion at the General Agreement on Tariffs and Trade (GATT) negotiations on Trade-Related Aspects of Intellectual Property (TRIPS), which was undertaken in an effort to harmonize and enlarge patent protection on a global scale. This, along with threats of sanctions by the United States in bilateral negotiations, puts increasing pressure on the governments of developing countries to strengthen the legal protection of the products of advanced technology, including biotechnology (van Wijk et al. 1993). The subject is currently under debate in the World Trade Organization (WTO), where member states are trying to reach a consensus on the intellectual-property protection of plant material. The latest developments in these negotiations are outlined in a paper by van Wijk (1998), in which he also discusses the perspectives of the different interest groups that influence the WTO member states in designing a plant patenting policy. Zilberman et al. (1997) analyze the economic and international implications of agricultural biotechnology for the relationship between developed and developing countries. They conclude the following:

> Clearly defined and enforceable intellectual property rights are essential for private sector research and development of new biotechnology products. However, overly broad patents may grant excessive market power to patent holders, reducing their incentives to provide socially desirable levels of production to investment in innovation. Unduly broad patents and/ or overly restrictive licensing of academic inventions will diminish the capacity for new entrants to compete. (...) Developed countries should not be overzealous in their enforcement of intellectual property rights in developing countries. First, excessive fees will encourage cheating and, second, undue emphasis on IPR protection may conflict with other goals, such as promotion of free trade. Consideration should be given to establishing two-tiered pricing systems for intellectual property rights, with developing countries paying lower prices (1997, 19-20).

Like IPR, Biosafety regulations are considered essential both to accessing modern biotechnology generated abroad and to undertaking domestic research and development (Komen and Persley 1993). Biosafety refers to the policies and procedures adopted by a government to reduce the potential risks to human health and the environment that may result from the application of modern biotechnology. In terms of national research and development activities, an efficient biosafety framework is important for handling new genetic material at the experimental stage, i.e., using new genetic techniques in the laboratory and releasing genetically engineered organisms in small-scale field trials. More than 3,600 official field trials of genetically modified plants were conducted in more than 30 countries between 1986 and 1995, although less than 10% of these were performed in developing countries. A survey carried out in 1995 indicates that only about 10% of developing countries have any established biosafety regulations (Virgin 1997). This is consistent with the findings of four regional agricultural biotechnology seminars carried out by the ISNAR Biotechnology Service (IBS). In terms of national policy, the development of a biosafety regulatory system was considered to be the most urgent need of the countries that participated in the seminars (Cohen et al. 1998).

Developing countries are under increasing pressure from industrialized countries to put a biosafety framework in place. There have been several initiatives by international organizations aimed at the global harmonization of biosafety systems. For instance, the Organization for Economic Cooperation and Development (OECD) has developed guidelines that many countries have since used for designing their national biosafety regulations. Recently, the Convention on Biological Diversity established an international biosafety protocol to facilitate the same procedure in developing countries. The procedure for establishing a national biosafety system is described by Persley et al. (1993), who recommend establishing such a system within a country's existing regulatory framework and drawing on existing institutions, personnel, and current legislation. Maredia (1998) adds to this discussion by providing an economic perspective on biosafety regulations. Maredia outlines the many issues related to the costs and benefits that developing countries need to consider if they wish to design an efficient biosafety framework. As for the pressure to create strict, global biosafety guidelines, Zilberman et al. (1997) point out that the willingness to take certain risks varies for each country. Developing countries may be more willing to risk perceived environmental safety in order to reduce hunger, increase income, and obtain other potential benefits from the development and application of agricultural biotechnology.

Finally, biotechnology is knowledge intensive. The lack of adequate national research capacity in developing countries has already been identified as one of the major hurdles for the exploitation of biotechnology's great potential (Bhagavan 1997b; Brenner 1996). Regardless of whether national technology policies are oriented toward the importation or the internal generation of biotechnology, developing countries need to create a local scientific base if they want to benefit from agricultural biotechnology. Even with importation, countries need a sufficient scientific capacity to absorb the imported technologies and to adapt them to local conditions. The need to build sufficient capacity is also relevant to conventional agricultural research, because research in biotechnology does not often result in a final product that can be transferred directly to the farm sector. Instead, it tends to produce intermediate outputs that facilitate and accelerate other research programs. Given all this, developing countries would do well to invest more heavily in strengthening their capacity, particularly in terms of institutional development and human resources.

## *Biotechnology Features and Priority Setting*

Policymakers and research managers in developing countries are increasingly facing complex decisions about investing in agricultural biotechnology research. Given the wide variety of potential applications in biotechnology—which also includes options to develop low-cost research activities—the question for most developing countries is not whether to invest in biotechnology, but rather, where, when, and how much of their resources they should allocate. This requires some very basic and strategic answers to complex scientific, legal, institutional, timing, and funding issues. These issues revolve around the science and technology policies to be pursued (e.g., the choice between importing knowledge and technology or building local biotechnology capacity), the appropriate level of IPR and biosafety regulations to implement, the institutional model to follow (e.g., centralized or decentralized research), the right time to embark on biotechnology (i.e., to invest now or wait until later), and the level and sources of funding that are available.[11] Whereas these matters concern very strategic decisions,

11. These and other issues in strategic decision-making are discussed in Cohen (1994), Gijsbers (1995), and Janssen (1995b).

this study focuses on the more tactical decisions that relate to setting priorities among projects. However, strategic issues are relevant because they enter the priority setting process as given elements. In other words, they are incorporated as decision criteria in the evaluation of research projects. In this section, these and the special features of biotechnology are analyzed in the context of priority setting. It is argued below that these features increase the complexity of the priority setting process by adding new factors, or by exacerbating the difficulties that may already be present.

The relevant legal framework for biotechnology research encompasses not only biosafety and IPR systems, but also regulations regarding the importation of special chemicals, equipment, and plant material that may be necessary for some projects. The way the regulatory system is organized also influences the success or failure of research activities. In terms of priority setting, the projects under consideration might be affected in very different ways by the existing regulatory situation. In this way, the regulatory framework can be used to discriminate between projects with regard to their research success. For example, projects dealing with transgenic material must comply with biosafety regulations, while others may use products or processes that are protected by IPR or depend on materials that fall under import restrictions. If no biosafety framework has been established, the testing of genetic material may be severely limited. These things contribute to the uncertainty of success by possibly delaying or even preventing the completion of some projects. In addition, there always remains a certain risk of environmentally undesirable incidents, even with the strictest safety systems. Possible hazards should always be taken into account when research projects are assessed. On the other hand, sound IPR regulations might allow some projects to generate additional benefits through selling the research results, or by stimulating public-private collaboration that leads to faster technology development.

The reduction of biodiversity is a concern that is often mentioned in the context of introducing transgenic plants into the environment, particularly in centers of diversity (Bhagavan 1997b; Cohen et al. 1998). Information about the potential effects on genetic diversity is still limited, and more empirical information needs to be gathered "in order to allow substantiated statements on potential ecological impacts resulting from the release of transgenic plants" (de Kathen 1996, 14). However, biotechnology research can also have a positive impact on biodiversity. Projects aimed at collecting, describing, and conserving genetic material can make a valuable contribution to the preservation of biodiversity and to the design of policies for managing in situ and ex situ conservation of crop genetic resources.

Another area that requires attention is the public perception of genetic engineering and transgenic crops (Cohen 1994). Uncertainty about the acceptance of transgenic crops by consumers may negatively affect the successful adoption of new technologies involving recombinant DNA techniques. In many industrialized countries, a significant proportion of consumers are skeptical about, or even

12. This does not imply that more information about biotechnology leads to a negative perception of transgenic products. Rather, it means that it is impossible to properly balance the benefits and risks of transgenic products and thus to form an opinion on the issue, without sufficient and relevant information.

disapprove of, transgenic products, but, curiously, this does not seem to be the case in developing countries. Nevertheless, the issue is relevant for research priority setting because many agricultural products are exported to the North from developing countries. In addition, with the increasing accessibility and availability of information (a prerequisite for the formation of opinion)[12] and possible shifts in priorities in developing countries (i.e., a shift from providing sufficient food toward protecting human health and the environment), resistance to transgenic products might develop in the future, a possibility that cannot be discounted.

Difficulties in priority setting due to the poor information base have already been mentioned. The problem is considerably aggravated for biotechnology research, because the ability to draw on past experience is extremely limited.[13] The country studies by Brenner (1996) confirm that little information is available regarding the costs of biotechnology research or the costs and benefits of biotechnology products for end users. Moreover, the dynamics of biotechnology development make it very difficult to evaluate the relevance of future research outputs, particularly if these are intermediate results that may rapidly become obsolete in the wake of new, more powerful techniques (Janssen 1995b). The fact that biotechnology research often generates intermediate outputs for use by other, related research programs, highlights the measurement and aggregation problems mentioned earlier. However, it is the ability of biotechnology to produce enabling techniques (e.g., genetic markers to be used as diagnostic tools), as well as end products (e.g., transgenic crops), that makes this new technology so powerful.

Biotechnology projects at the basic and strategic end of the research continuum provide an opportunity for building scientific capacity by strengthening human resources and institutional development.[14] Because of this, the governments of many developed and developing countries identify biotechnology as a national priority area for investments (Gijsbers 1995). Governments have recognized the strategic importance of biotechnology and have formulated science and technology objectives aimed at developing the necessary capacity in this area of research. For research priority setting, this means incorporating "capacity building" into the process as an objective, in addition to existing economic, social, environmental, and food security objectives. This allows the contribution of the strategic component to building scientific capacity to be assessed and allows this component to be weighted and compared relative to the other objectives. The capacity of biotechnology research to produce intermediate results strongly suggests that it should be integrated with conventional research programs. This applies in particular to research on plant improvement because "biotechnology presents a complementary set of tools not to be isolated from breeding, but rather to become part of it" (Cohen 1994, 16). The consequence for priority setting is that understanding the linkages between biotechnology and conventional research becomes critical in the evaluation of research success. The necessary

13. Even when past data are available, caution must be exercised. Shumway discusses the conditions that would permit the use of historical data to predict future research payoffs. The most restrictive condition concerns the S-shape of the new knowledge production function, which Shumway strongly questions. He concludes that "objective historical observations may be relevant, but the linkage between past and future knowledge generation is sufficiently weak to require gross subjective synthesis and assessment" (1981,173).
14. However, to some extent, even biotechnology projects classified as applied or adaptive research contribute to building scientific capacity and, in this sense, have a strategic component.

linkages should take the form of collaboration between different research institutes, as well as between scientists from different areas of specialization.

## Addressing the Issues in Priority Setting Processes

This final section is an attempt to synthesize all the issues discussed in the previous sections. Three working hypotheses are defined to aid in the assessment of the procedure applied in the case study. A set of key requirements are also defined to serve as guidelines for choosing an appropriate methodological approach, and for adapting the priority setting process to agricultural biotechnology research.

### *The Working Hypotheses*

Working hypotheses are not usually intended for statistical testing, i.e., to be accepted or rejected with a certain probability. Instead, they are used to uncover issues that are potentially relevant and therefore merit closer attention. The following working hypotheses are used as assessment criteria for the approach applied in this study.

1. The specific features of biotechnology-based research influence the expected costs, benefits, and chances of success of research alternatives in different ways. Special criteria have to be defined and included in the priority setting approach, in order to discriminate between these features and to properly capture their impact on the performance of the alternatives.
2. Uncertainty regarding the success of agricultural research, and the successful adoption of the results by end users, is inherent in all research processes. In biotechnology research, uncertainty is more prevalent due to the limited historical evidence and the accompanying lack of data. Priority setting in biotechnology research should attempt to identify the sources of uncertainty, assess their influence on research success and adoption, and carefully evaluate the chances of success of each research alternative vis-à-vis the individual sources of uncertainty.
3. The strategic component, in terms of strengthening research capacity, can constitute an important part of the expected benefits of biotechnology research. Therefore, priority setting should explicitly consider the potential contribution of research alternatives to building scientific capacity.

### *Key Requirements for Priority Setting*

The requirements for priority setting approaches largely depend on the perspective one takes. The economist or analytical scientist is concerned with measurement precision and theoretical soundness, while the decision maker is interested mainly in the outcome of the decision. Meanwhile, the research manager emphasizes process, consensus seeking, and commitment. Because priority setting is a management tool, the manager’s concerns should be the primary focus when the requirements for priority setting are being defined. In the past, economists who were involved in priority setting for public research were preoccupied with tools, devoting too little attention to the process (Norton et al. 1992). In the private sector, classical project-selection models are concerned with outcomes, and have also generally ignored the process through which projects are selected in real organizations. According to Schmidt and Freeland,

> classical models generally assume that decisions are made at a single instant in time by a single decision maker. Because of the lack of participation, decisions made by such techniques often fail to build support and consensus from the various parties whose commitment is required for successful project implementation. Building commitment and consensus is one of the key functions of project-selection processes and, for this reason, classical models are unlikely to be useful in real organizational contexts (1992, 190).

Thompson argues along similar lines for the public sector:

> Too much emphasis upon technical consequences assessment diverts energy from consensus seeking and participatory planning. (...) Sometimes it can be more important to make the wrong decision in the right way (1998, 50).

This does not imply that the methodological tool is irrelevant or that the outcome is immaterial. What it means is that investing in improvements to the priority-setting process may instead produce the most practical benefits for public research institutions (Janssen 1995c).

Priority setting processes have three requirements: participation, transparency, and a standardized measurement procedure. As argued previously, priority setting must draw extensively on the subjective judgments of participants. This necessitates the effective involvement of a range of knowledgeable people. Effective participation can be achieved through the use of various tools. For example, the Delphi method (Leviston and Turoff 1975) is an established technique for eliciting subjective judgments from experts,[15] while questionnaires and interviews are less time-consuming options. However, for group decision processes, direct participation is the best option because it stimulates the pooling of knowledge, the elimination of inconsistencies, and the resolution of differences, all of which may bring about consensus and commitment. Moreover, in deciding about public research, particularly in sensitive areas like biotechnology, it is critical that stakeholders[16] participate directly in the priority setting process. This ensures ownership of the decision and assures its successful implementation. Key stakeholders include policymakers in the field of science and technology, research managers, researchers, and end users (i.e., farmers, consumers, and the private sector). With regard to end users, there is little doubt that their participation improves the outcome and relevance of priority setting processes (Ashby and Sperling 1995; Bunders and Broerse 1991; Janssen 1995b). On the other hand, client involvement in the decision-making process is not without problems because "users are not usually in a position to understand the importance of long-term basic and strategic research, nor can they be expected to take into account the research training, teaching, and infrastructure requirements of the research system as a whole" (Stewart 1995, 120). There is a trade-off between

15. The technique was successfully applied in a study to forecast the relevance of future biotechnology research activities in cocoa (Braunschweig and Gotsch 1998).
16. A stakeholder is defined as "any person, group, or organization that can place a claim on an organization's attention, resources, or output, or is affected by that output" (Bryson 1987, 6)

efficiency and effectiveness in decision making. Enhancing participation may result in decisions that are more effective, but an increased number of participants also means that as consensus becomes more difficult, the process becomes less efficient, and vice versa.

The second requirement, transparency, is related to the issue of participation. The priority setting process must be transparent enough to ensure the active participation of stakeholders. A transparent process is critical to eliciting subjective judgments, and participants can provide more accurate information if they clearly understand the approach of the exercise. Moreover, explaining a decision outcome and the procedure used to achieve that outcome requires opening the "black box" of priority setting. Decision making in agricultural biotechnology research sometimes involves sensitive issues of public interest and always involves public resources. Therefore, broad acceptance is required for the successful implementation of the selected research activities. This is achieved through a process that is transparent and easy to explain.

Finally, the complexity of priority setting is largely due to the multicriteria nature of public research decisions. The impact of different research alternatives on different criteria are measured on different scales. Some of these scales are inherently qualitative, which makes it virtually impossible to compare a unit of one criteria scale against a unit of another in a meaningful way. A standardized measurement procedure allows the scores for different criteria to be aggregated in order to obtain an overall assessment of each research alternative.

# 3. Methodological Framework

This chapter explores methodological issues in priority setting. First, the need for formal priority setting approaches is examined. Then, the different evaluation methods that have been developed for priority setting in agricultural research are reviewed, with a discussion of how they have been implemented in the public research institutions of developing countries. To determine the most appropriate method, the different approaches are analyzed based on the key requirements identified in chapter 2. AHP is then introduced as a methodological tool for priority setting—the first time it has been recommended for decision support in public agricultural research—and explained in some detail. The final section introduces the methodological framework designed for the priority setting of agricultural biotechnology in public research.

## The Need for Formal Approaches in Priority Setting

Public research institutes are increasingly faced with the challenge of improving their efficiency and proving their relevance. The main reasons for this are cutbacks in research budgets, growing pressure for accountability and transparency, and, finally, the increased complexity of allocation decisions due to the globalization of research, the broadening research agenda, and the need to involve stakeholders more actively. Research managers can enhance efficiency and credibility by improving methods and capacities for priority setting (Byerlee and Alex 1998). In turn, more formal approaches aid priority setting because they permit managers to elicit, categorize, order, compare, and summarize information and data in ways that are internally consistent and systematic (Shumway 1981). More transparent decision making also facilitates the implementation of the outcome, making the process less costly.

Systematic priority setting has a number of additional benefits, particularly if it is carried out in a participatory manner (Contant and Bottomley 1988; Janssen 1995c; Schuh and Tollini 1979). These benefits should be taken into account when assessing the cost and benefits of the priority setting exercise. With a more formal approach,

- more emphasis is placed on longer-term impacts (whereas informal priority setting often focuses on short-term effects);
- the negative consequences are identified, and corrective measures are adopted at an early stage to compensate for potential losses;
- managers are in a better position to defend their decisions, particularly against donors with a conflicting agenda;
- additional funds may become available;
- the information used for educating the public about sensitive decisions is improved;

- the chances of a successful adoption of new technologies increase because stakeholders are included in the decision process;
- the research objectives are better identified, and differences of opinion are clarified, therefore facilitating consensus building;
- useful information is generated regarding changes that are necessary in the research environment; and
- team building and communication within the institution are improved.

In spite of the advantages of more formal approaches, most public research institutions do not use systematic priority setting (MacKenzie 1996). In a review of different country studies carried out under the auspices of the OECD, Brenner (1996) concludes that, in general, developing countries have no clear priorities or focus in terms of biotechnology research. Similar results are reported by Juma and Mugabe (1997), who analyze the situation in sub-Saharan Africa. The weakness of developing countries in priority setting has also been confirmed by a World Bank review on the achievements and problems of NARS. The review recommends that "the Bank, the donor community, and borrowers need to pay considerably more attention to this area" (Purcell and Anderson 1997, 164). An action plan that echoes this concern was formulated at the annual International Centers Week meeting of the CGIAR in 1996. Increasing NARS capacity for priority setting was presented as one of the plan's five goals (CGIAR 1996).

## Overview of Priority Setting Methods

Since the pioneering study of hybrid corn by Griliches (1958), agricultural economists have invested much effort in evaluating public research. Literature reviews of the analytical and empirical work on research evaluation methods have been conducted by Shumway (1977), Schuh and Tollini (1979), Norton and Davis (1981), Anderson and Parton (1983), Fox (1987), and Daniels et al. (1990), among others. Contant and Bottomley (1988) discuss some formal methods for priority setting, and Alston et al. (1995) provide a comprehensive review of agricultural research evaluation and priority setting methods, with an emphasis on the economic surplus approach.

The reason for conducting such "research on research" is either to estimate the rates of return of past research investments or to improve the prediction of research impact. Research evaluation is therefore categorized as either ex post or ex ante. Results from ex post studies can provide predictions that are useful for the allocation of research resources.[1] However, in the case of emerging technologies such as modern biotechnology, it is not actually possible to use historical evidence in allocation decisions. Therefore, this study focuses on ex ante evaluation. Five types of approaches have been developed for establishing research priorities: rules of thumb, scoring models, cost-benefit analysis, mathematical programming, and simulation models. These approaches are described briefly below.

1. See Echeverría (1990) for a review of more than 100 ex post studies.

### *Rules of Thumb*

This type of approach is the least sophisticated and the simplest to use, and its major advantage is that its data requirements are low. However, this is nothing more than a starting point for more formal priority setting. The two most significant methods in this type of approach are precedence and congruence (Anderson and Parton 1983). The precedence method uses the previous year's funding as the basis for the current year's allocations. Changes in budgets and other resources are shared proportionally by each research activity. This has the advantage of permitting continuity in terms of accumulating research skills and experience. However, the precedence approach does not consider the diminishing returns on certain research investments that may warrant a shift in funding. Similarly, it does not take into account the emerging problems in agriculture, or any promising new areas of research. In congruence analysis, the available resources are allocated across research areas in proportion to their relative value of production. This approach is more flexible than precedence in that it allows research activities in areas of decreasing value to be phased out. However, it favors well-established research activities and discriminates against new ones that may have potentially high benefits. A further limitation is its exclusive focus on economic efficiency, at the expense of other research objectives. Generally, both methods emphasize the status quo and rely heavily on historical data.

### *Scoring Model*

Scoring or weighted criteria methods involve ranking and do not provide decisions on resource allocation *a priori*. Criteria that reflect the research objectives are defined and weighted by decision makers, and the research alternatives are scored according to each criterion by using a discrete scale. These scores are then multiplied by each criterion weight and then added up to determine the order of priorities. This ordinal ranking of alternatives can serve as a basis for allocation decisions, and the alternatives can be funded according to their ranking until the research budget is exhausted. A formal method is linear integer programming, which incorporates resource requirements and other constraints of the research alternatives. Scoring models have several advantages that make them attractive priority setting tools. They are relatively easy to apply, and they facilitate the incorporation of multiple objectives. The model can cope with both quantitative and qualitative criteria, and this allows applied projects to be evaluated against more basic research projects. However, there are no clear guidelines to prevent problems of criteria overlap and unit mix-ups, which invites criticism of its theoretical foundation. Another drawback, which also underscores the participatory nature of scoring models, is the considerable time that is required of participants who usually have high opportunity cost of time.

### *Cost-Benefit Analysis*

Cost-benefit methods usually employ the concept of economic surpluses, whether explicitly or implicitly. Its basic principles are best explained in a market framework, represented by supply and demand curves.[2] The technological innovation generated by research will shift the supply curve to the right. This

2. Because simplified cost-benefit approaches assume a completely elastic (horizontal) and inelastic (vertical) demand and supply curve, there is no need to estimate elasticities. However, this simplification comes at the expense of accuracy and of analyzing distribution effects.

shift denotes benefits that can be measured as net changes in consumer and producer surpluses. To calculate the net social benefit, the benefits are then compared to the cost of research. These estimates can be expressed as an internal rate of return (IRR), a cost-benefit ratio (C/B ratio), or a net present value (NPV). Since the benefits accrue in the future, they have to be discounted in order to get meaningful measures. These values are dependent upon the success and the adoption rate of the new technology. To accommodate uncertainty, expected values need to be estimated based on different assumptions or probability distributions.

Cost-benefit methods are very useful for estimating the economic consequences of different research activities. Its appeal stems from the consistent economic framework on which it is based. In various extensions of the basic model, attempts have been made to include spillover effects, market distortions, and externalities. This brings the approach closer to real-world problems and therefore makes it more valuable. However, the approach is still based on rather stringent assumptions. Its main shortcomings, as identified by Antony and Anderson (1991), are the simplistic modeling of the relationship between a new technological development and its resulting economic benefits, and the extensive use of historical data in an ex ante analysis. The former refers to the necessity of expressing all costs and benefits in monetary terms, which is the fundamental limitation of cost-benefit approaches.

### *Mathematical Programming*

Mathematical programming is an optimization procedure for guiding the allocation of limited resources. Unlike scoring and cost-benefit methods, which only produce a ranking of alternatives, mathematical programming aims to select an "optimal" research portfolio. Therefore, programming methods can also be used to formalize the allocation process of the two previously discussed approaches. The basic approach is to formulate an objective function that is maximized subject to certain constraints, such as funding requirements, human resources, or institutional capacity. The objective function can include multiple objectives and a weighting system to reflect differences in the importance of the objectives. Several variations are possible, including multiple-objective programming, goal programming, and compromise programming.[3]

An interesting feature of mathematical programming methods is their ability to deal with varying levels of funding for each activity. In other words, decisions do not have to be made on an all-or-nothing basis, allowing for the partial funding of activities. However, the functional relationship between the level of funding and the benefits must be known. Mathematical programming can be used to illustrate the trade-offs among objectives (by generating a non-inferior set of solutions), and to analyze the implications of changing constraints. Only a few applications of programming methods to the allocation of research resources are reported in the literature. This may be due to the considerable analytical skill required for the proper formulation of a model. Also, programming methods are time-consuming. The effort required to collect and process data is similar to that

3. See Romero and Rehman (1989) for more details on the formulation and underlying principles of different mathematical programming methods.

required of cost-benefit and scoring models, with additional time required to design, test, and run the model.

### Simulation Models

Simulation models are based on principles of production economics. They estimate the functional relationship between input (i.e., research investments) and agricultural output. By modeling the agricultural production sector or parts of it, simulation models usually operate on a higher aggregated level. A production function may be used to represent the econometric relationship between agricultural productivity on the one hand, and research (and extension) expenditures and additional determining factors on the other. Then, the effects on productivity of various research expenditures, such as introducing different technological innovations, are simulated. The resulting changes in productivity are translated into a supply curve shift, illustrating its economic consequences. In addition to the expected benefits from investment in research, the output of the model can include information about distribution, employment, and nutrition effects. Dynamism can be achieved by running the model over several periods, where the output of period $t$ is used as input for period $t+1$. Simulation models are very flexible and can be used to analyze the wider impact of research investments. However, substantial time and skills are required for collecting the detailed data and determining the mathematical relationships necessary to build the model. Also, estimating econometric relationships is based on time-series data, which are not readily available in the case of biotechnology.

### Other Approaches

Contant and Bottomley (1988) mention two other methods—checklist and domestic resource cost ratio (DRC). The former is best classified as a rule of thumb method, while DRC is a type of cost-benefit analysis. Calling the checklist approach a priority setting method is probably an overstatement since it consists only of a list of relevant criteria against which the research alternatives are checked. However, a checklist can be used as a starting point in combination with other methods. For instance, Marks and Papps (1992) suggest using a checklist prior to a cost-benefit analysis in order to identify the potential constraints that may inhibit the successful implementation of biotechnology projects. DRC is a method of estimating a given country's comparative advantage in producing a certain good. It calculates a benefit-cost ratio using the concept of opportunity cost, which indicates the social profitability of producing a certain commodity.[4] However, the DRC ratio has major shortcomings as a single measure to allocate resources. Its ability to compare the research benefits of different crops is questionable, because the ratio does not consider the differences in size of the production areas. Furthermore, decisions based solely on a favorable DRC ratio tend to be biased against research investments in commodities that, at present, do not have a comparative advantage. However, the DRC approach is a relatively easy method of calculating the social costs and benefits of producing different commodities and can provide useful information for setting research priorities.

4. See also Monke and Pearson for a discussion of the policy analysis matrix (PAM), which, as an extension of DRC, is "particularly well suited to the empirical analysis of technical change" (1989, 30).

## *The Methods in Practice*

Priority setting exercises range from sectoral studies to narrow evaluations of particular research projects. It is often argued that the use of costly methods is not warranted for project-level evaluations. The cost of the exercise should, of course, be reasonable in relation to the amount available for funding. However, one should also keep in mind that project selection is the means by which technology strategies are actually implemented (Schmidt and Freeland 1992). Moreover, in cases where no clear strategy exists, setting priorities at the project level will help shape the future of the organization. In the previous chapter, the trend of replacing institutional budget assignment with project-based funding was mentioned. This shift in the funding mode further confirms the importance of adequately investing in priority setting exercises at the project level.

In recent years, there have been substantial efforts to improve the tools for priority setting. Despite these efforts, only a few of the more sophisticated methods have been implemented by public research organizations in developing countries. Norton et al. explain it as a failure of economists "to communicate adequately to priority setting practitioners the progress that has been realized on developing research performance measures and priority setting methods" (1992, 1094). Shumway, on the other hand, argues that "the perceived benefits to most organizations of the more sophisticated procedures are apparently outweighed by their cost" (1983, 101). As repeatedly mentioned in the literature, the availability of accurate data is often the key limitation of the more demanding methods. Moreover, the extreme uncertainty surrounding knowledge production further limits the potential of sophisticated methods (Shumway 1981). As a result, research managers often turn to simplified methods, knowing that data errors far outweigh errors caused by imprecise procedures.

Scoring models have been used widely, often in combination with other simple methods, and are probably the most frequently applied of formal procedures (Contant and Bottomley 1988). An early application of the scoring model for prioritizing the research program at the North Carolina Agricultural Experiment Station is reported by Shumway and McGracken (1975). One example from biotechnology research that is based on a scoring model is the approach of Solleiro and Quintero (1993). Franzel et al. (1996) used scoring techniques in a priority setting exercise for multipurpose trees. They collected a broad set of data from various stakeholders and used this information to narrow down the list of potentially useful species in a stepwise procedure. Recent examples that involve a combination of methods include two priority setting studies in Latin America, in which an economic surplus approach was incorporated into a scoring model (Lima and Norton 1993; Palomino and Norton 1992). Other examples are the priority setting exercises applied by the International Potato Center (CIP) and the CGIAR. The method used for resource allocation at CIP combines a scoring model with a cost-benefit analysis (Collion and Gregory 1993). For the CGIAR, McCalla and Ryan (1992) evaluate a hybrid of congruence analysis and scoring models.

## Choosing an Appropriate Method

In this section, the different approaches are evaluated with respect to the three key requirements discussed earlier in chapter 2—participation, transparency, and a standardized measurement procedure. The shortcomings of the different approaches are discussed, and an alternative method is introduced, one with potential to overcome some of the problems indicated. The "rules of thumb" approaches are not considered here because the precedence method is not applicable to new programs, and congruence analysis does not take into account the innovative nature of biotechnology, and thus neglects new research areas with high potential. The use of such crude approaches can hardly be justified in light of the potentially far-reaching consequences of biotechnology decisions.

Cost-benefit analysis, mathematical programming, and simulation models all place analysts at the center of the priority setting process. Although the specifications of the model may be based partly on subjective judgments elicited through techniques such as the Delphi method, the analyst plays the main role. Consequently, these approaches have a low potential for active participation. In fact, the only approach that allows (and even requires) extensive participation at each stage, i.e., eliciting information, defining the criteria, assessing the alternatives, and establishing priorities, is the scoring model. The methodological complexity of simulation models and mathematical programming results in poor transparency, which is reinforced by the lack of participation. Cost-benefit analysis (in particular, its less sophisticated versions) and scoring models are fairly transparent because, in both approaches, the process of generating priorities is easily understood. Cost-benefit analysis focuses on the economic impact of the research. Other consequences are only included insofar as they can be quantified in monetary values. Simulation models can take into account a wider range of research effects. However, they do not provide a ranking of research projects based on multiple objectives. Both mathematical programming and scoring models can incorporate many different impacts, including qualitative ones. This requires eliciting the preferences of decision makers. The scoring model provides a more systematic procedure by dividing the process into two steps: a) scoring the contributions of the projects with respect to each criterion and b) weighting the criteria. In programming models, the decision maker has to attach utility values directly to one unit of each criterion, a rather difficult task given the different measurement units of each criteria.

Of the different priority setting approaches discussed earlier, only the scoring model fits all the requirements imposed by the complexity of biotechnology decision making. However, the different approaches are not mutually exclusive. For instance, the outcome of a cost-benefit analysis could be used as input for a scoring model. Also, a simple integer programming approach could be used to allocate the resources based on the priorities generated by the scoring model. Of course, the scoring model is not without shortcomings. The two major ones noted in the literature are its high cost and the absence of a sound theoretical framework. The high cost is due to the considerable amount of time required from scientists and other participants in the process. However, as mentioned earlier, this cost is balanced by the important benefits that result from greater participation. For example, the potential of lowering the implementation cost of the decision outcome, due to a broader consensus among researchers and managers, may in itself justify the high cost of the exercise. The second criticism, concerning the theoretical basis of scoring models, raises several concerns. There is no systematic procedure to prevent double counting due to overlapping criteria, to translate the differently measured (quantitative) impacts and verbally expressed (qualitative) impacts into meaningful scores, or to aggregate the scores across all the criteria, taking into account their different weights. However, the AHP approach presented below has the potential to overcome this deficiency.

## The Analytic Hierarchy Process

The method proposed for the priority setting exercise in Chile is AHP, which is described by Saaty and Vargas as a

> … multiobjective, multicriteria decision-making approach that employs a pairwise comparison procedure to arrive at a scale of preferences among a set of alternatives. To apply this approach, it is necessary to break down a complex, unstructured problem into its component parts, and arrange these parts, or variables, into a hierarchic order (1991, 14).

AHP, which was initially developed by Saaty (1980), has already been applied to a wide range of complex decision problems. For developing countries, Ramanujam and Saaty (1981) use AHP to deal with technological choice, and Alphonce (1997) suggests its use for agricultural decisions, while Anders and Mueller (1995) apply it to the design of a long-term field experiment at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Its numerous applications have been surveyed by Zahedi (1986), Golden et al. (1989), and Vargas (1990), and special issues of several journals have been devoted to AHP.[5] AHP has also been used to support the selection of research portfolios in the private industry (Liberatore 1989; Lockett et al. 1986; Manahan 1989). However, no application of AHP has been reported in the literature for portfolio selection in public agricultural research.

The AHP procedure is based on three principles corresponding to the steps described below: decomposition of a complex unstructured problem; comparative judgments about its components; and synthesis of priorities derived from the judgments. A software package called "Expert Choice" considerably facilitates the application of AHP. However, decision making is a process that involves discussions, learning, and verification. AHP exemplifies this process, providing a consistent framework in which subjective judgments are formally incorporated. The elicitation and subsequent discussion of these subjective judgments are particularly encouraged in group decision making, and AHP is a powerful and straightforward tool for supporting such group sessions. One of its unique features is its ability to compute a measure of the inconsistencies made by the decision makers. This enables the decision makers to identify "errors," revise their judgments, and improve the quality of their decision. Below, the basic prin-

5. *Socio-Economic Planning Sciences* 20(6), 1986; *Communications of the Operations Research Society of Japan* 31(8), 1986; *Mathematical Modelling* 9(3-5), 1987; *European Journal of Operations Research* 48(1), 1990; *Socio-Economic Planning Sciences* 25(2), 1990; *Mathematical and Computer Modelling* 17(4-5), 1993.

ciples and steps of the AHP are discussed, followed by an explanation of its theoretical basis.

## *The Basic Model*

**Step one**

This consists of breaking down the decision problem into a hierarchical structure. Figure 3 shows a basic hierarchy made up of three levels. The top level represents the general goal of the exercise, i.e., prioritizing a given set of research projects. The second level represents the criteria relevant to this goal, i.e., the research objectives, and the bottom level represents the research alternatives, i.e., the research projects. For greater precision, the criteria may be divided into subcriteria, creating an additional level in the hierarchy.

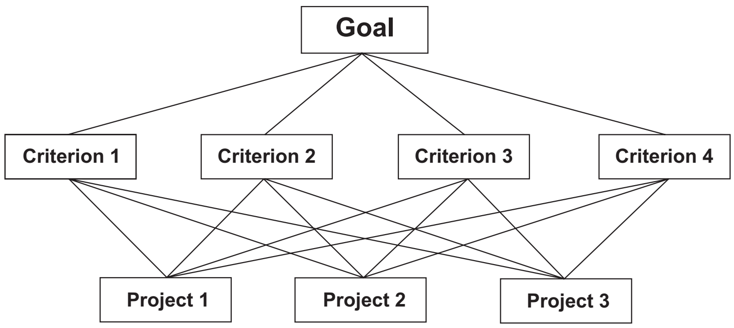



*Figure 3. The basic structure of a hierarchy.*

**Step two**

The second step involves evaluating the projects and weighting the criteria. The projects are compared in pairs to assess their relative performance with respect to each of the criteria. Similarly, the criteria are compared in pairs to define their importance with respect to the general goal. The comparisons are based on hard data, as well as on the intuition, experience, and expertise of the participants. Therefore, AHP explicitly allows for subjective judgments and recognizes their legitimate role in ex ante analysis.

The fundamental scale presented in table 1 is used to elicit the comparisons. The use of verbal comparisons facilitate the weighting of criteria, as well as the evaluation of projects in terms of non-quantifiable criteria. Once the verbal comparisons are made, they are translated into the numerical values of the fundamental scale. Each set of comparative judgments is entered into a separate matrix to derive the so-called "local" priorities, i.e., the preferences of the projects with respect to a specific criterion. The weights of the criteria are derived in a similar fashion.

Figure 4 depicts the type of matrix used to enter the pairwise comparisons. The comparison of project 1 with project 2, for instance, yields the value $a_{12}$. For obvious reasons, the diagonal cells always contain the value 1. If the judgments

*Table 1. Fundamental Scale for Comparative Judgments*

| Numerical values | Verbal terms |
|---|---|
| 1 | Equally important, likely or preferred |
| 3 | Moderately more important, likely or preferred |
| 5 | Strongly more important, likely or preferred |
| 7 | Very strongly important, likely or preferred |
| 9 | Extremely more important, likely or preferred |
| 2, 4, 6, 8 | Intermediate values to reflect compromise |

| | Project 1 | Project 2 | Project 3 | Local Priority |
|---|---|---|---|---|
| Project 1 | 1 | $a_{12}$ | | |
| Project 2 | | 1 | | |
| Project 3 | | | 1 | |

*Figure 4. Matrix to derive local priorities*

were perfectly consistent, any column of the completed matrix could simply be normalized to yield the respective "local" priority of the project, i.e., its relative performance regarding criterion X. However, the judgments may not be consistent, therefore the eigenvector method described below is used to compute the these values.

**Step three**

The third step consists of synthesizing the local priorities throughout the hierarchy, in order to compute the global priorities of the alternatives. The principle of hierarchic composition is applied for this task (Saaty 1980). The principle simply states that, for each project, the local priorities are multiplied by the corresponding criterion weight, and the results are summed up to obtain the global priority of the project with respect to the goal stated at the top level. Thus,

$$P_l = \sum_{m=1}^{M} p_{lm} v_m \quad \text{with} \quad \sum_{l=1}^{L} p_{lm} = 1 \quad \text{and} \quad \sum_{m=1}^{M} v_m = 1$$

where:
$P_l$ = final priority of project *l*
$P_{lm}$ = priority of project *l* with respect to criterion *m*
$V_m$ = weight of criterion *m*
$l$ = (1, . . . , L)
$m$ = (1, . . . , M)

## *Theoretical Foundations*

The following section draws heavily on the work of Harker (1989), who provides a clear and concise description of the basic theoretical foundations of the method. A more thorough treatment of the issues discussed in this section can be found in the work of Saaty (1977, 1980, 1994, 1995).

The first major task in AHP is estimating the weights of a set of elements (criteria or alternatives) from a matrix of pairwise comparisons A = ($a_{ij}$) that is positive and reciprocal. The matrix is given as

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdot & a_{1n} \\ a_{21} & a_{22} & \cdot & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & a_{n2} & \cdot & a_{nn} \end{bmatrix}$$

where:

$a_{ij} = 1/a_{ji}$ for all $i,j$ = 1, 2, . . . , n.

A vector of weights or priorities $w = (w_1, w_2, \ldots, w_n)$ is then computed. Note that by using ratio scales, the estimated weights are only unique up to multiplication by a positive constant. That is, $w$ is equivalent to $cw$ where $c > 0$. For convenience, $w$ is typically normalized so that it adds up to 1 or 100. If the judgments were perfectly consistent, i.e., $a_{ik}a_{kj} = a_{ij}$, then the entries of the matrix $A$ would contain no errors, and could be expressed as $a_{ij} = w_i/w_j$.

To see this last result, note that

$a_{ik}a_{kj} = w_i w_k / w_k w_j = w_i/w_j = a_{ij}$ for all $i,j,k$ = 1, 2, . . . , n.

In this case, simply normalize any column $j$ of $A$ to yield the final weights:

$$w_i = a_{ij} / \sum_{k=1}^{n} a_{kj} \qquad \text{for all } i = 1, 2, \ldots, n.$$

However, errors in judgment are common, and, therefore, the final result using column normalization would depend on which column was chosen.

Saaty (1977) suggests the eigenvector method for estimating the weights when there are errors in judgment. The method computes $w$ as the principal right eigenvector (or Perron right vector) of the matrix $A$:

$$A_w = \lambda_{max} w,$$

where $\lambda_{max}$ is the maximum eigenvalue (Perron root) of the matrix, or

$$w_i = (\sum_{j=1}^{n} a_{ij} w_j) / \lambda_{max} \qquad \text{for all } i = 1, 2, \ldots, n.$$

The eigenvector method is a simple averaging process by which the final weights $w$ are computed as the average of all possible ways of comparing the alternatives. Thus, the eigenvector is a "natural" method for computing the weights.

The eigenvector method also yields a natural measure for inconsistency. As shown by Saaty (1977, 1980), $\lambda_{max}$ is always greater than or equal to $n$ for positive, reciprocal matrices, and is equal to $n$ if, and only if, $A$ is a consistent matrix. Thus $\lambda_{max} - n$ provides a useful measure of the degree of inconsistency. Normalizing this measure by the size of the matrix, Saaty defines the consistency index (*C.I.*) as:

$$C.I. = (\lambda_{max} - n)/(n - 1)$$

For each size of matrix $n$, random matrices are generated, and their mean *C.I.* value, called the random index (*R.I.*), is computed. These values are illustrated in table 2.

*Table 2. Random Inconsistency Index (R.I.)*

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R.I. | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 | 1.57 | 1.59 |

Using these values, the consistency ratio (*C.R.*) is defined as the ratio of *C.I.* to the *R.I.*; thus, *C.R.* is a measure of how a given matrix compares to a purely random matrix in terms of their *C.I.*'s. Therefore

$$C.R. = C.I./R.I.$$

A value of the $C.R. \leq 0.1$ is typically acceptable, but at larger values, the decision maker must reduce the inconsistency by revising judgments.

Computing the principal right eigenvector is accomplished by raising the matrix $A$ to increasing powers $k$ and then normalizing the resulting system:

$$\lim_{k \to \infty} A^k e / e^T A^k e$$

where:
$e = (1, 1, \ldots, 1)$.

The process converges in a few iterations. The reasoning behind this approach and its interpretation as an averaging process is found in Harker and Vargas (1987). Once the weights are computed by raising the matrix $A$ to increasing powers $k$ and normalizing the resulting system, the consistency measure can be computed as follows:

$$C.R. = [(\lambda_{max} - n)/(n - 1)]/R.I._n$$

where

$$\lambda_{max} = (\sum_{j=1}^{n} a_{ij} w_j) / w_i$$

## *Axiomatic Foundations*

The axiomatic foundations of AHP are described below. This set of axioms was first defined by Saaty (1986a) and is further described in Harker and Vargas (1987). These axioms describe the two basic tasks in AHP: formulating and solving the problem as a hierarchy (axioms 3 and 4) and eliciting judgments in the form of pairwise comparisons (axioms 1 and 2). Here, the axioms are paraphrased for clarity. For their full mathematical form, interested readers should consult the references cited above.

**Axiom 1**
Given any two alternatives (or subcriteria) *i* and *j* out of the set of alternatives *A*, the decision maker is able to provide a pairwise comparison $a_{ij}$ of these alternatives under any criterion *c* from the set of criteria *C* on a ratio scale that is reciprocal, i.e.,

$a_{ji} = 1/a_{ij}$ for all $i,j \in A$.

**Axiom 2**
When comparing any two alternatives $i,j \in A$, the decision maker never judges one to be infinitely better than another under any criterion $c \in C$, i.e.,

$a_{ji} \neq \infty$ for all $i,j \in A$.

**Axiom 3**
The decision problem can be formulated as a hierarchy.

**Axiom 4**
All criteria and alternatives that have an impact on the given decision problem are represented in the hierarchy. That is, the decision maker's intuition pertaining to the criteria and alternatives must be fully represented (or excluded) in the structure, and this intuition must be assigned compatible priorities.

## *Extensions*

The advantages of using relative measurements in the pairwise comparisons have already been discussed. However, if many projects are prioritized, the number of required comparisons becomes unmanageable as they increase exponentially with each additional element. For example, for $n=12$ projects there are already $N=66$ comparisons to complete for each criterion $[N=n(n-1)/2]$. To mitigate such time-consuming and tedious procedures, an alternative mode of evaluation was developed, called "rating" (Saaty 1986b, 1995). This alternative mode is applied in the Chilean case study, and it is explained briefly here. Rating is based on absolute measurement and employs scales of intensity that are established for the criteria. A project is then compared against these scales by identifying for each criterion the rating that describes the project best (Saaty and Vargas 1991).

Figure 5 shows a hierarchy with the scales of intensity at the lowest level (i.e., the projects do not appear in the hierarchy). There is considerable flexibility with regard to creating and defining these scales of intensity. For the rating exercise, there are three steps to be completed: determining the scales of intensity, defin-

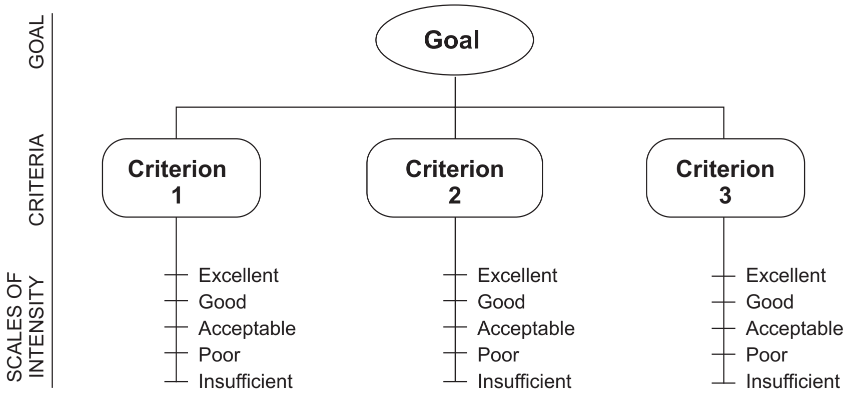



*Figure 5. The hierarchical structure with scales of intensity*

ing the meaning of the intensities vis-à-vis the criteria, and weighting the intensities themselves in a pairwise fashion.

Finally, it is important to emphasize that the use of relative measurement by means of the fundamental scale (table 3) and absolute measurement by means of scales of intensity (figure 5) are two completely different concepts. However, as can be seen from table 3, the types of measurement used in the procedure vary only for the evaluation of projects (i.e., either a fundamental scale or scales of intensity is used). When absolute measurement is used instead of pairwise comparisons, AHP loses some of its appeal, since comparing two alternatives is usually easier than rating them individually against a predefined intensity scale, particularly if it concerns an impact that is rather intangible. In addition, the inconsistency of decision makers cannot be assessed when absolute measurement is applied.

*Table 3. Scales According to Mode of Measurement*

| Evaluation of | Relative measurement | Absolute measurement |
|---|---|---|
| Criteria | Fundamental scale | Fundamental scale |
| Subcriteria | Fundamental scale | Fundamental scale |
| Scales of intensity | — | Fundamental scale |
| Projects | Fundamental scale | Scales of intensity |

## Developing the Model for Priority Setting in Biotechnology

In this section, the model within the methodological framework for the priority-setting process is described. It is based on AHP, which has been identified as a suitable method for selecting research projects under a set of decision criteria. As indicated above, AHP meets the key requirements of participation and transparency and has a credible procedure for comparing and aggregating a variety of project impacts. In developing the model, particular attention is paid to the issues that are raised in the working hypotheses: that uncertainty, the specific features, and the strategic component of biotechnology research should be incorporated into the priority setting process.

First, a hierarchy that reflects the basic problem of setting priorities within a set of research projects is structured. The general goal appears at the top of the hierarchy. The secondary level consists of the main decision criteria, which are the development objectives. For this study, scientific capacity building (i.e., the third working hypothesis) is identified as a critical benefit of research projects, and an additional criterion to capture this impact is incorporated into the level. Because evaluating the projects using only these broad criteria would be too crude, a third level of subcriteria is needed. The specific features of biotechnology (i.e., the first working hypothesis) are built into this tertiary level. The lowest level consists of the research projects under consideration.

The hierarchy serves to assess the potential impact of each project. However, this will yield potential impacts without taking into account the uncertainty of the research and adoption process. Simultaneous evaluation would be too complex a task for decision makers, so the chances of success have to be estimated separately. The separate analysis of uncertainties and preferences is a common approach for selecting under conditions of uncertainty. In the second working hypothesis, it was argued that uncertainty is particularly relevant in biotechnology research evaluation, and warrants more careful scrutiny. Therefore, two additional hierarchies are formulated, one for evaluating the chances of research success, and one for evaluating the chances of successful adoption of the research results. These hierarchies are structured similarly (with four levels each) and incorporate other biotechnology concerns, such as the acceptance of transgenic products and enforcement of regulations regarding IPR.[6]

Saaty (1995) suggests the use of a separate hierarchy to introduce risk in an AHP-based model, but he simply multiplies the outcome of the hierarchies to obtain the final ranking of the alternatives. In this case study, a more sophisticated procedure is used since not all research impacts ($p_{ln}$) are subject to the chances of success ($\alpha_l$, $\beta_l$). Project costs, for instance, accrue to the research organization regardless of project success. In contrast, other impacts, such as institutional capacity building, or the potential hazard of transgenic material escaping from the laboratory, depend on research success ($\alpha_l$) but not on the successful adoption ($\beta_l$) of the research results. Finally, other impacts depend on the success of both the research and the adoption of results. As a consequence, the outcome of the two hierarchies associated with uncertainty (i.e., the chances of research success and the chances of successful adoption) must be selectively combined with the partial results from the impact hierarchy. In this model, $\theta_l$ is used to perform this selective multiplication. Therefore, the model can be formally expressed as:

6. The specifications of the hierarchies are provided in chapter 4.

$$P_l = \sum_{m=1}^{M} \sum_{n=1}^{N(m)} \theta_{ln} p_{ln} v_m s_{mn}$$

where:
$P_l$ = final priority of project $l$
$P_{ln}$ = priority of project $l$ with respect to subcriterion $n$
$V_m$ = weight of criterion $m$
$S_{mn}$ = weight of subcriterion $n$ from criterion $m$
$l$ = (1, . . . , L)
$m$ = (1, . . . , M)
$n$ = (1, . . . , N)

$$\theta_{ln} = \begin{cases} \alpha_l & \text{if impact of project } l \text{ on subcriterion } n \text{ is subject to only chances of research success} \\ \alpha_l \beta_l & \text{if impact of project } l \text{ on subcriterion } n \text{ is subject to chances of research and adoption success} \\ 1 & \text{if impact of project } l \text{ on subcriterion } n \text{ is neither subject to chances of research nor adoption success} \end{cases}$$

$\alpha_l$ = chances of research success of project $l$
$\beta_l$ = chances of adoption success of project $l$.

The model developed here consists of three hierarchies: potential impacts, success of research, and success of adoption. The hierarchies have the same structure, consisting of four levels: goal, criteria, subcriteria, and projects. The specific features of biotechnology have been included at the subcriteria level of each hierarchy, and the strategic component is incorporated through the addition of a criterion to the hierarchy for potential impacts. Uncertainty is addressed by two hierarchies that evaluate the chances of success in the research and adoption processes separately. The chances of success are selectively multiplied by each project’s potential impact on individual subcriteria.

# 4. The Chilean Case Study

This chapter describes the pilot application of the AHP-based approach in Chile. The main purpose of the case study is to evaluate AHP as a support tool for decision making. The evaluation is aimed specifically at testing the ability of the tool to accommodate the working hypotheses and deal with the strategic component of research activities, major uncertainty, and the specific characteristics of biotechnology, as discussed in chapter 2. A more general objective is to determine the tool's relevance and viability in terms of tackling group decision making and other real-world problems.

First, the country-selection process is discussed, followed by a brief overview of Chile, its agriculture history, and its agricultural research system. Next, the context of the exercise is provided by a survey of Chile's national biotechnology program, its history, and its current status. The third section consists of a thorough, step-by-step account of the AHP-based procedure, and how it was implemented in this project. The results are then discussed in terms of the criteria weights and the project priorities that were produced, followed by a sensitivity analysis of the results. This is followed by a critical assessment of the procedure as it was applied in the case study. The chapter concludes with a few remarks about the positive aspects of the exercise, and the shortcomings that need to be addressed for future applications.

## Country Selection

For Chile, the case study was attractive because it introduced a formal procedure to support allocation decisions in the National Program for the Development of Agricultural Biotechnology (PNB). The potential benefits included allowing research managers to deal with an approach for priority setting and undertaking a rigorous evaluation of project proposals for the biotechnology program.[1] There was no guarantee that the case study would be successful, but all the parties involved were aware of the risk, and there were no false expectations concerning the outcome.

The choice of an adequate case-study country is itself a multicriteria decision problem. The selection process started with the nine potential case-study countries listed in table 4.

*Table 4. Country Candidates for the Case Study*

| **Africa** | **Asia** | **Latin America** |
|---|---|---|
| Kenya | Indonesia | Brazil |
| Tanzania | Philippines | Chile |
| Uganda | Thailand | Colombia |

1. The case study was carried out with a limited set of projects, and the outcome of the priority setting exercise was not intended to be used directly by the PNB for resource allocation purposes.

The ISNAR Biotechnology Service (IBS) was asked to recommend three countries each from Africa, Asia, and Latin America that might be interested in a priority setting exercise. Then, decision criteria were developed and indicators were defined, all of which are presented in table 5.

*Table 5. Decision Criteria and Their Indicators*

| Criteria | Definition | Indicators |
|---|---|---|
| Biotechnology Program/ Coordination Agency | Existence of a national biotechnology program or national coordination agency | • Biotechnology program or coordination agency established for agricultural research |
| Resources/ Capabilities | NARS resources and capabilities to carry out biotechnology research | • Number of institutes involved in biotechnology research<br>• Number of researchers involved in biotechnology research<br>• Past and future financial situation of the NARS |
| Complexity/ Integration | Complexity of the biotechnology program and its integration into the NARS | • Degree of complexity of the biotechnology program<br>• Degree of integration of the biotechnology program into the NARS |
| Relevance/ Importance | Relevance and importance for biotechnology integrated priority setting | • Need and intention to go through a biotechnology integrated priority setting exercise |
| Collaboration/ Contacts | Collaboration or contacts between NARS and ISNAR | • Existing or planned joint activities in the field of biotechnology or in general<br>• Personal contacts of ISNAR collaborators |
| Working Environment | Possibility of carrying out research activities effectively | • Availability of sound and reliable data and statistics in the field of agricultural research and economy<br>• Situation concerning political stability, natural disasters and infrastructure conditions<br>• Prevailing language in the country |

A preselection round was conducted, aimed at eliminating one country from each region. After a brief evaluation using the above criteria, Tanzania, Indonesia, and Brazil were deleted from the list, a decision that was subsequently confirmed by regional experts at ISNAR. The remaining countries were then evaluated by scoring. A five-point scale was used for each criterion, and the points for all scales were defined. For the “Complexity/Integration” criterion, for instance, the scale was defined as follows:

1. very complex and not integrated biotechnology program
2. complex and poorly integrated biotechnology program
3. complex or poorly integrated biotechnology program
4. well-structured or well-integrated biotechnology program
5. well-structured and well-integrated biotechnology program.

Information from country reports, statistical reviews, and biotechnology documents were used in assessing the countries according to the first three criteria.

*Table 6. Ranking of the Six Candidate Countries*

| **Criteria** | **Countries** | | | | | |
|---|---|---|---|---|---|---|
| | Kenya | Uganda | Philippines | Thailand | Chile | Colombia |
| Biotechnology Program/ Coordination Agency | 3 | 1 | 2 | 4 | 2 | 2 |
| Resources/Capabilities | 2 | 2 | 2 | 5 | 3 | 3 |
| Complexity/Integration | 4 | 3 | 2 | n.a. | 4 | 3 |
| Relevance/Importance | 3 | 3 | 3 | n.a. | 5 | 4 |
| Collaboration/Contacts | 4 | 3 | 3 | 2 | 4 | 5 |
| Working Environment | 4 | 4 | 4 | 3 | 3 | 3 |
| **Total** | **20** | **16** | **16** | **n.a.** | **21** | **20** |

Regional experts at ISNAR judged the suitability of the countries based on the remaining criteria. Prior to assigning scores to the countries, the answers and assessments based on the literature were discussed with the experts. Since the criteria were not weighted, i.e., all criteria had similar importance, the scores could simply be summed up to determine the overall ranking. Table 6 shows the scores for each criterion and the final ranking of the countries.

Countries were eliminated from the list for a variety of reasons. There was insufficient information to score Thailand on the criteria of “Complexity/ Integration” and “Relevance/Importance.” However, according to the regional expert, the Thai coordination agency deals not only with agricultural biotechnology but with biotechnology in general, and agricultural research in Thailand is spread across six different ministries. With such a complex structure, Thailand was not considered ideal for the case study. The main reason for eliminating Kenya was the existence of an ongoing priority setting activity as part of the Kenya Agricultural Biotechnology Platform. Given this situation, there was no need for an additional priority setting exercise in this country. Two factors influenced the decision to exclude Colombia: a reorganization of its NARS was in progress, and the delicate political situation created potential security problems for the person who was in charge of the exercise.

In the end, Chile was selected for very different reasons. Chile was in the process of planning a comprehensive biotechnology program, and was actively looking for assistance in priority setting. At the same time, IBS was already planning to collaborate with Chile in the field of biotechnology. This mutual interest created an excellent opportunity to conduct a priority setting exercise. In addition, first contacts with the coordinator of the Chilean biotechnology program confirmed that the time was right for a case study.

## Overview of the Case-Study Country

This section provides some background information on Chile that contextualizes the case study. After a brief description of the main political and economic developments of the last few decades, Chile’s agricultural sector and its agricultural research system are described.

## *Background*

Chile covers an area of about 750,000 $km^2$, stretching for more than 4,000 km from north to south, but no more than 460 km from east to west. Chile's climate ranges from extreme arid zones in the north to areas with an annual precipitation of more than 2,000 millimeters. The population is predominantly urban—approximately 85% of Chileans live in cities, with 5 million in Greater Santiago alone. The population grows at an annual rate of 1.5% and is now at 14.5 million. According to World Bank (1997) classifications, Chile is an upper middle-income country, with a gross national product (GNP) of US$4,160 per capita. The adult literacy rate is 95%, and 71% of Chileans have access to sanitary facilities. Today, the infant mortality rate is 12 per 1,000 live births, down from 77 per 1,000 in 1970.

From the 1930s to 1973, when the socialist government of President Allende was overthrown by a military junta led by General Augusto Pinochet, Chile pursued an import-substitution strategy. It was a period of sluggish growth, with foreign exchange shortages, large fiscal deficits, and high inflation rates. By 1973, macro-economic indicators showed signs of a deep economic crisis. After the military takeover, the government adopted a liberal economic strategy and initiated a structural adjustment program that eventually transformed Chile into the fastest growing economy in the region. However, the process was long and difficult, spanning 20 years and including two severe recessions (Venezian and Muchnik 1995). The democratically elected governments that followed the Pinochet dictatorship—under Aylwin (1990 to 1993) and Frei Ruiz-Tagle (1994 to present)—maintained the neoliberal economic model, i.e., free market prices, an open economy, with the private sector playing a leading economic role. However, they also adopted various policy measures to tackle the social imbalances that they inherited from the previous military government.

The military government's rigorous stabilization policy started to bear fruit only in the last 10 years, when Chile's economy entered a sustained expansion path. Inflation has declined to single-digit levels, the gross domestic product (GDP), on average, has grown at rate of 7% per year, and the unemployment rate has fallen to around 5%. Total private and public investments have reached a record level of 27% of GDP. Substantial progress has also been made in export diversification, bringing the share of copper in total export earnings down from approximately 75% in 1970 to 45% in 1990 (Meller et al. 1996). For 1996, the provisional figures were 7.2% GDP growth, an inflation rate of 6.6%,[2] and an unemployment rate of 5.4%. Exports rose more than 40% between 1994 and 1995, and export value reached US$15.4 billion in 1996. The trade balance turned slightly negative (-6.4%) for the second time in the 1990s, due to the continuous increase of imports in the form of capital goods, petroleum, chemical products, vehicles, and electronic equipment (MINAGRI 1997).

Chile's development strategy is heavily dependent on international trade. Its impressive economic performance is driven mainly by exports, which account

2. For the period of January to November 1997, inflation declined further to 5.9%.
3. Chile is the world's largest copper producer and exporter, the second largest aquaculture producer of salmon, the second largest exporter of table grapes, and has one of the world's five largest fishing industries.

for almost 25% of GDP. Its major export commodities are copper, other metals and minerals, wood and paper products, fish and fishmeal, and fruits.[3] Its largest markets are the European Union, Japan, the United States, Brazil, and South Korea. The Chilean government pursues a very active role in foreign trade policy. Since 1991, they have signed free trade agreements with many different countries. Chile is now an associate member of the common market of South America's southern-cone countries (MERCOSUR), a member of Asia-Pacific Economic Cooperation (APEC), and is negotiating a trade agreement with the European Union. In addition, Chile is keenly interested in joining the North American Free Trade Association (NAFTA).

According to Meller et al. (1996), Chile's government faces two big challenges—one environmental and the other social. Despite the government's effort to diversify exports, the product bundle still depends heavily on natural resources, with a relatively low value-added content. Almost 90% of Chilean exports are directly related to natural resources. Therefore, the vigorous export promotion has resulted in the depletion of native forests, overfishing, and severe environmental problems in mining regions. Moreover, growth rates in these sectors have been overstated, because the resulting depletion of resource stocks has not been considered.[4] The second challenge is the country's highly unequal income distribution. In 1992, 40% of the low-income group had a relative income share of only 15.1%, whereas the top 20% of the high-income group had 52.4%. In 1990, 5 million people—almost 40% of Chile's population—were living in poverty. The high annual growth rates of GDP in the last few years, the substantial reduction of unemployment, and increased social expenditures, have already led to a reduction in the number of poor by over a million. However, improvements in income distribution require not only that the momentum of growth be maintained, but also that the low-income group benefits more from the growth process itself. As Meller et al. have pointed out, this "is not an easy task in a free-market economy starting from a highly unequal distribution" (1996, 256).

## *Agricultural Sector*

Agriculture has played an important role in the economic recovery of Chile. The macroeconomic reforms made after 1973, in particular the redistribution of previously nationalized land, the privatization of input and product markets, and trade and price liberalization, have led to the rapid growth and development of the agricultural sector. The improved policy environment allowed farm entrepreneurs to exploit Chile's comparative advantages: a dry summer climate in the central and south-central provinces (where 95% of Chile's agricultural output is produced), rich land watered by melting snow from the Andes (irrigation plays a major role in Chilean agricultural production), and growing export products in the northern hemisphere during winter.

The main agricultural export products are table grapes (23%), apples, wine, pears, tomato paste and juice, kiwis, plums, and fruit juices. Berries, nuts, seeds, and other specialty food products are gaining importance and are contributing to

4. See Alston, Anderson, and Pardey (1995) for a critical discussion of conventional productivity measures that account for only part of the reduced stock of natural resources.

the increasing diversification of Chile's agricultural exports. The principal domestic products are wheat, oats, potatoes, sugar beets, corn, oilseeds, milk, beef, poultry, and pork. Of the 1.8 million hectares under cultivation, 47% is devoted to annual crops, 16% to fruits and vineyards, 4% to horticulture and flowers, 23% to seeded pasture and forage crops, and the remaining 10% is fallow land. In addition, 1.7 million hectares are covered with industrial plantations of pine and eucalyptus (MINAGRI 1997).

Chile's agriculture is characterized by a dual structure. Large and middle-sized commercial farms produce the bulk of agricultural exports. These farms have already invested considerably in modernization and diversification, in the form of capital and the latest technology, and have successfully boosted their production and penetrated foreign markets with quality products. There are also around 200,000 small-scale farmers (*campesinos*) who produce mainly traditional staple crops. They are often in less-favored agroecological regions that have low production potential and few production alternatives. They also do not have the same capital or access to markets as the larger, commercial farms. The situation of the *campesinos* has been aggravated by existing and planned trade agreements, and by the revaluation of the Chilean peso against the US dollar by more than 30% in the last 10 years. Small-scale farmers are increasingly forced to compete with imports from countries that are more competitive and/or subsidize their products (e.g., wheat from Argentina, corn from the USA, and milk from the European Union). Addressing the needs of these farmers is a major agricultural challenge for the Chilean government.

The shift away from the import-substitution policy of the 1960s and early 1970s ended the discrimination of the agricultural sector. It also stimulated higher fertilizer applications and the widespread adoption of improved production technology, resulting in substantially increased land productivity for traditional staple crops. Moreover, the extraordinary opportunity for profit attracted multinational agribusiness, and agriculture became much more export-oriented due to capital investment in fruit plantations, land improvement, drainage, packing facilities, and cold storage. For the period of 1974 to 1990, growth in agricultural GDP (including forestry) averaged 4.7% per annum (Venezian and Muchnik 1995). The performance of agricultural exports has been impressive, with average growth rates of 27% per annum from 1974 through 1990. Agricultural export revenues, as a percentage of total export revenues, increased from 2.7% in 1970 to 6.0% in 1980, and increased further to 11.2% in 1990. Together with an increased domestic output for major import-competing crops, agricultural exports have led to a consistent surplus in agricultural trade since 1985 (after chronic deficits).

The key indicators of Chile's agriculture, and their development since 1990, are presented in table 7. Agricultural GDP growth is behind total GDP growth (which averaged 6.8%) for the period under consideration (1990 to 1996). This caused the sector's contribution to national growth to decrease from 7.9% to 6.5%. On the other hand, exports of agricultural and forestry products doubled in the last six years, generating a trade surplus in this sector of almost US$3 billion in 1996. Agricultural employment as a share of total employment is continually decreasing, but unemployment in agriculture is only half the national employment rate.

*Table 7. Development of Key Indicators in Chilean Agriculture*

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1990-96 (average) |
|---|---|---|---|---|---|---|---|---|
| Growth rate of AgGDP (%) | 7.6 | 1.8 | 7.0 | 1.6 | 6.9 | 4.8 | 1.5 | 4.4 |
| AgGDP, as % of total GDP | 7.9 | 7.5 | 7.3 | 6.9 | 7.1 | 6.9 | 6.5 | 7.2 |
| Agriculture and forestry exports (FOB, millions of US$) | 2,030 | 2,418 | 2,768 | 2,703 | 3,275 | 4,473 | 4,170 | 3,119 |
| of which: - agriculture | 1,223 | 1,580 | 1,729 | 1,596 | 1,824 | 2,208 | 2,626 | 1,828 |
| - forestry | 807 | 838 | 1,039 | 1,097 | 1,451 | 2,266 | 1,544 | 1,292 |
| Agriculture and forestry imports (CIF, millions of US$) | 355 | 506 | 652 | 684 | 807 | 1,043 | 1,248 | 756 |
| Agriculture and forestry exports/ total exports (%) | 23.7 | 26.7 | 27.3 | 28.7 | 28.1 | 27.2 | 27.1 | 27.0 |
| Employment in Agriculture, Oct.–Dec. (%) | 19.2 | 19.1 | 18.0 | 17.0 | 16.2 | 15.7 | 15.0 | 17.2 |

*Source:* MINAGRI (1997)

## The National Agricultural Research System[5]

The reorientation and modernization of the agricultural sector has also had major effects on the national agricultural research system (NARS) of Chile. New players appeared on the scene, funding modes changed, and competition increased, forcing competing actors to implement more demand-driven research policies. Traditionally—that is, before economic reforms started—the NARS consisted of the national agricultural research institute (INIA) and the agricultural faculties of four major universities. The private sector was almost non-existent in agricultural research, with the exception of two experimental stations from the National Farmers' Association (SNA), and a private company, Semillas Bear.

INIA, the cornerstone of Chile's NARS, was founded in 1964 as semi-autonomous government agency under the control of the Ministry of Agriculture. It is a decentralized institution with seven regional research centers (CRIs), a national center for entomology, and several experimental stations throughout the country. Between 1970 and 1990, INIA's professional staff increased from 153 to 230, and its budget increased from US$3 million to US$10.5 million,[6] accounting for almost 80% of total NARS expenditures. By 1997, INIA had a research staff of 270 professionals, and a budget of US$43.6 million. The way in which INIA's research is financed also changed considerably during this period. Originally, 90% of its budget came from government sources, but this share dropped to 44% in 1997. The remaining funds were obtained through the sale of products and services (25%), research grants and contracts with public and private entities (11%), administration of external resources (11%), and through other, unspecified sources of income (9%) (INIA 1998).

5. This section draws heavily from Venezian (1992) and Venezian and Muchnik (1995).
6. In constant U.S. dollars of 1997.

Two striking features of agricultural research in Chile are the import of foreign technology and the establishment of competitive funds. Both developments emerged as a consequence of the changing economic policy environment and rapid agricultural growth. The structural transformation of the agricultural sector, which involved a shift in emphasis to export production, required new and different technological innovations. Because the NARS focused on traditional crops, Chile imported the technology directly from abroad, mainly from California, where the agroclimatic conditions are similar to Chile's, but also from Europe and New Zealand. The imported technologies included planting materials, agronomic practices, irrigation methods, production inputs, and (post-)harvest techniques. These were intended primarily for the fruit subsector, and more recently for the production of seed, vegetables, and ornamentals. Import and export companies played a key role in this development, but they received considerable assistance from public-sector researchers who were working part-time for the private sector. Therefore, even though the NARS was not directly responsible or in charge of importing this technology, the accumulated knowledge, expertise, and personal contacts of its researchers were critical to the successful import, adaptation, and rapid adoption of the new technology. In other words, the presence of a sound NARS provided the preconditions for introducing innovations from abroad.

The second feature, the introduction of competitive research funds, began in the early 1980s and was the logical consequence of applying the liberal economic strategy to the science and technology policy.[7] In the field of agricultural research, competitive grant schemes became the new medium of resource allocation. Various publicly sponsored funds were established for the promotion of scientific and technological developments. The most significant ones are the funding programs of the National Committee for Science and Technology Research (CONICYT), which is part of the Ministry of Education. With the exception of the Fund for Agricultural Research (FIA), the programs are open to all research institutions and individuals. This means that the agricultural research community competes for funding with all other entities in the field of science and technology. The funds also require collaborative research and private sector involvement. The new funding mechanism and the strong demand for agricultural technologies and expertise created additional research institutions. This includes new faculties and schools of agriculture, faculties of other disciplines, non-governmental organizations, and private companies. However, most of them focus on applied research on a project-by-project basis. The direct involvement of the private sector in agricultural research is still marginal. According to the Ministry of Agriculture, the bulk of research resources still comes from the public sector (MINAGRI 1996), but this is expected to change. The government intends to increase research expenditures from 1% of agricultural GDP at present to 3% in the future, with a significant contribution from the private sector.

In 1994, INIA initiated a restructuring process to modernize its structure and balance its budget (INIA 1994; MINAGRI 1996). Twenty-two national programs, which were structured by crop and discipline, were abolished and replaced by four departments: animal production, plant production, natural

7. This was after a failed attempt to privatize INIA during the early adjustment years.

resources, and management and productive systems. Each CRI also established a department for agricultural business relations. Further changes included: decentralization to give the CRIs more financial autonomy and responsibility, the focus on projects as operational units, and the separation of accounting for research and development. In order to eliminate the budget deficit and to free resources for new initiatives such as PhD programs abroad and salary increases for professional staff, some staff have been laid off and the sale of land has been planned. During the adjustment process, INIA focused its activities on large commercial farmers, but, since 1990, the emphasis has shifted to small-scale farmers. This shift was prompted by a loan from the Inter-American Development Bank (IDB) to support research for the benefit of this target group. However, budgetary pressures and the new institutional strategy may again lead to a focus on more commercially oriented clients.

There are two organizations responsible for most of the agricultural extension in Chile: the Technology Transfer Groups (GTT) and the Institute for Agricultural Development (INDAP). The GTT system was set up by INIA in order to guarantee the effective transfer of new technological innovations to agricultural entrepreneurs. With INIA's shift in focus toward small-scale farmers, the responsibility for technology transfer was taken over by the National Farmers' Association. INDAP, which is organized under the Ministry of Agriculture and has established agreements with various research institutions, also focuses its extension services on small-scale farmers. However, INDAP's mandate is much broader, and involves all manner of assistance to poor rural areas, including providing credit and infrastructure, implementing irrigation projects, and advising for organizational development (MINAGRI 1996).

Overall, the Chilean NARS has adjusted well to the changes in economic policy and funding strategies. Although the growing demand for agricultural innovations was, for the most part, met by importing technology from abroad, the research community played a critical role in the transfer, adaptation, and diffusion of the new technology. However, the changing conditions also had some adverse effects. First, a failure to replace foreign financial assistance, which had funded staff training abroad, has eroded the human capital stock. Furthermore, the relatively low salaries in public-sector research do not motivate its professional staff and impede the employment of highly qualified researchers. Second, the reduction of government spending has led to a serious deterioration of INIA's physical infrastructure and equipment. Third, the introduction of the competitive grant system has weakened research cooperation (despite collaborative agreements) due to increased competition among researchers. Fourth, the new funding approaches are emphasizing research productivity and competition, which is shifting research activity toward short-term projects. This may result in the neglect of research problems that require continuity or whose solutions do not produce obvious financial benefits. The consequences of these trends for the agricultural research system of Chile can only be assessed in the future.

Although all the institutions of the Chilean NARS may submit research proposals to the PNB, only projects from INIA were considered in this exercise, for several reasons. First and foremost, the exercise was restricted to one institution in order to keep the exercise manageable. Second, INIA is by far the most important player in agricultural research. Third, the coordinator of the PNB and partner in the case study is also an INIA researcher. Finally, existing contacts with INIA and the institution's firm commitment to the exercise favored collaboration.

## Chile's Biotechnology Program

Preparatory work for the biotechnology program included a comprehensive survey of research activities in agricultural and forestry biotechnology, which was conducted in 1995 (Villalobos 1995; Vio 1995). The main results of this survey are discussed below.

### *Agricultural Biotechnology in Chile*

Chile has 42 laboratories working totally or partially in biotechnology; 33 of them are located in universities or public research institutes, and nine are private laboratories. About 40% of the public- and all of the private-sector laboratories are oriented toward tissue culture, primarily for micropropagation. The infrastructure varies significantly, ranging from fully equipped laboratories to extremely limited facilities. Of the 80 researchers involved in agricultural biotechnology, very few are at the PhD or MSc level, and a large proportion of them use biotechnology only sporadically or for very specific purposes. Between 1982 and 1994, approximately 120 research projects were carried out in the field of biotechnology. Of these projects, 50% involved tissue culture, with only an insignificant number involving animal biotechnology, and most of the projects were executed in universities. In an effort to promote biotechnology in Chile, CONICYT established a national commission for biotechnology. However, it has neither an explicit coordination function, nor specific funding for biotechnology, nor does it have a particular focus on agriculture (Gil et al. 1996). In 1989, INIA established a program for plant biotechnology, but it was only after signing an agreement with the Japanese Development Cooperation two years later that significant activities in biotechnology were developed.

Chile does not have policies to deal specifically with the legal issues of biotechnology. Instead, existing laws are applied to biosafety and patenting issues. For example, existing regulations for the importation and multiplication of genetically modified seed (for re-exportation) are also used for regulating the environmental release of transgenic organisms. The Ministry of Agriculture also established the Advisory Committee for the Release of Transgenic Organisms (CALT) to oversee this process. The Recombinant DNA Advisory Committee, created to oversee projects presented through CONICYT, also issues biosafety recommendations that, together with respective guidelines from international organizations, serve as behavioral codes for researchers who work with transgenic material. For the patenting of developments in biotechnology, existing legislation such as the Plant Breeders' Rights Act and the General Patent Act are applied (Villalobos et al. 1995).

The survey revealed a number of deficiencies in Chile's biotechnology research program. Although most of the modern techniques currently applied in plant and animal biotechnology are available in Chile, research activities focus primarily on tissue culture, and many of the more complex techniques remain at the experimental stage. The role of the private sector is marginal, in terms of executing and financing biotechnology research. The activities of private laboratories are limited to the micropropagation of commercial crops, such as fruits and flowers. The existing infrastructure varies greatly. Aside from laboratories that are capable of conducting internationally competitive research, there are other laboratories with serious limitations in even the most elementary supplies. In terms of animal biotechnology, the infrastructure is scarce and aged. But Chile seems to be quite advanced in terms of computer networks and their applications. There is a lack of qualified personnel for biotechnology research, in both the total number of researchers and the proportion who have completed postgraduate studies. The insufficient number of skilled scientists impedes the acquisition of modern technologies and delays the training of young professionals. At the same time, a significant number of well-trained Chilean researchers are working abroad, but the lack of attractive positions at home prevents their repatriation.

At present, Chile does not have a system to support and coordinate agricultural biotechnology (or biotechnology in general) at the national level. There is no organizational structure to promote interaction, provide incentives, or define research priorities in this area. As a result, collaboration among Chilean biotechnologists is limited. Their linkages with other researchers, particularly plant breeders, are weak, and linkages with the productive sector are almost non-existent. Furthermore, the lack of national coordination in biotechnology research makes it difficult to pursue and implement regulations.

## *The Initiative for a National Biotechnology Program*

Chile's agriculture and forestry sector has contributed significantly to the country's economic performance, as mentioned earlier. In order to maintain and enhance the sector's competitiveness, the Ministry of Agriculture has proposed a new strategy that involves the diversification of production, quality improvement, a decrease in production costs, a higher value added to agricultural exports, and the protection of the environment. The science and technology system is expected to play a central role in implementing this new strategy (Muñoz 1997).

The Ministry of Agriculture regards biotechnology as an important tool for supporting its new policy and for reducing dependence on foreign technology.[8] For this reason, it initiated a National Program for the Development of Agricultural Biotechnology (PNB). INIA, which was instructed to coordinate the preparation of the program, established a technical advisory committee, which then commissioned a consultant from the Food and Agriculture Organization of the United Nations (FAO) to carry out a survey on the potentials and limitations of agricultural biotechnology in Chile, the results of which are presented here. Subsequently, a team of international experts was hired to design a draft proposal for the PNB. Three workshops were held to set the respective priorities in plant, animal, and forestry biotechnology. The outcome of the workshops, together with the draft proposal, served as the basis for a planning conference with broad national and international participation. Despite numerous invitations, only a few representatives from the private sector attended the conference (Muñoz

8. In the horticulture and fruit subsector, where Chile depends heavily on varieties from abroad, the expenses for royalties increase production costs and erode Chile's competitiveness (MINAGRI 1996).

1998). The final proposal produced by the conference recommends an allocation to the PNB of US$44 million, for a period of 10 years. The main objective of the PNB is to double the country's existing capacity for biotechnology, in terms of both human resources and physical infrastructure, in order to stimulate the competitiveness of Chile's agricultural sector. For the development of human resources, funds are to be allocated to advanced training programs and to the repatriation of Chilean researchers who are currently working abroad. Scientists and administrators are also to be trained in the relevant legal issues such as biosafety and patent rights. The bulk of the funds are earmarked for competitive grants. Since the survey indicated that the private sector does not have immediate interests in biotechnology, the proposal does not address co-financing. However, interaction with the private sector is considered an important criterion for the approval of research projects (Muñoz 1997).

### *The Need for Further Priorities*

The program proposal has been well received by both government authorities and the scientific community in Chile. However, one of the objectives—elaborating a set of well-defined research ideas from which specific projects can be derived—has not yet been achieved. In the workshops mentioned above, the participants established priorities through simple discussions within their working groups, without any formal procedure. According to Muñoz, the resulting set of prioritized biotechnology disciplines was far too general and "of little help for the assessment of individual projects proposals" (1997, 14). Moreover, the suggested sequence for the development of biotechnology created some confusion regarding the selection of decision criteria.

The PNB acknowledges that capacity building is needed as a first, fundamental step, and that a focus on the production of specific products should be done only at a later stage. However, it soon became clear that depending solely on the criteria that refer to the former objective would not be acceptable. Additional criteria that reflect national goals need to be included. Establishing criteria specifically for the funding of individual projects to make the biotechnology program operational is perceived as a pressing need.[9] This is the reason why Chile expressed keen interest in a priority setting exercise for the PNB, and why the situation in Chile offered an excellent basis for the case study.[10]

## A Ten-Step Procedure for Priority Setting

The procedure that was followed in the priority setting exercise of the Chilean biotechnology program is depicted in figure 6. It consists of 10 steps that are structured around four major meetings. The initial and final meetings lasted a full day and a half day, respectively, while the workshops lasted two days each. Altogether, the entire process took nine months, but it is expected that future applications can be managed in a much shorter time. Each step of the procedure is discussed in some detail below.

9. According to Vio (1995), specific projects should form the basis for resource allocation.
10. A Spanish report of the case study can be found in Braunschweig and Janssen (1998).

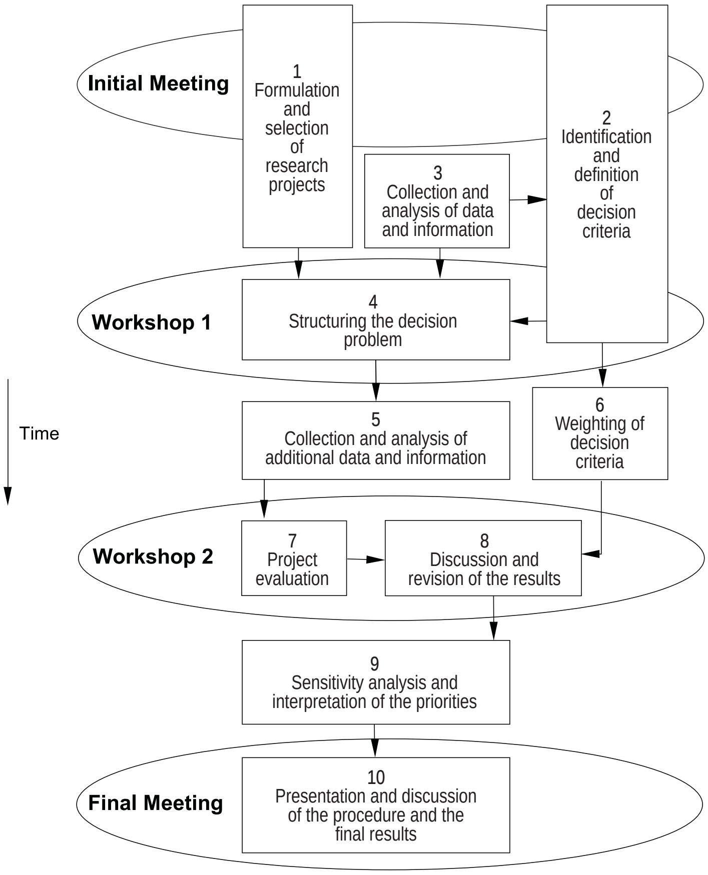



*Figure 6. Procedure for research priority setting*

**1. Formulation and selection of research projects**

Researchers from different CRIs of INIA were asked to outline research projects that were suitable for submission to the PNB and to fill in the project proposal forms designed for this purpose. Twelve project ideas, all in the field of plant biotechnology, were presented and discussed at the initial meeting. At the same meeting, the participants—i.e., project leaders, additional members of the research teams, and research managers from INIA—were informed about the case study and about its objectives, methodological approach, and procedure. The original plan of selecting only six or seven proposals was not immediately possible, because some of the project ideas required modification, and the researchers whose projects were excluded showed some resistance. However, due to limited resources, the list of proposals had to be narrowed down. Eventually, a preselection procedure was carried out at an additional meeting, which was attended by the coordinator of INIA's biotechnology program, the subdirector of the planning division, and the analyst. Three preselection criteria were applied: the maturity of the project idea, its scientific relevance for the PNB, and the existence of an important research component (as opposed to its development). The project ideas that were eventually selected for the priority-setting exercise are outlined below.

**Cherimoya**

| | |
|---|---|
| Title: | Genetic transformation of cherimoya to obtain fruits with delayed ripening. |
| General objective:[11] | To generate new varieties with delayed ripening, in order to better withstand long-distance transport, and improve the post-harvest life of the fruit. |
| Duration: | 3 years |
| Resources required: | CH$69 million |

**Grape**

| | |
|---|---|
| Title: | Genetic transformation of grapes to induce resistance against phytopatogene fungi. |
| General objective: | To obtain a new variety of table grapes with total or partial resistance to infestation of Oidio and *Botrytis*, the two fungi that most affect grapes in Chile. |
| Duration: | 3 years |
| Resources required: | CH$60 million |

**Potato**

| | |
|---|---|
| Title: | Use of ligament maps of RFLP with the gene H1 marker to genetically improve potato resistance against cyst nematodes in Chile. |
| General objective: | To development varieties with long-lasting resistance to the cyst nematode of potato (*Globodera rostochiensis*). |
| Duration: | 2 years |
| Resources required: | CH$29 million |

**Tomato**

| | |
|---|---|
| Title: | Use of molecular markers to study the genetic diversity of native tomato germplasm. |
| General objective: | To optimize in situ conservation systems for native germplasm of the genus *Lycopersicon*, and identify genes of interest to be introduced in tomato varieties (*Lycopersicon esculentum*). |
| Duration: | 2 years |
| Resources required: | CH$24 million |

**Wheat**

| | |
|---|---|
| Title: | Implementing techniques of genetic engineering applicable to integrated manipulation of diseases based on fungi. |
| General objective: | To implement techniques of genetic engineering applicable to integrated manipulation of diseases based on fungi. |
| Duration: | 3 years |
| Resources required: | CH$42 million |

**Nothofagus**

| | |
|---|---|
| Title: | Biochemical, molecular, and dasometrical characterization in six species of the genus *Nothofagus*, which grow between regions V and IX of Chile. |
| General objective: | To determine the genetic diversity of six species of *Nothofagus*, using morphological, biochemical, and molecular markers. |
| Duration: | 3 years |
| Resources required: | CH$173 million |

**Flowers**

| | |
|---|---|
| Title: | Characterization, selection, and production of native flowers in Chile, with the possibility of exportation. |
| General objective: | To enhance the value of two species of native flowers, through characterization and conservation of resources. |
| Duration: | 3 years |
| Resources required: | CH$82 million |

11. In order to evaluate the impact of the projects on the productive sector, researchers were asked to formulate the final goal of the research activity under "general objective," even if several projects must be completed before this goal can be achieved.

Annex A provides a summary of each project proposal, along with the comments made by the external reviewers.

**2. Identification and definition of decision criteria**

The first activity was a thorough review of different policy documents from MINAGRI, INIA, and the PNB. Based on this review, the objectives of biotechnology research in Chile were identified. The decision criteria derived from these objectives were categorized as either "Economic," "Social," "Environmental," or "Institutional." Furthermore, criteria were identified to capture the chances of research success and adoption. To describe each criterion, a range of subcriteria were formulated, and indicators were determined. The conceptual framework used to generate and structure the decision criteria is discussed extensively in Braunschweig et al. (1998), where its implementation and the resulting criteria lists are also described and commented upon.

At the initial meeting, a list of potential criteria was presented for assessment. However, the ensuing discussion revealed that defining and weighting decision criteria are highly strategic tasks, tasks that may not be appropriate for researchers. Therefore, the decision was made to work with two different groups: a "strategic group" consisting of research managers and experts from different institutions, and a "technical group" consisting of the project leaders and other INIA representatives. The strategic group was made responsible for selecting and structuring the main criteria (i.e., those with strategic characteristics) and for weighting all of the criteria and subcriteria. In order to discuss this task, a separate meeting was held with the members of the strategic group. The technical group dealt with the more technical criteria, and with the evaluation of the projects.

**3. Collection and analysis of data and information**

The purpose of this step was to further modify the list of criteria vis-à-vis their relevance to the projects under consideration and the available data. After interviews with project leaders and discussions with the PNB coordinator and a representative of INIA's planning division, appropriate and unambiguous indicators were identified for each criterion. A consultant created profiles of the crops associated with the research projects. These profiles covered agronomic characterization, production data, researchable problems, transformation and commercialization, and national and international (for export crops) market data.

**4. Structuring the decision problem**

This task was accomplished during the first workshop, with the participation of the project leaders, individuals responsible for biotechnology, representatives from INIA's planning division, and an international expert. The participants had all the information generated in the previous step at their disposal. The objective was to agree on the list of criteria, their definitions, and the model, which was prepared based on the earlier meeting with members of the strategic group. As described in the previous chapter, the model consists of three hierarchies. The main hierarchy (H1) evaluates each project's potential impact, while the other two hierarchies estimate the chances of research success (H2), and the chances of successful adoption by end users (H3). Figures 7, 8, and 9 show the hierarchical structure and the elements that were agreed upon by the participants.

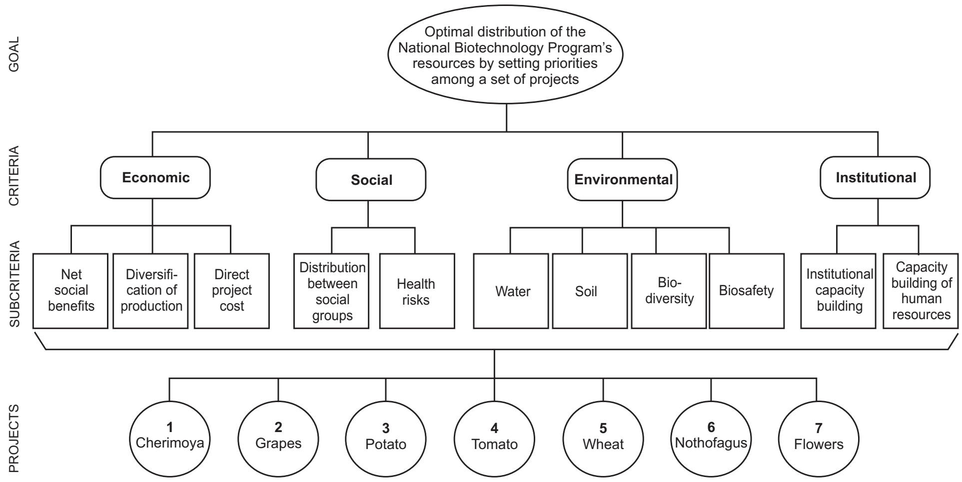



*Figure 7. "Potential impacts" hierarchy (H1)*

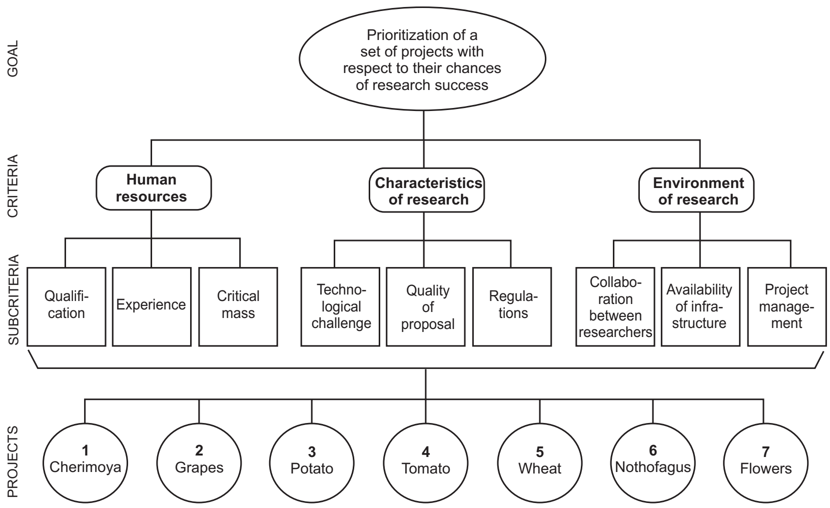



*Figure 8. "Success of research" hierarchy (H2)*

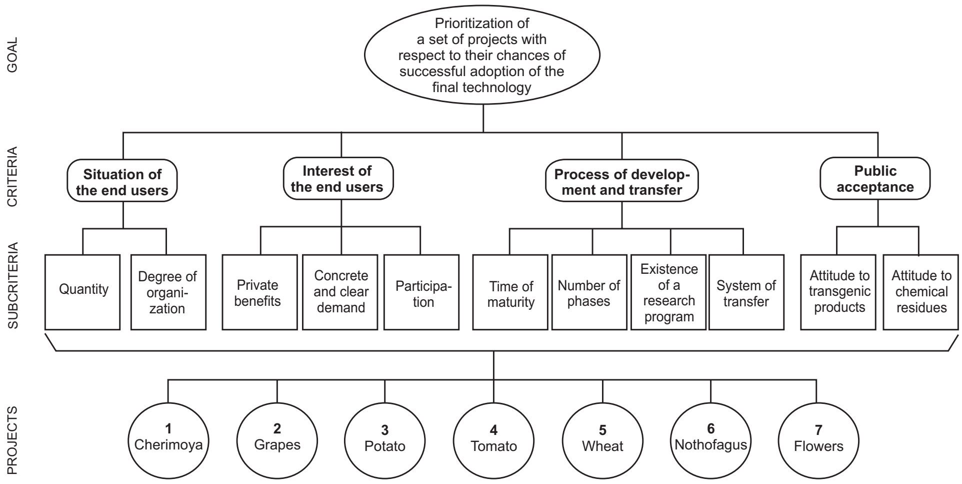



*Figure 9. "Success of adoption" hierarchy (H3)*

**5. Collection and analysis of additional data and information**

The purpose of this step was the compilation of relevant information for the evaluation of the projects in the second workshop. Data collection for the projects focused on information pertaining to the subcriteria and their indicators, which were already defined in the previous step. The sources of information were detailed project proposals and external evaluations, as well as statistics, market surveys, and technical reports on the relevant crops. A separate proposal form was designed to obtain accurate information on each project. It includes questions about the project's possible effects on economic, social, environmental, and institutional issues, as well as possible effects on the criteria used to determine the chances of successful research and adoption. With regards to the latter, the proposal form includes a section on the project's ultimate objectives and the assumptions that are necessary to attain these objectives.

The proposals were then peer reviewed, in order to get an impartial judgment regarding the quality of the proposals in terms of their consistency with the literature, the feasibility of their hypotheses, the degree of correspondence between the resources solicited and the activities planned, and their consideration of prior results. In addition, the external reviewers were asked to evaluate the qualitative aspects represented by the decision criteria, including the complexity of the technology, the generation of knowledge, and the need for regulation. The form used for this evaluation also includes a section on how realistic the indicated results appeared to be. The final source of information were the secondary data that were collected and processed by the consultant. All this information was then compiled into a comprehensive document[12] that was used to assist participants in the second workshop.

12. This document is in Spanish and is available from the author upon request.

**6. Weighting of decision criteria**

The strategic group weighted the criteria and subcriteria of the three hierarchies. About half of the group's 21 members came from INIA, and the other half came from other public institutions, i.e., the Ministry of Agriculture, universities, National Committee for the Environment, CONICYT, INDAP, and PNB. The strategic group was divided into four subgroups that maintained the institutional parity between INIA and non-INIA representatives. Each subgroup weighted the criteria and subcriteria pertaining to its respective area of expertise, as shown in table 8.

*Table 8. Weighting Tasks per Subgroup*

| Name | No. of members | Weighting task |
|---|---|---|
| Subgroup 1: Research (principal subgroup) | 9 | • Criteria of H1, H2, and H3<br>• Subcriteria of criterion "Institutional"<br>• Subcriteria of H2 |
| Subgroup 2: Socioeconomic | 4 | • Subcriteria of criterion "Economic"<br>• Subcriteria of criterion "Social" |
| Subgroup 3: Environment | 4 | • Subcriteria of criterion "Environmental" |

Because it is normally rather difficult to gather senior managers for this type of exercise, the weighting was carried out through interviews. A different questionnaire was designed for each subgroup, and judgments were elicited through pairwise comparisons in the presence of the analyst. During each interview, AHP software (Expert Choice) was used to process the judgments in order to provide the respondent with his or her final criteria or subcriteria weights. In this way, the respondents were given the opportunity to compare the resulting weights with their perception of the importance of the criteria, and they were able to make any necessary revisions. In case of a high inconsistency ratio, the respondent could do the pairwise comparisons again, in order to improve consistency. The results of the weighting process are presented in the next section, under "Results and Analysis."

**7. Project Evaluation**

The projects were evaluated and prioritized in the second workshop. The participants were the members of the technical group, i.e., the project leaders and other representatives from INIA. They worked in two groups, each assisted by a facilitator who handled the software. The key source of information was the comprehensive document produced in step 5. It was structured by criteria and included a summary of the projects and of the reviewers' comments, a definition of each criterion, the performance indicators used to measure each project's contribution to the subcriteria, and crossreferences to the pertinent sections of the each proposal. The structure of the document allowed for an efficient and well-focused discussion. Further materials, such as visualization aides and various forms, facilitated interaction during the meetings and the presentation of results in the plenary sessions.

Through the use of pairwise comparisons, the participants assigned scores to the projects based on the subcriteria of H1. This hierarchy was modified only slightly; the subcriterion "water" (under the "Environmental" criterion) was eliminated due to its perceived lack of discrimination potential. Rating (i.e., absolute measurement) was used in H2 and H3, as previously discussed. Prior to the workshop, the subcriteria were removed from the hierarchies and were used as weighted indicators. That is, scales of intensities were developed directly in order to save time. Figure 10 presents H3 as it was used in the evaluation. The group working on this hierarchy defined two types of scales and subsequently defined the corresponding numerical values of each scale through pairwise comparisons of the scale elements. The projects were then assessed for each criterion. The other group followed a similar procedure for H2 but used only one type of scale.

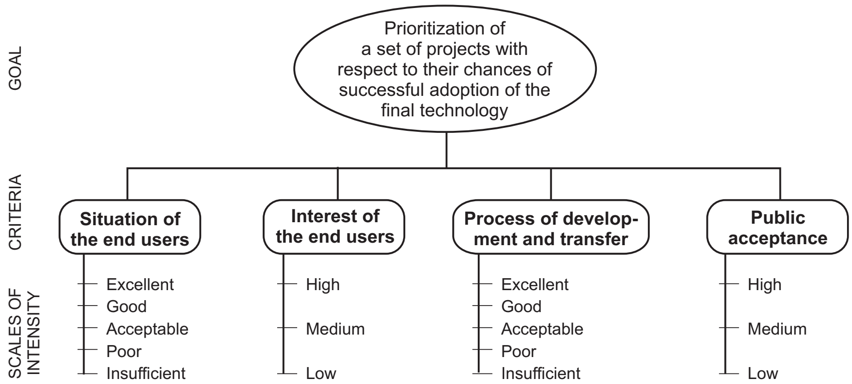



*Figure 10. "Success of adoption" hierarchy, as used in the evaluation*

**8. Discussion and revision of the results**

The only major need for revision came about when H2 was being considered. The group did not feel comfortable with the resulting priorities. One reason for this was that the element "Quality of proposal" was originally positioned at the subcriteria level. However, the group regarded a well-developed and well-formulated project proposal as crucial for achieving any results. Consequently, "Quality of proposal" was moved up to the criteria level, and the weights had to be redetermined. A second problem was the lack of subcriteria in H2. This forced the participants to make very general evaluations, which tended to blur the differences between the projects. It was decided, therefore, to reintroduce the subcriteria (figure 11). The same scale was used for all subcriteria, and equal weights were applied to all the scales. These changes significantly improved the logic of the results. However, the revision of H2 caused a major delay, precluding a discussion of the final results of the evaluation and the assessment of the procedure. To compensate, the participants carried out a written evaluation of the exercise instead.

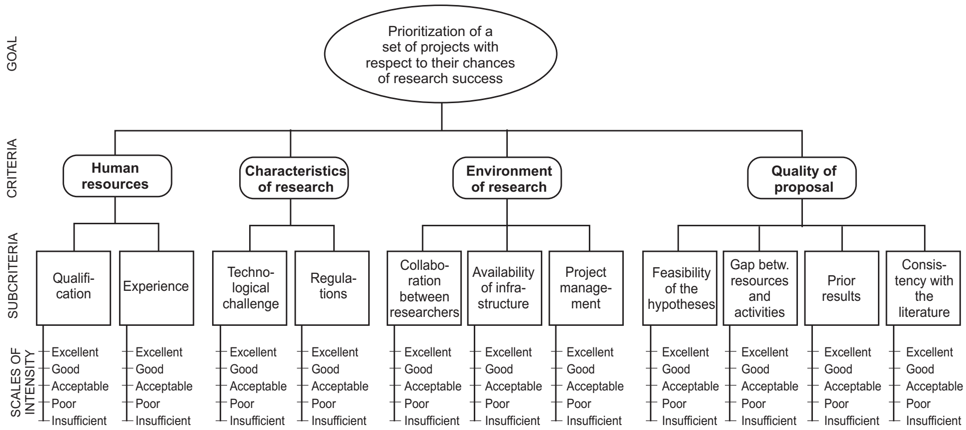



*Figure 11. Modified "Success of research" hierarchy*

**9. Sensitivity analysis and interpretation of the priorities**
The first task was to compute the end results, i.e., to combine the outcomes of the individual hierarchies in order to get the final project priorities. To test the stability of the rank order, several scenarios were formulated using different criteria weights. The results of the sensitivity analysis were then submitted to the participants of the second workshop for comments.

**10. Presentation and discussion of the procedure and the final results**
The final step took place during the final meeting, to which all participants and other interested persons were invited. The presentation of the procedure and the results was followed by a discussion of the shortcomings of the approach and the potential remedies. An important part of the discussion centered around possible follow-up activities and future applications of the procedure in the PNB.

# Results and Analysis

This section begins with a discussion of the criteria and subcriteria weights for each hierarchy that were elicited from the strategic group and partly modified by the technical group. This is followed by an analysis of the project priorities that were generated by the exercise and ends with the results of the sensitivity analysis undertaken for H1. Annexes B and C provide an overview of all the results that were generated during the exercise.

## *Criteria Weights*

The final criteria weights for H1 are depicted in figure 12. The values presented are averages, computed from the individual weights that were assigned by the first strategic subgroup. The large pie chart shows the criteria weights and the four smaller charts show the subcriteria weights, i.e., their contribution to each criterion.

Note that the "Environmental" and "Economic" criteria have about the same weights. This may indicate concern over sustainability issues in Chile. The rela-

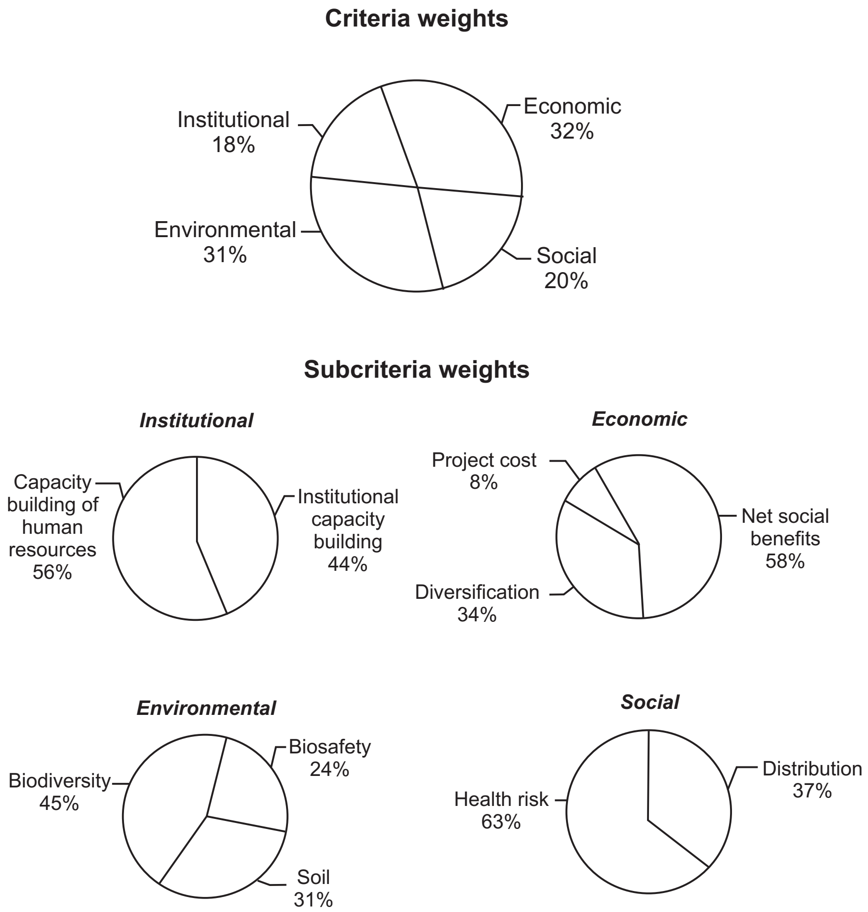
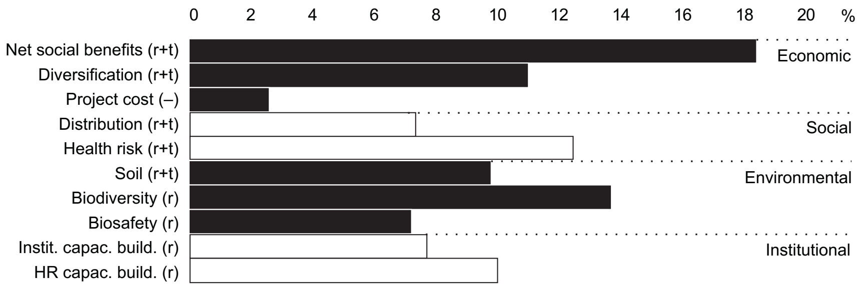



*Figure 12. Criteria and subcriteria weights for "Potential impacts" hierarchy*

tively low weight of the "Institutional" criterion is surprising, given the PNB's strong emphasis on capacity building. At the subcriteria level, capacity building for human resources is considered slightly more important than institutional capacity building. However, it was difficult for several group members to separate the two elements, because they considered adequate human resources to be critical for strengthening institutions. The diversification of production for promoting exports captured a third of the "Economic" criterion. The low weight given to "project cost" is based on the fact that the research costs are already included in the net social benefits, expressed through the net present value (or NPV, see "Cost-benefit Analysis" in chapter 3). This means that the subcriterion represents only the absolute amount of the project requests from the PNB, because the NPV does not show the scale of the investment (see also the section "Research Cost" in chapter 5).

"Biodiversity" was given the highest weight under the "Environmental" criterion. This judgment might have been influenced by the national mandate of INIA to conserve Chile's genetic resources. In contrast, "biosafety" received a considerably lower weight. The “Environmental” pie chart represents the final weights used for the project evaluations, i.e., after the subcriterion “water” was eliminated in the second workshop.[13] The original distribution was 36% for biodiversity, 27% for soil, 20% for biosafety, and 17% for water. The subcriteria weights of the “Social” criterion indicate a much greater concern over health risks (e.g., exposure of agricultural workers to chemicals) than over the distribution of benefits. One explanation for this may be that the generation of net social benefits under the “Economic” criterion is seen as already having a significant social effect.

In order to compare the importance of subcriteria from different criteria, their absolute weights are determined by multiplying the relative weights by the weight of their respective supercriteria. Figure 13 depicts the absolute weights (which add up to 100%) for the subcriteria under H1. The most important element appears to be the net social benefits (i.e., the financial benefits to society), which captures more than 18%, followed by “biodiversity,” “health risk,” “diversification,” and “human resources capacity building.” The remaining subcriteria each capture less than 10% of the total weight. In the final evaluation, the projects are selected according to the impact adjusted for their chances of successful research and adoption. The notations (in brackets) made in figure 13 indicate how each project score was treated with respect to uncertainty.




Note: (r+t) subject to the chances of successful research and adoption
(r) subject to the chances of successful research
(–) subject to neither the chances of successful research nor adoption

*Figure 13. Absolute subcriteria weights for “Potential impacts” hierarchy*

As mentioned earlier, the structure of H2 (Success of research) was modified, and the weights of the criteria were reassessed.[14] The large pie chart (figure 14) shows that the “Quality of proposal” criterion received the largest proportion of total weights, while “Human resources” received around a fourth. “Characteristics of research” captured only 10%, while “Environment of research” received a marginal weight of 5% from the technical group. One possible reason for the latter criteria’s low weights is that most of their elements are perceived as already

13. If a (sub)criterion is taken out after the weighting process, its weight is distributed equally among the remaining (sub)criteria.
14. The original criteria weights for H2 are listed in annex B.

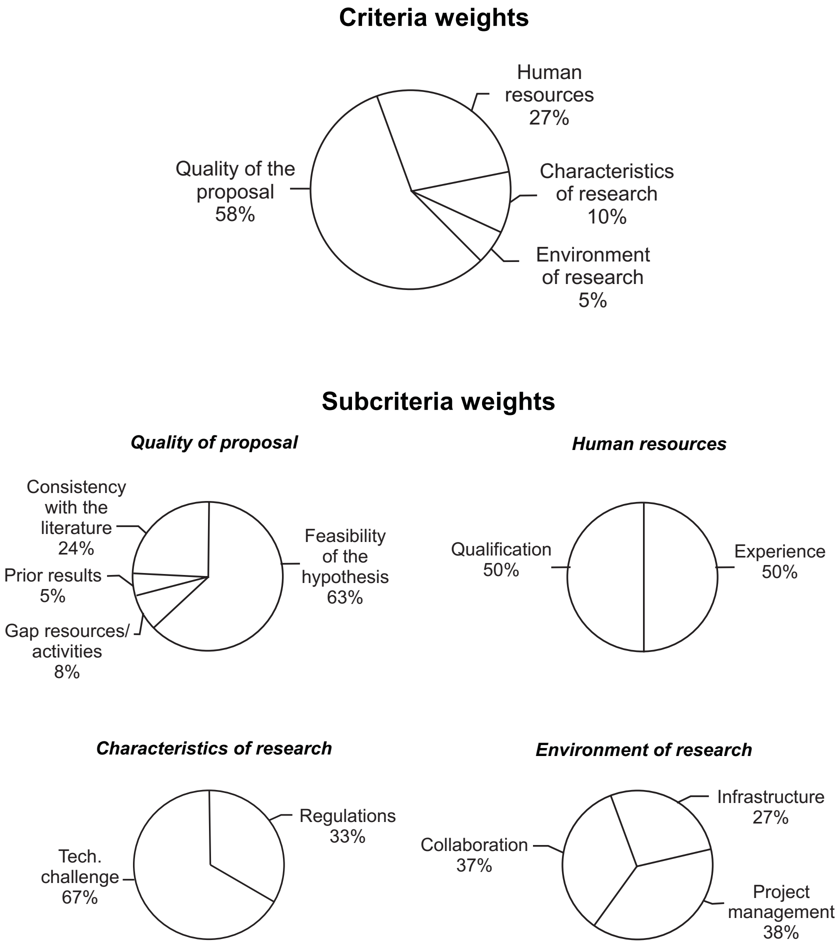



*Figure 14. Criteria and subcriteria weights for "Success of research" hierarchy*

being subsumed by the "Quality of proposal" criterion. Another reason may be that the members of the technical group, being mostly researchers, underestimate the importance of the characteristics and environment of the research to the successful execution of projects.

With regard to the subcriteria, most of the weight under "Quality of proposal" was given to "feasibility of the hypothesis," followed distantly by "consistency with the literature." As a consequence, about 50% of "Success of research" is actually determined by these two elements. In terms of "Human resources," the qualifications and experience of collaborating researchers were judged to be of equal importance. Note that "regulations," with an absolute weight of only around 3%, do not seem to be a major concern under "Characteristics of research." Under "Environment of research," the weights of all three elements are balanced, but together they are responsible for only a bit more than 5% of research success.

Figure 15 shows the criteria weights for H3 (Success of adoption). As mentioned earlier, the projects were evaluated directly against the criteria, with the subcriteria serving as performance indicators. Nevertheless, the weights of the subcriteria were taken into account when the group discussed the influence of individual indicators. “Interest of the end users” received the highest criterion weight because the participants felt that research must have a clear, demand-oriented focus if it expects to be adopted by its clients. Therefore, the anticipated benefits for the farmers and the existence of a clear, concrete demand are the governing subcriteria of this hierarchy, whereas direct participation by the end users in the research process was not given high priority.

The “Process of development and transfer” criterion received 30% of the weights. Its first component refers to the development process and includes the number of phases (i.e., additional R&D projects) and the amount of time from the completion of the actual project to the availability of a marketable technology. It

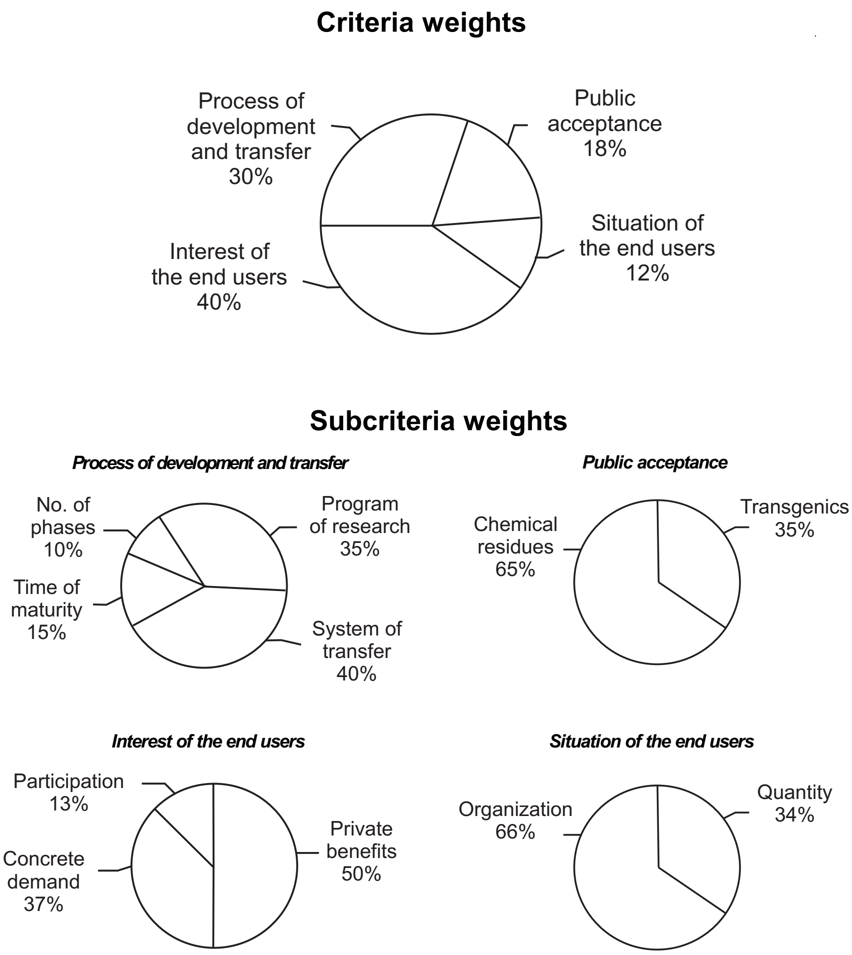



*Figure 15. Criteria and subcriteria weights for “Success of adoption” hierarchy*

also includes the much more relevant issue of an existing research program within the institution. The logic behind including the development component is that the more phases or time required to achieve the end result, the smaller the chances that the research activity will result in transferable technology. Similarly, the weaker the institutional support, indicated by the lack of an established research program, the smaller the chances of completing the research process. Incomplete research may be the result of cutbacks in research budgets, the obsolescence of the technology being developed, or changing economic circumstances. The criterion's second component, "system of transfer," refers to the real transfer process and is evaluated in terms of the proposed technology transfer system.

Curiously, "Public acceptance" was not regarded as having a major influence on adoption success. Equally curious is the fact that products with chemical residues are considered to be more problematic in terms of public acceptance than products resulting from genetic engineering. This judgment may have been influenced by a recent incident in which the USA temporarily halted grape imports from Chile, due to some chemical residues found in a random sample. At the same time, genetic engineering is not much of a public issue in Chile at present.[15] The "Situation of the end users" was considered the least important of the four criteria, receiving only 12% of the weights. Its weight was distributed between the number of potential end users and their degree of organization in a ratio of 1:2.

## *Project Priorities*

In this section, the final ranking of the projects is presented and analyzed, along with the rankings for all three hierarchies . In order to analyze the final project ranking in greater detail, the final priorities for the individual criteria of H1 are also presented and analyzed.

The final priorities of the seven projects, which are depicted in figure 16, are the result of selectively multiplying the outcome of H1 with that of H2 and H3. The

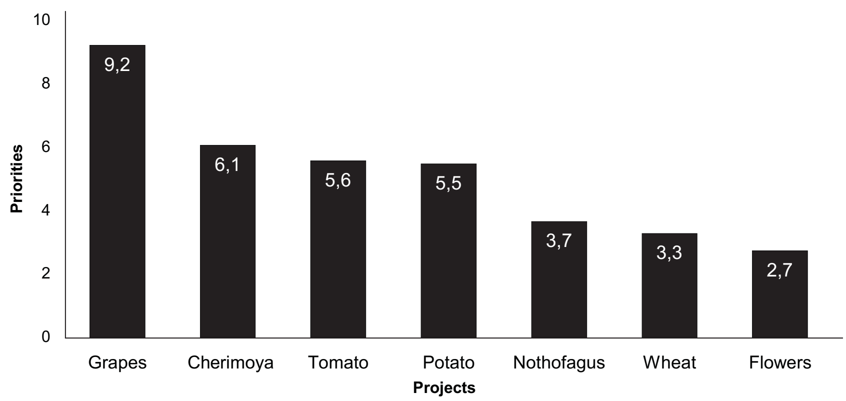
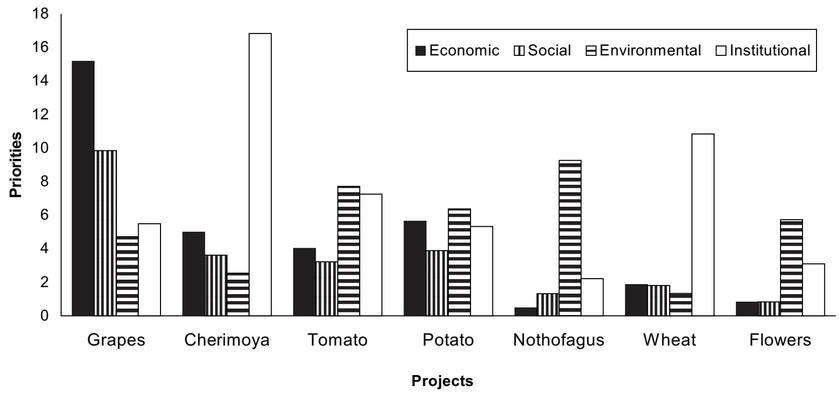



*Figure 16. Final project priorities*

15. However, the pertinent subgroup was explicitly instructed to bear in mind the somewhat more negative public perception of transgenic products in the importing countries.

ranking forms roughly two groups. The top research projects are Grapes, Cherimoya, Tomato, and Potato, with Grapes clearly the most preferred. Nothofagus, Wheat, and Flowers comprise the lowest-ranked group of projects. A look at project performance vis-à-vis the individual criteria allows a more detailed analysis of the final ranking (figure 17).




*Note:* The chances of success are already included in the values, but all the criteia have to be taken into account in order to assess the implications for the final priorities.

*Figure 17. Project performance against H1 criteria*

The leading position of Grapes is based on its large contribution to the "Economic" and "Social" criteria. For both sets of criteria, it has by far the strongest performance of all the projects. The economic contribution of Grapes is its expected loss reduction, which, in combination with the huge area planted, results in large net benefits (i.e., higher marketable share and lower production cost). The loss reduction is due to genetically introduced fungus tolerance. This means that there is a substantially reduced need for fungicide applications, resulting in a lower health risk, which, in turn, is important to the "Social" criterion.

Cherimoya makes a strong contribution to the "Institutional" criterion. It performs best in terms of strengthening the institution (i.e., generating relevant knowledge, linkages with other institutions, and spillover effects), and is only second in building human resource capacity (i.e., involved researchers, linkages with universities, and usefulness of knowledge for teaching purposes). When all the above are considered together with its great chances of research success, Cherimoya becomes the undisputed leader in generating institutional benefits.

A comparison of Tomato and Potato is instructive because, in the final ranking, their performance is virtually equal. Because they have similar performance patterns that are distributed over the different criteria in a relatively even manner, it is very difficult for research managers to select one over the other, even if criteria weights are altered. However, the two projects have significantly different chances of success, which provides a basis for selection. This is discussed further below.

Nothofagus, Wheat, and Flowers all make weak contributions to three out of four criteria and are clearly given lower priority. Nothofagus is strong only against the "Environmental" criterion, thanks to its extensive activities in collection, description, and conservation of wild species. Wheat performs well against the "Institutional" criterion, particularly in terms of human resources capacity building. Meanwhile, Flowers has just average performance against the "Environmental" criterion (i.e., biodiversity), with no substantial contributions to either the "Economic" or "Social" criteria.

For the remainder of this section, the projects' chances of research success (H2) and chances of adoption success (H3) are analyzed. Figure 18 represents the assessments that were made under these hierarchies. Cherimoya and Tomato show the greatest chances of research success, followed by Grapes and Potato. Here, there is a grouping similar to that found in the final priorities, with the four previously mentioned projects at the top, and Nothofagus, Wheat, and Flowers lagging behind. This grouping makes sense because a major criterion for assessing the chances of research success is the quality of the project proposal, which is also of paramount importance in every evaluation. The slightly better performance of Cherimoya over Grapes is, in this case, based solely on the broader experience of the former project's research group.

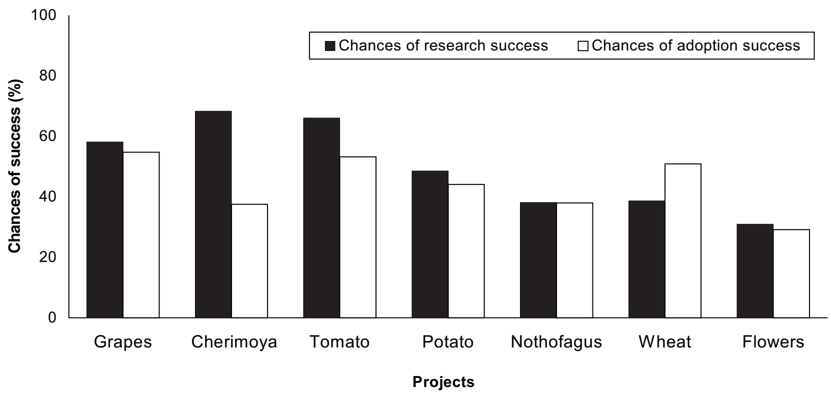



*Figure 18. Chances of research and adoption success*

In terms of adoption success, the evaluation shows a very different picture. Grapes, Tomato, and Wheat are the strongest performers, while Cherimoya is rather weak. The reason lies in the crop's long development process (cherimoya is a perennial) and the lack of an existing research program. The relatively good chances of successful adoption for the first three projects come from their excellent contacts with the private industry (Grapes), and the fact that INIA researchers are also the end users of the research results (Tomato and Wheat). Figure 18 is useful for analyzing the two measures of success separately. However, decision makers may be more interested in the overall chances of each project's success, i.e., the extent to which the potential impacts expect to be realized. The figure provides no conclusive information, since not all of the potential impacts of a project are affected by both research and adoption success (see figure 13). As long as decision makers are assumed to be risk-neutral, the final ranking shown in figure 16 forms a good basis for choosing the most promising projects. If the risk behavior of decision makers deviates from neutrality—that is, they are either risk-averse or are prepared to take risks[16]—the relationship between potential and risk-adjusted impacts provides valuable information for decision support.

Figure 19 shows the priorities based on the potential and adjusted impacts (left-hand axis), and the ratio of these priorities (right-hand axis). This ratio is a measure of the overall chances of realizing the expected impacts of the projects. The higher the ratio, the better the chances of turning the potential impacts into reality.

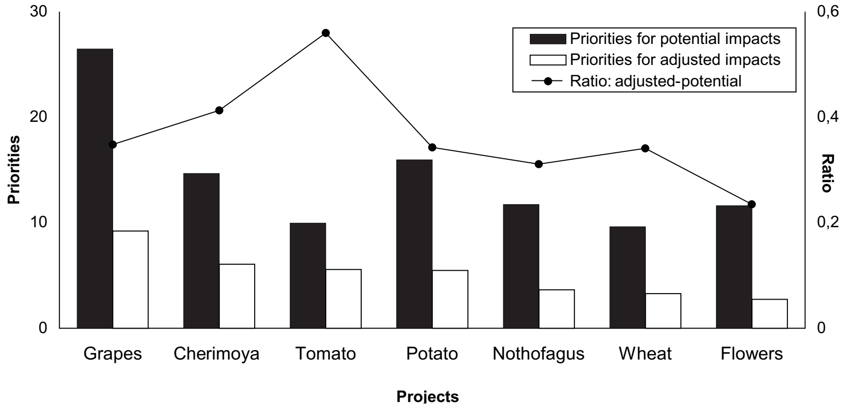



*Figure 19. Priorities and ratios of potential and adjusted impacts*

The new, very different ranking of Tomato and Potato illustrates the usefulness of this ratio in decision making. These two projects have similar final priorities, and choosing between the two, based on their final ranking, would be very difficult. In this situation, the ratio serves as an additional criterion for discrimination. Decision makers who are risk-averse would prefer Tomato, because its higher ratio means that it has better chances of capturing the adjusted impacts. On the other hand, decision makers who are prepared to take risks would choose Potato, because, if successful, its impact would be considerably greater than that of Tomato.

## *Sensitivity Analysis*

The criteria weights presented so far have been averages (arithmetic means) that were calculated from the individual weights provided by the strategic subgroups. However, the experts had widely diverging perceptions of the importance of the decision criteria (see annex B). For a closer analysis of the final criteria weights, the "Potential impacts" hierarchy (H1) is subjected to a sensitivity analysis.

16. Chile's PNB, for instance, was advised to also fund high-risk projects and to allocate a portion of the budget to this research category (Villalobos et al. 1995).

Figure 20 represents the weight variations for each criterion, with the experts being represented by numbers. The relative weights vary from 10.9 to 51.6 for the “Economic” criterion, from 4.5 to 54.4 for the “Social” criterion, from 15.6 to 57.4 for the “Environmental” criterion, and from 5.6 to 58.3 for the “Institutional” criterion.

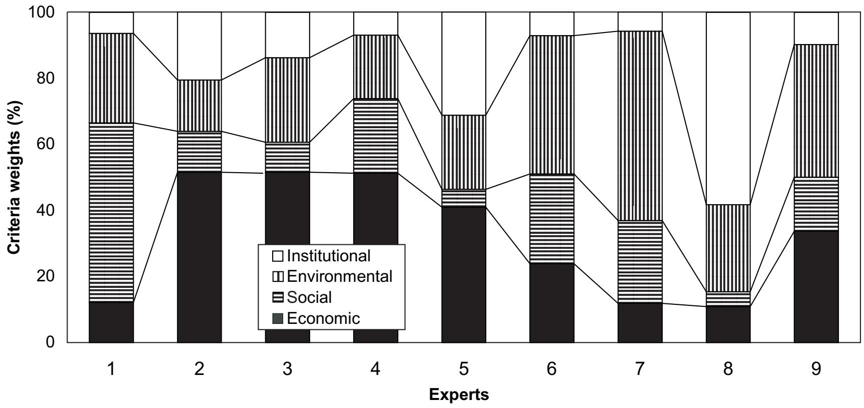



*Figure 20. Variation in individual criteria weights of H1*

Since the criteria weights are fundamental to the evaluation of research projects, the stability of the rank order under different weighting schemes was tested in a sensitivity analysis. This was done by formulating several scenarios based on the individual weightings made by the experts. Table 9 describes the six scenarios selected for the sensitivity analysis. One set of scenarios (S-1 to S-3) uses the average weights but excludes the highest outliers, while a second set (S-3 to S-6) uses only the weights provided by these outliers. The bottom half of figure 21 depicts the criteria weights resulting from each scenario, while the top half lists the resulting project ranking. The numbers to the right of each project name indicate the values of the priorities as calculated from the modified weights.

The first three scenarios (S-1 to S-3) show an ever-increasing weight for the “Economic” criterion. The rank order, however, remains essentially stable, and is similar to the baseline scenario (S-0). The same basic grouping remains—with Grapes, Cherimoya, Tomato, and Potato at the top, and Nothofagus, Wheat, and Flowers at the bottom of each rank order. The only variation is that Potato moves up in rank with each new scenario. However, the values of the priorities indicate that this change is not significant.

The second set of scenarios (S-4 to S-6) gives quite a different picture. Each scenario makes a distinct value judgment, emphasizing the importance of either institutional, social, or environmental aspects. In S-4, 58% of the total weight is assigned to the “Institutional” criterion. This weighting favors Cherimoya and Wheat, the projects with the highest institutional performance (see figure 17). On the other hand, Grapes falls back since its high economic and social benefits are not valued in this scenario. The higher values of the priorities in absolute terms are explained by institutional performance that is not subject to the chances of

*Table 9. Scenarios for Sensitivity Analysis*

| Scenario | Expert weighting used | Description |
|---|---|---|
| Scenario 0 (S-0) | all (baseline) | arithmetic means of all experts |
| Scenario 1 (S-1) | all, without 8 | arithmetic means of all experts except the one with the highest sum of deviations from the average of each criterion |
| Scenario 2 (S-2) | all, without 8 and 1 | arithmetic means of all experts except the two with the highest sum of deviations from the average of each criterion |
| Scenario 3 (S-3) | all, without 8,1, and 7 | arithmetic means of all experts except the three with the highest sum of deviations from the average of each criterion |
| Scenario 4 (S-4) | only 8 | weights of the expert with the highest sum of deviations from the average of each criterion |
| Scenario 5 (S-5) | only 1 | weights of the expert with the second highest sum of deviations from the average of each criterion |
| Scenario 6 (S-6) | only 7 | weights of the expert with the third highest sum of deviations from the average of each criterion |

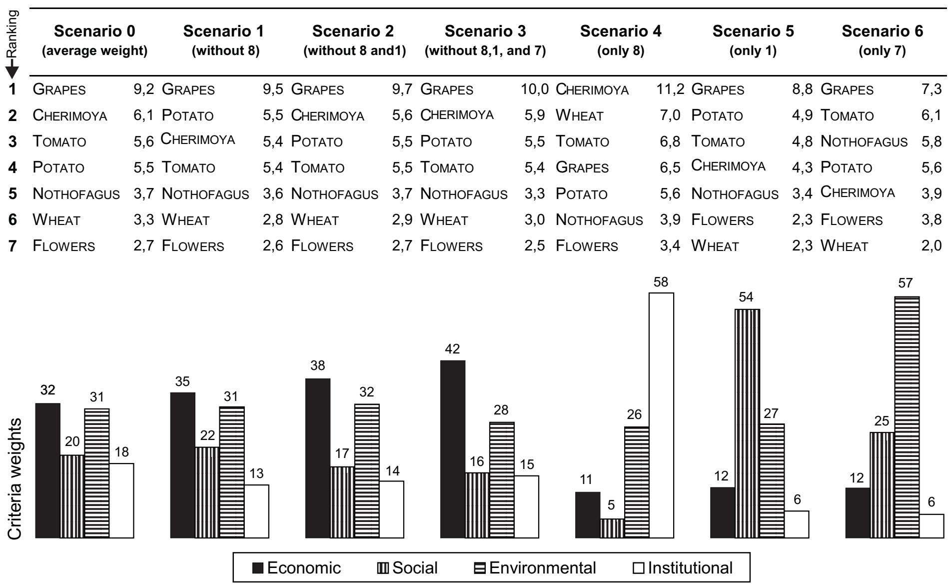



*Figure 21. Rank order of projects under different scenarios*

adoption. In S-5, the “Social” criterion is given the greatest importance (with a weight of 54%), leaving only low weights for the “Economic” and “Institutional” criteria. As a result, Wheat, with its strong institutional value but weak social performance, drops to the bottom of the ranking. Cherimoya also loses, becoming the least preferred of the highest-ranked projects. However, this is not due to its social value (i.e., Tomato and Potato fare no better) but to its marginal contribution to the “Environmental” criterion, which still received 27% of the total weight. The final scenario (S-6) shows this situation in reverse—the “Environmental” criterion is given the highest weight (57%), while identical weights are given to the remaining criteria. The considerable enhancement of Nothofagus’ rank—due to its contribution to biodiversity, by far the highest of all the evaluated projects—is notable. The focus on environmental aspects also favors Tomato, while Wheat—with the weakest environmental performance of all—goes to the bottom of the list. Cherimoya also ranks low due to its poor contribution to both the “Environmental” and “Social” criteria.

The scenarios clearly show that the rank order is stable when moderate changes are made in the criteria weights. Even if the weight of the “Economic” criterion were to increase strongly relative to the other criteria (not shown), the ranking of the projects would remain essentially the same. Although the positions of Potato and Wheat improve slightly with a very high “Economic” weight, the grouping of the highest and lowest ranked projects remains unchanged. However, for accentuated weightings that emphasize either the institutional, social, or environmental impacts of the projects, the priorities change substantially. This leads to a very different rank order, with significant consequences for allocating research resources. This illustrates the critical importance of establishing unambiguous criteria weights.

## Assessing the Case-Study Procedure

With regard to the basic functioning of AHP, this case study has, for the most part, allowed a favorable judgment of its ability to support decision making in public research. The case study produced sensible project priorities that, together with other results from the exercise, form a good foundation for determining resource allocation. In this section, the procedure used in the case study is assessed. After some general observations, there are brief discussions of some of the issues that revolve around the country choice, the availability of information, problems with participation, the validity of the results, and the costs involved. An overall assessment of the approach, including a comprehensive discussion of its ability to cope with the working hypotheses and key requirements that were outlined in chapter 2, is provided in the next chapter.

### *General Observations*

The objective of the Chilean case study—the evaluation of AHP as a tool to support group-decision making for biotechnology research in developing countries—has been achieved. The principal aim of the pilot application was to analyze the performance of a previously designed priority setting approach in a real-world setting, in order to test its viability and identify its shortcomings. For the PNB in Chile, the incentive for cooperation was to acquire expertise in using a formal procedure for project selection and to establish a specific set of decision criteria that can be used to evaluate biotechnology research projects. Thanks to close collaboration with INIA's planning division and the biotechnology program coordinator, the PNB now has all the information and knowledge necessary to apply the procedure, as well as an adequate set of criteria ready for use. Moreover, the contacts that were established and the various documents that were produced in the course of the exercise, including the final report of the case study, will now allow Chile to apply the approach without any major difficulties.[17]

For Chile, the priority setting exercise initiated a learning process that helped the participants determine what makes a project valuable. The representation of various stakeholder groups strengthened the "ownership" of the decision outcome. Participating researchers, in particular, gained insights that increased their understanding of the difficulties of the decision-making process. The transparency of the procedure facilitated the communication of the results during the final meeting, and increased the acceptance of these results.

In the preselection process, a simple checklist based on three criteria was used to create a shortlist of project ideas. For future applications, a more formal approach is recommended in order to proceed from a more solid basis. A rigorous preselection process, particularly in the case of numerous potential projects, may also be useful for eliminating deficient proposals effectively. This would substantially reduce the work load for the subsequent, more detailed evaluation to follow. AHP could be applied using only a few fundamental criteria and the rating mode of evaluation (absolute measurement) to obtain a shortlist that includes only the most promising research proposals. This point is discussed further in the next chapter.

### *Country Choice*

Chile was an excellent country choice for the case study. Local experience with biotechnology research and a well-prepared biotechnology program were conducive to the exercise, and provided a realistic environment as well. The timing of the case study coincided with the need of the PNB to establish a sound priority-setting procedure. The decision to accept project proposals from only one institution was beneficial from an organizational viewpoint, and did not affect the relevance of the pilot application.

In retrospect, three additional factors support the choice of Chile for this exercise. First, the direct and close interaction with the coordinator of the PNB proved highly beneficial. His personal interest and decision-making powers were critical to the successful execution of the exercise. Second, the firm institutional commitment of INIA provided a favorable working environment and also helped manage the process efficiently. In fact, the support shown by INIA is exemplary. Finally, the motivation of the participants contributed greatly to the good quality of the exercise. The project leaders, whose workload increased considerably in the course of the exercise, deserve particular recognition. All

17. The documents developed in the course of the case study constitute an additional benefit for Chile. They include instructions for the methodological approach, the generation of decision criteria, and the case-study procedure; specifically designed forms for project proposals and project evaluations; questionnaires to elicit criteria weights; and various workshop materials. These materials are all in Spanish and are available from the author.

these points confirm the validity of the country-selection process and the validity of the six criteria that were used.

### *Information*

The availability of information is the critical factor for any research evaluation. In the case of biotechnology research, there is always a poor information base, owing to the lack of documented and representative experience with this emerging technology. Naturally, this makes ex ante evaluation very difficult. To overcome this unavoidable constraint, subjective judgments were elicited for the procedure. These judgments were based on the expertise, intuition, and experience of knowledgeable people. Furthermore, group sessions were held to reduce or possibly eliminate any potential biases carried by the experts. Subjective judgments are improved or, at the least, can be supplemented by any information gathered from different sources, such as reports, statistics, databases, interviews, and surveys. Unfortunately, this information does not simply fall out of the sky. It must first be collected, compiled, and processed before it can be useful to the evaluation process. Therefore, the considerable costs of generating additional information needs to be weighed against the improvements that might be made in the quality of the final outcome.

Overall, the information was managed satisfactorily in this exercise. The available policy documents, the project proposals, and the discussions that were held with many of the stakeholders all led to the compilation of an adequate list of decision criteria. The proposal forms were tailored to meet the specific information needs of this exercise. Given the importance of the proposals to the evaluation of research success, a peer review was well justified. The peer review checked the credibility of the statements made in the proposals. Collaboration with a local consultant, one who specializes in gathering and analyzing agricultural information, permitted a wealth of information resources to be tapped effectively. The resulting document was key to the evaluation of the projects in the second workshop. In a written evaluation, a large majority of the participants assessed the quality and quantity of information included in the document as “adequate” or “very adequate.”

The sequence of steps is critical to minimizing the effort required for collecting information, but this is also somewhat tricky. On the one hand, considerable detail is needed about the projects in order to define the relevant criteria and indicators. On the other hand, the degree of detail that is necessary depends largely on the relevance of particular criteria. In other words, it is senseless to invest heavily in collecting information for a criterion of minor importance. There is no simple solution to this “catch-22” situation, but it illustrates the importance of fine-tuning the sequence of steps. It also makes clear that individuals who have good knowledge about the availability of information should be involved early in the process. Another information problem is the definition of the social and environmental criteria—in particular, the identification of adequate indicators and the evaluation of the respective project impacts. Participants in the second workshop perceived a lack of precise information for the evaluation of project impacts. This was one shortcoming of the case-study procedure, and it would have been useful (and necessary) to collaborate closely with subject specialists in order to address this issue more adequately.

Finally, there are two points to be made about the substantial effort that was invested in gathering information. First, the pilot application of the priority-setting approach required the collection and analysis of some very basic data and information. However, these are activities that do not need to be replicated in future applications. Second, the effort is worthwhile in light of the additional benefits that were accrued. Detailed information about the deficiencies of the projects provides researchers with the opportunity to either improve their proposals (in case of rejection), or take preventive action against unwanted effects and increase the chances of success (in case of approval). It also facilitates the design of future projects. Meanwhile, such information can be used by INIA for other planning purposes, and the decision criteria, their weights, and the indicators may all be of use to other institutions that are concerned with resource allocation for biotechnology research.

### *Participation*

The decision-making process was carried out in a participatory manner and included project leaders, research managers, individuals responsible for biotechnology, and experts from different institutions. However, there were no representatives from either the private sector or farmers' organizations. This deficiency in terms of broader participation is an obvious shortcoming of the exercise. It is significant because the end users were not involved in the process. End users include farmers, the private sector (input providers, processors, exporters), and researchers who apply the resulting technologies, such as plant breeders. Because the participating project leaders had sound knowledge of this kind of downstream research, there was no pressing need to involve such researchers directly in the process. The lack of interest demonstrated by the private sector during the preparations of the PNB led to a similar conclusion regarding direct participation. However, the private sector has recently shown interest in co-financing the Grape project (personal communication from the project leader), which promises greater involvement by this sector in future priority setting exercises. Since farmers are the ultimate end users of public agricultural research, representatives from this group should participate directly in the process. This was overlooked in the case study, partly because researchers claimed to know farmers' needs through their consultancy work for farmers' organizations and individual producers.[18] But farmers may also be a valuable source of information for potential research impacts and the chances of adoption. Therefore, closer collaboration is justified, and future applications cannot afford to ignore this.

Regarding the technical and strategic groups, the need to work with two different groups became obvious early in the process. The more technically-oriented people lacked competence in defining and weighting the main decision criteria, while the senior managers and research planners did not have the detailed knowledge (and neither the time nor interest) necessary to evaluate the research projects. A "technical" group and a "strategic" group were therefore created for the priority setting process. This grouping was very useful, and it allowed specific information to be generated through the elicitation of judgments appro-

18. INIA permits its staff to earn external income through consultancy and other contractual and part-time work (Venezian and Muchnik 1995). The existing contact with farmers was also repeatedly mentioned in the context of technology transfer.

priate to each group's special expertise. The technical group consisted mainly of the project leaders. Though they appeared to be the most suitable persons to assess the research projects, their double role carried a potential conflict of interest. As project leaders, they are interested primarily in getting their proposals approved,[19] whereas experts are expected to make an unbiased judgment. The suitability of project leaders might therefore be questioned, but there are three arguments that counter this objection. First, a threefold control mechanism was built into the exercise: (1) the peer review of the proposals, (2) the group members without their own projects, and (3) the other project leaders who, for obvious reasons, took great care that other projects did not receive undue credit. The experience with the case study confirms the effectiveness of this mechanism. Second, in most developing countries, biotechnology research is just emerging, and the pool of experts in this field is restricted. In small countries such as Chile, the research community consists of only a handful of individuals with the necessary expertise. Third, the additional benefits that accrue with the involvement of the project leaders further justify their participation in the exercise. However, a potentially more serious problem is the feasibility of involving one representative of each project when there are a large number of projects to be evaluated. One solution to this problem is a rigorous preselection process that eliminates all but a few projects for the main evaluation.

The strategic group included representatives from a broad range of institutions. The members of subgroup 1, who were responsible for the weighting of the main criteria, were mainly senior managers, while the other subgroups were comprised mainly of subject-matter experts. The diversity of views represented in the strategic group shows in the variation in the individual weighting of the criteria. With this wide range of perspectives, new information was provided, unique viewpoints were aired, and a "constructive conflict" was initiated that, in theory, would have resulted in a greater consensus. The drive towards a greater consensus is based on the assumption that variation is due in part to basic misunderstandings, differences in interpretation of the criteria, and insufficient information regarding the PNB. Therefore, theoretically, greater interaction between the members of the strategic group would reduce variation. Unfortunately, there were no opportunities to exchange arguments. This was the biggest problem in terms of grouping the participants in this manner. The lack of interaction was due to the use of questionnaires in lieu of more time-consuming group sessions. In future applications, communication between members of the strategic group must be emphasized, even if it means that the participants will have to invest more time in the process. Interaction between the two groups is another issue that needs attention. During the exercise, members of the technical group disagreed with some of the subcriteria weights. Moreover, they had some relevant expertise, and they were closely involved in the definition of the subcriteria as well. Therefore, collaboration between the members of the technical and strategic groups may be justified.

A further point concerns the policy on information. How much should one group know about the results produced by the other group? In order to prevent strategic

19. "A clear bias of the managers towards their own key projects" is reported by Islei and Lockett (1991, 74), who applied AHP for the selection of industrial research projects. It should be noted, however, that unlike the Chilean case study under consideration, that assessment was not done in groups but on an individual basis.

behavior, the technical group was informed about the criteria weights only after they had already evaluated the projects. However, it could have been beneficial for them to be informed in advance about the results in order to improve time management (i.e., to prevent too much time from being invested in the less important criteria). Meanwhile, the strategic group received only a brief profile of each project, and no additional information was requested. This kind of information may seem inadequate, but according to the principles of AHP, criteria weights should be based on the element at the next higher level of the hierarchy and not on the research alternatives.

### *Results*

The exercise produced reasonable and valid priorities that are intuitively appealing and that have been generally accepted. The ranking of the projects gives a clear indication of how the program's research resources should be allocated. Moreover, additional results—such as the different scenario outcomes, the project priorities vis-à-vis the individual criteria, the chances of success, and the external peer reviews—provide further support for decision makers.

There was never any intention to directly translate the resulting priorities of this exercise into funding decisions.[20] However, the more important result for Chile was the considerable variation in the criteria weights that were produced. Not surprisingly, this was the most heavily debated issue in the final meeting. The highly conflicting opinions of the strategic group (particularly from subgroup 1) brought attention to the fact that a clear institutional policy on science and technology in general, and on biotechnology in particular, was lacking. This divergence of opinions was consistent with the difficulties that were observed, in terms of establishing a set of decision criteria, during the preparation of the PNB. The exercise advanced the discussion one step further in the sense that the decision criteria have now been defined and broadly accepted. It is now up to those responsible for the PNB to elaborate on a common policy that allows the relative importance of the criteria to be specified. INIA is planning a workshop to address this need.

### *Time and Cost*

A discussion about the time and cost of the exercise must make a clear distinction between the resources that were required for the pilot application, and those that are required for regular applications. Here, the resources that were invested in the case study are first described. Estimates for future applications are then derived, while the particularities of the pilot application are taken into account.

The case study lasted nine months and involved considerable human resources. An analyst was hired for the entire duration of the case study, while two Chilean collaborators each worked one week on the project. The 10 members of the technical group also invested about one week of work each, while the 21 members of the strategic group took only about two hours to fill in the questionnaire and, in some cases, an additional three hours to agree on the criteria. A consultant was

20. At the time of writing, the PNB, in fact, was not yet implemented. Because the Minister of Agriculture was replaced, it is doubtful that the program will ever be put into effect. However, the results were still used by INIA to request funding for biotechnology research. The rank order was also helpful in determining which projects should be referred to other funding sources (personal communication from the coordinator of the PNB).

contracted for two-and-a-half months, and two international experts were brought in for a total of one week. The total cost of the exercise was around US$50,000, 70% of which went to salaries. The remaining expenses were for the meetings and workshops, materials and equipment, the peer reviews, and travel. The costs were shared by INIA, the PNB, and the originators of the project—ISNAR and ETH.

For future priority setting exercises, it is estimated that INIA can apply the approach in considerably less time, i.e., in four-and-a-half months instead of nine months. A considerable savings in time is anticipated for the following reasons: (1) the formulation of project proposals—a time-consuming but necessary activity in the pilot application—is not actually a part of the priority setting process, (2) the theoretical groundwork has already been laid and does not need to be repeated in subsequent exercises, (3) new proposal and evaluation forms do not need to be designed, and new workshop materials do not need to be prepared, (4) inefficiencies due to "trial and error" will be substantially reduced, (5) less time will be needed to identify suitable experts, reviewers, and consultants, and to familiarize all the participants with the approach, and finally, (6) defining the criteria and structuring the decision problem do not need to be repeated from scratch. With a shorter time frame, the greatest savings will be in the salary of the external analyst, which, in the pilot application, made up 45% of total costs. With the added potential of replacing the external analyst with a skilled local planner from INIA, about one-third of the cost could be reduced.

However, other potential reductions will be counterbalanced by the additional time and expenses required for modifications. For example, implementing the important suggestions that were made earlier—in terms of a more rigorous preselection process, stronger interaction between members of the strategic group, and broader stakeholder participation— will require new investments of time and money.

The total cost of future priority setting exercises in Chile is estimated at US$34,000. This figure is comparable to international standards for investments in priority setting. ISNAR (1998) recommends spending 5% of total resources on the planning exercise, while priority setting itself may take one-third of the planning resources (about 1.7%). The originally proposed PNB budget was US$4 million per year, of which some US$2 million was earmarked for collaborative research projects (Villalobos et al. 1995). The amount estimated for future priority setting exercises amounts to exactly 1.7% of the PNB's proposed budget.

# 5. Assessment of the Priority Setting Approach

In this chapter, the performance of the AHP-based approach is assessed in terms of its accordance with the working hypotheses,[1] research cost, and other methodological issues. The first three sections examine the value of incorporating the factors that are emphasized by the working hypotheses—the special features of biotechnology, uncertainty, and the strategic component of biotechnology research—into priority setting. The fourth section examines how research costs have been incorporated into the model, and the final section discusses some methodological issues that were raised by this particular application of the AHP-based priority setting procedure.

## Biotechnology Features

The special features of biotechnology are first reviewed in terms of the weights that they were accorded by the participants. Then, the effects of excluding certain features from the final ranking of projects are discussed. Table 10 lists the biotechnology features and summarizes the indicators that were used to operationalize them at the subcriteria level.

The biotechnology features included in the methodological framework are the "biodiversity" and "biosafety" subcriteria in the "Potential impacts" hierarchy (see figure 7), the "regulations" and "collaboration between researchers" subcriteria in the "Success of research" hierarchy (figure 8), and the "attitude to transgenic products" subcriterion in the "Success of adoption" hierarchy (figure 9). The "Institutional" criterion, which was included to capture the strategic component of the research projects, is discussed separately elsewhere in this chapter, under Strategic Component.

The importance of the individual biotechnology features are manifested in the weights that were assigned to their subcriteria. The information in table 11 gives the relative weights of each feature, i.e., its respective criterion weight, its absolute weight in each hierarchy, and the aggregated weights.

1. The three working hypotheses are reprinted from chapter 2:
   a. The specific features of biotechnology-based research influence the expected costs, benefits, and chances of success of research alternatives in different ways. Special criteria have to be defined and included in the priority setting approach, in order to discriminate between these features, and to properly capture their impact on the performance of the alternatives;
   b. Uncertainty regarding the success of agricultural research, and the successful adoption of the results by end users, is inherent in all research processes. In biotechnology research, uncertainty is more prevalent due to the limited historical evidence and the accompanying lack of data. Priority setting in biotechnology research should attempt to identify the sources of uncertainty, assess their influence on research success and adoption, and carefully evaluate the chances of success of each research alternative vis-à-vis the individual sources of uncertainty;
   c. The strategic component, in terms of strengthening research capacity, can constitute an important part of the expected benefits of biotechnology research. Therefore, priority setting should explicitly consider the potential contribution of research alternatives to building scientific capacity.

*Table 10. Subcriteria Related to Biotechnology Features and Their Indicators*

| Hierarchy | Subcriteria | Indicators |
|---|---|---|
| Potential impacts | Biodiversity | • time of collection<br>• time of description<br>• time of conservation of genetic material<br>• number of accessions<br>• cultivated or wild form |
| | Biosafety | • transgenic plant/microorganisms (or not) |
| Success of research | Regulations | • requirements for IPR, biosafety, or import regulations |
| | Collaboration between researchers | • number of researchers involved<br>• number of institutions involved<br>• time and intensity of previous collaboration<br>• previous joint publications |
| Success of adoption | Attitude to transgenic products | • transgenic product (or not) as result of the project |

*Table 11. Weights of Biotechnology Features*

| Biotechnology feature | | Relative weight | | Absolute weight | |
|---|---|---|---|---|---|
| Biodiversity | | 45% | of criterion “Environmental” | 14% | of hierarchy “Potential impacts” |
| Biosafety | | 24% | | 7% | |
| | Σ | 69% | | 21% | |
| Regulations | | 33% | of “Characteristics of research” | 3% | of hierarchy “Success of research” |
| Collaboration between researchers | | 35% | of “Environment of research” | 2% | |
| | Σ | - | | 5% | |
| Attitude to transgenic products | | 35% | of “Public acceptance” | 7% | of hierarchy “Success of adoption” |

“Biodiversity” is by far the most important biotechnology feature that was included in the model. Together, “biosafety” and “biodiversity” account for more than two-thirds of the “Environmental” criterion, and more than one-fifth of the “Potential impacts” hierarchy. “Regulations” and “collaboration between researchers” each constitute about one-third of their respective criteria, but their relevance for the chances of research success are marginal. The reason for this is that the “Quality of the proposal” and “Human resources” criteria are already responsible for 85% of the research success, which leaves only 15% for the remaining two criteria, “Characteristics” and “Environment of research.” “Attitude to transgenic crops” contributes 7% to successful adoption. The reasons for its relatively small share (when compared to “attitude to chemical residues”) of “Public acceptance” were discussed in the previous chapter.

To assess the importance of the features individually, it may be considered that each hierarchy consists of roughly 10 subcriteria. This means that a single subcriterion has an average weight of 10%. According to the experts’ judgments, “biodiversity” makes a significant contribution, and “biosafety” and “attitude to transgenic products” are slightly below average but still relevant, while the contributions of “regulations” and “collaboration between researchers” are negligible. However, it should be noted that project performance in terms of either “biodiversity” and “biosafety” is not subject to the chances of successful adoption (see figure 13). As a consequence, contributions to these criteria will, in the final priorities, carry more weight than contributions to other subcriteria.

Several scenarios were created in order to assess the individual effects of the biotechnology features. In each scenario, a different feature was excluded from the calculation of project priorities. In order to evaluate the features' cumulative effect on the priority setting outcome, there is one scenario in which all the features are excluded. Table 12 displays the results of this sensitivity analysis. The baseline scenario shows the original priorities and project ranking. The next five scenarios each exclude one biotechnology feature, while the final scenario excludes all the features. In the table, the resulting changes in rank are highlighted in gray.

The results presented in table 12 indicate that the ranking is fairly stable across all the scenarios. Overall, the individual biotechnology features have a marginal effect on the priority setting exercise that was conducted in Chile. Only when either "biodiversity" or "biosafety" is excluded do any projects change rank. There is also a change in ranking in the scenario that excludes all the features, including "biodiversity" and "biosafety." This example shows the limited discrimination potential of these particular features for these particular projects. But the lack of further evidence does not allow for generalizations. It might well be that these special characteristics of biotechnology will play a more critical role in the outcome of a different set of research projects. At the very least, the weights of some of the features point to their significance in terms of evaluating biotechnology activities, in the opinion of the expert group. Therefore, the significance of these features is strongly context-dependent. For example, in an unclear regulatory situation, certain weights may be considerably higher. Similarly, in a situation where transgenic products generate controversy or ambivalence, "Public acceptance" will increase in importance for successful technology adoption.

*Table 12. Scenarios for Evaluating the Effects of Features on Ranking*

| | **Baseline** | | **Biodivers.** | | **Biosafety** | | **Regulat.** | | **Collabor.** | | **Accept.** | | **Cumulat.** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | R | P | R | P | R | P | R | P | R | P | R | P | R |
| Grapes | 9.2 | 1 | 9.8 | 1 | 9.5 | 1 | 9.2 | 1 | 9.4 | 1 | 9.8 | 1 | 11.9 | 1 |
| Cherimoya | 6.1 | 2 | 6.2 | 2 | 6.0 | 2 | 6.0 | 2 | 6.1 | 2 | 6.3 | 2 | 6.6 | 2 |
| Tomato | 5.6 | 3 | 5.8 | 3 | 4.9 | **4** | 5.5 | 3 | 5.6 | 3 | 5.6 | 3 | 4.4 | 3 |
| Potato | 5.5 | 4 | 5.4 | 4 | 5.0 | **3** | 5.4 | 4 | 5.5 | 4 | 5.5 | 4 | 4.2 | 4 |
| Nothofagus | 3.7 | 5 | 2.2 | **6** | 3.7 | 5 | 3.6 | 5 | 3.8 | 5 | 3.7 | 5 | 1.3 | **6** |
| Wheat | 3.3 | 6 | 3.4 | **5** | 3.3 | 6 | 3.3 | 6 | 3.3 | 6 | 3.3 | 6 | 3.6 | **5** |
| Flowers | 2.7 | 7 | 2.1 | 7 | 2.6 | 7 | 2.7 | 7 | 2.8 | 7 | 2.7 | 7 | 1.3 | 7 |

P = priority; R = ranking

## Uncertainty

A clear, conceptual separation between potential impacts and the chances of effectively realizing them on the one hand, and between the two major areas of uncertainty (research and adoption) on the other, is necessary to elicit meaningful judgments. Methodologically, the separation was achieved in this exercise by employing three distinct hierarchies. The innovation lies in the selective combination of each project's contribution to the different criteria of H1 with the outcomes of the other two hierarchies. This allows the project impacts that emerge over time to be captured in a more realistic manner. The separation also permitted a detailed analysis of the sources of uncertainty and facilitated an assessment of their importance.

The isolated treatment of uncertainty in research and adoption and the representation of these processes as hierarchical structures were beneficial to the focused discussion on individual determinants. The results pertaining to each project's chances of success vis-à-vis the determinants are also useful for overcoming obstacles to research and adoption. Moreover, the results from the two hierarchies that relate to uncertainty (H2 and H3) generate additional insight regarding project risks. As discussed previously, this insight may be used as an additional criterion, in case the behavior of decision makers deviates from risk neutrality. Scales of intensity (i.e., absolute measurement) were used to evaluate the chances of success for each research alternative. The use of the rating mode is imperative to approximating probabilities of success, but experience is needed in order to assess more precisely the congruence between the intensities and the percentages that express the chances of success.

A major problem that was encountered in the Chilean exercise came about while the chances of adoption success were being evaluated for the more strategic projects (i.e., Tomato, Nothofagus, Wheat, and Flowers). These projects are considered strategic because they do not result in a product that is directly transferable to the productive sector within the period of analysis. In other words, the end users of the resulting technology are other researchers, rather than farmers or private industry. Because some of the determinants that are included in the "Success of adoption" hierarchy are oriented towards technology transfer to the productive sector, the participants had considerable difficulty in evaluating the strategic projects correctly. In an attempt to preempt possible errors in this part of the evaluation, the chances of adoption success for the strategic projects were reestimated, assuming no restrictions for the "Situation of the end users" and "Interest of the end users" criteria. However, the resulting change in the final project ranking was limited to a switching of rank between Cherimoya and Tomato. In fact, this option may actually introduce a bias in favor of strategic projects. A better solution for future applications would be to develop criteria for adoption success that are not specific to the end users.

As mentioned in chapter 2, some additional sources of uncertainty are the natural, economic, and political environment of the NARS in question. However, in this Chilean case study, the environment was assumed to be stable over time. The trends towards globalization will accelerate changes in the economic and political environment of a NARS, and changing value systems may be another factor that influences the future environment. Therefore, uncertainty about these developments should be considered when future research activities are being decided upon. For example, changing patterns in competitive advantage will have major effects on the direction of technology development (Cooper 1997). The substance of IPR regulations and the timing of their implementation will also influence biotechnology decisions significantly (Van Wijk et al. 1993).

Future applications need to enhance the decision framework in order to accommodate the potential effects of a rapidly changing environment. Scenarios can be made based on economic forecasts, which would improve accuracy in evaluation. Once such scenarios are defined, they can be incorporated into AHP. There are two ways of assessing a scenario's likelihood of occurrence using AHP. Environmental scenarios can be weighted through the pairwise comparison process directly in the main hierarchy by adding a new level (Dyer and Forman 1992). For more detailed evaluations, an entirely separate hierarchy can be constructed (Ramanujam and Saaty 1981). The use of scenarios may lead to different outcomes, and, instead of providing the "best" choice, the evaluation will produce a set of options.

## Strategic Component[2]

The capacity-building component of research projects is captured by the "Institutional criterion" in the "Potential impacts" hierarchy. This allowed the evaluation of each project's contribution to developing institutional capacity and to strengthening human resource capacity, two elements that are included in the model as subcriteria. The information that was used to determine the subcriteria indicators (table 13) came from the proposals and the external project reviews.

*Table 13. Indicators for contributions to the "Institutional" criterion*

| Subcriteria/ Definition | Indicators |
|---|---|
| Institutional capacity building<br>*Definition: Strengthening institutional capacity in order to improve the efficiency and effectiveness of future research, and the reputation of the institution.* | • novelty of the generated knowledge<br>• scientific significance of the generated knowledge<br>• spill-over effects of the generated knowledge<br>• total amount of hours spent jointly with researchers of different institutions |
| Capacity building of human resources<br>*Definition: Contribution to the formation of professionals in different areas, from within, as well as from outside the institution.* | • number of researchers involved and time spent on the project<br>• number of intended publications<br>• weekly hours of teaching at universities<br>• potential of the generated knowledge for teaching purposes |

The "Institutional" criterion received a weight of 18%, which was divided between "capacity building of human resources" (56%) and "institutional capacity building" (44%). This confirms that the strategic component is relevant when research projects are being selected for funding. However, differences between the weights that were assigned by the individual experts are considerable, ranging from 6% to 58%. Because the highest weight for "Institutional" comes from the expert with the best knowledge about the purpose and objectives of Chile's national biotechnology development program (PNB), it is possible that

2. Additional details are reported in Braunschweig and Janssen (1999).

the weight of “Institutional” would have increased substantially if the other experts were equally knowledgeable about the PNB.

The effect of the strategic component on the project scores is even more significant than a criterion weight of 18% would suggest, since a contribution to “Institutional” does not depend on adoption success. The proportion of final project scores that stem from the strategic component ranges from about 10% to over 50%, with an average contribution of 25%.

Figure 22 depicts the development of project scores under different relative weights for the “Institutional” criterion. Because the strategic component has a very high weight in the priorities of Cherimoya and Wheat, the ranking changes immediately when that weight is modified. The decreasing priority for Grapes is explained by the declining relative importance of the remaining criteria. As a result, Cherimoya takes over as the most preferred project when the “Institutional” weight increases over 35%. On the other hand, Cherimoya and Wheat rapidly lose rank under lower “Institutional” weights. There is little doubt that the strategic component matters in priority setting, and that the AHP-based approach proved useful in capturing project contributions to scientific capacity building.

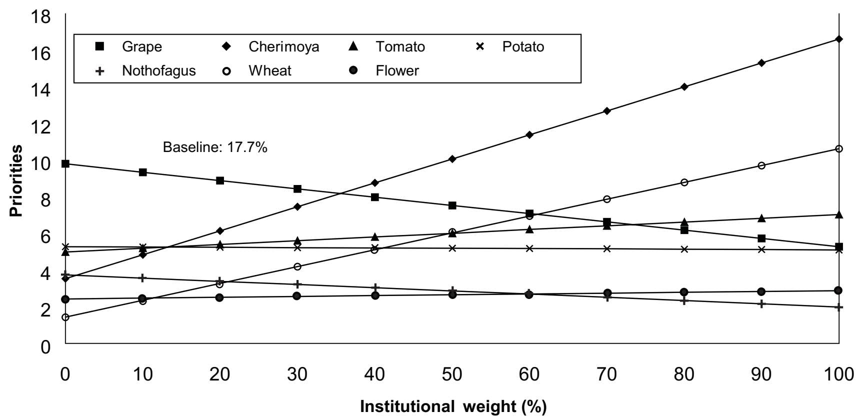



*Figure 22. Development of project scores under different “Institutional” weights.*

## Research Cost

The accurate treatment of research costs is an important concern in priority setting. If research funds are unlimited, cost is not an issue, and all research activities with a positive impact could be implemented. By the same token, when funds are limited, but all research activities have the same (or at least comparable) cost, setting priorities among alternatives does not require taking cost into account. When project costs differ, however, they must be properly considered in the priority setting exercise.

The projects that were considered in the Chilean case study entail different costs, and these costs were included in the evaluation through the "direct project cost" subcriterion, under the "Economic" criterion. However, these costs were not considered in the assessment of project benefits against the other criteria of the main hierarchy (H1). The focus of the priority setting exercise was the effectiveness of the research, as opposed to its efficiency. "Effectiveness" (i.e., doing the right things) involves selecting and achieving the most relevant objectives and is not necessarily concerned with the cost of achieving these objectives. In contrast, "efficiency" (i.e., doing things right) seeks to achieve some output with the least possible input but is basically unconcerned with the kind or level of output achieved (Gijsbers and Contant 1996). As a result, the project assessment was more concerned with achieving the objectives than with their cost. However, partial consideration of the project costs (under one but not all criteria) is a rather unsystematic way of dealing with the cost issue.

Three options are proposed to properly address this issue when research alternatives with different costs are being evaluated. First, cost could simply be taken out of the AHP model entirely, which means that the resulting priorities will reflect only the effectiveness of the research projects. A simple linear programming model can then be used to solve the resource allocation problem, i.e., how the available research budget should be distributed among the projects. Liberatore (1989) and Schmoldt et al. (1994) propose a zero-one integer approach[3] for dealing with resource allocation. Each project $x_i$ is either implemented (1), or not implemented (0), in order to maximize total project benefits $Z$ from a given budget $B$. The formula is shown below, where $p_i$ is the priority of project $i$ taken from the AHP outcome, and $c_i$ is the cost of project $i$.

$$\text{Maximize} \qquad Z = \sum_{i=1}^{n} p_i x_i$$

$$\text{subject to:} \qquad \sum_{i=1}^{n} c_i x_i \leq B$$

$$x_i = 0,1 \text{ for all } i$$

Second, costs could be evaluated in a separate hierarchy, giving the highest priority to the project with the lowest cost (Saaty 1995). This approach enables the incorporation of other, non-pecuniary costs, such as loss of biodiversity. Third, the project impacts could be expressed in terms of intensities, i.e., dividing each benefit component by the cost of the pertinent research activity. However, this option may be difficult to implement, because participants might have difficulty comparing intensities.

## Methodological Aspects

The experience of and feedback from the Chilean exercise suggest that AHP is an appropriate tool for managing the types of priority setting problems that were

3. See also Peterson et al. (1994), who recommend a standard linear programming formulation, instead of an "all or nothing" approach.

encountered in the Chilean biotechnology development program. AHP is a method that is easy to communicate, which ensures the participation of stakeholders. Its simplicity and intuitive logic also facilitate interaction between stakeholders and the broader public, even though the latter may not be directly involved. AHP provides highly detailed results, permitting a thorough analysis of the strengths and weaknesses of the research alternatives. The rigorous structure of the AHP model is conducive to collective thinking, reasoning, and efficient group discussions. AHP is also highly flexible, in terms of the degree of detail that is required to structure the decision problem, the accuracy of data used in the evaluation, and the intensity of stakeholder involvement. As a consequence, it can be adapted to fit almost any budget. Another advantage is the possibility of combining it with other approaches, such as cost-benefit analysis (for the evaluation of economic impact) or linear programming (for resource allocation under additional constraints). Finally, the analytical rigor and transparency of AHP increase trust in the priority setting process. This is significant because “the need for trust is a common element in public decision making, and trust, ironically, cannot be assured merely by making the right decisions” (Thompson 1998, 50). The capacity of AHP to accommodate the issues that were raised in the working hypotheses adds to the favorable assessment of the method. Also, the requirements for priority setting that were formulated in chapter 2—participation, transparency, a standardized measurement procedure to cope with different impacts—were fully met by this methodological tool.

Of course, AHP is not without its shortcomings. The biggest problem by far, in the case of numerous alternatives, is the heavy workload required for the pairwise comparisons. The required pairwise comparisons can seem an excessive and tiresome task, an issue that has been raised more than once in the literature (e.g., Davey and Olson 1998; Lockett et al. 1986; Olson et al. 1996). One way out of this problem is using the rating mode, i.e., absolute measurement, as opposed to relative measurement, which is normally used in pairwise comparisons. However, as discussed previously in chapter 3, AHP loses some of its appeal when absolute measurement is used. The evaluation that followed the second workshop in Chile confirmed that the participants felt less comfortable with the rating mode. Therefore, the rating mode should be used only when necessary. The optimal relation between the two modes can only be determined through further research and more applications. Empirical data are needed in order to weigh the costs and benefits of incorporating absolute measurement, especially in terms of time savings, participant motivation, and decision quality.

There are more options for reducing the number of pairwise comparisons: introducing a threshold level, below which the weight of a certain criterion is no longer considered significant; or using a two-stage procedure that, first, creates a short list of alternatives through a preselection process that uses only a few major criteria. Harker (1987a, 1987b) and Millet and Harker (1990) also developed an incomplete pairwise comparison technique that allows impressive time savings by stopping the process when the added value of questions decreases below a predetermined level.

Another problem faced in the AHP application in Chile was an attempt to reduce the time needed to complete the evaluation by eliminating the subcriteria level and assessing the projects directly against the criteria (see step 8 in chapter 4). Because this aggregation blurred the differences between the projects, the participants were not satisfied with the outcome, and the subcriteria had to be reintroduced. However, improving the efficiency of the decision process was one of the goals of the exercise. Therefore, the attempt at time savings was legitimate, and it raised significant questions: how far can the criteria be aggregated, and at what point should decomposing be stopped? Again, further research is needed in order to weigh the costs and benefits of this option.

# 6. Conclusion

The objective of this project was to develop a tool to support decision makers in public agricultural research institutions in developing countries. These decision support tools are important for making increasingly complex decisions, as already limited resources become even more scarce. Systematic priority setting approaches facilitate the selection of the most promising research activities, and aid the efficient allocation of and accounting for resources. This exercise has developed such an approach, geared specifically toward the evaluation of biotechnology projects.

A priority setting approach was developed based on the Analytic Hierarchy Process. The procedure was built from three assumptions about some issues that are unique to biotechnology research and that may affect project selection: the special features of biotechnology, uncertainty regarding the processes of research and adoption, and its strategic component in terms of strengthening institutional and human resources capacity. From these assumptions, three key requirements were derived for the design of the priority setting approach, i.e., the tool should encourage participation, it should be transparent, and it should be able to accommodate multiple criteria with multiple standards of measurement.

AHP was identified as an appropriate methodological tool on which to base the priority setting approach. It was tested in a pilot application with the national biotechnology program of Chile and positively assessed for usefulness. The remainder of this chapter summarizes the major findings of the study. It is structured according to the conceptual, methodological, and procedural issues that were encountered.

## Conceptual Issues

The incorporation of decision criteria that reflect the specific features of biotechnology—namely, regulations, public acceptance, and collaboration between scientists from different research fields—enabled the decision problems that were encountered to be managed in a more realistic manner. Because these features appear to be strongly context dependent, no final conclusions can be drawn regarding their universal relevance for priority setting. In the Chilean application, their significance differed widely, as shown in the range of criteria weights that were assigned. But the influence of even the most relevant criteria appeared to be marginal when it came to the final ranking of the research projects.

A clear, conceptual separation between the potential project impacts, the chances of research success, and the chances of successful adoption (manifested by the three distinct hierarchies that were employed) facilitated a detailed analysis of the sources of uncertainty that were inherent in the research. It also produced a range of highly specific results that provided additional information for the decision makers.

The incorporation of decision criteria to capture the contribution of strategic research projects to the strengthening of scientific capacity is an important innovation. The relevance of this element to biotechnology research has been demonstrated. Its incorporation into the procedure itself highlights the AHP's superiority to other priority setting procedures, which tend to have a bias against more basic or strategic projects.

A special effort was made to develop a conceptual framework that allows the process of identifying and selecting criteria for agricultural research decisions in public institutions to be structured systematically. The framework that was developed made a positive impact on the quality of the procedure, because it promoted the incorporation of many different views and helped to structure and clarify the major elements against which the projects were to be evaluated. The framework also introduced transparency to the process, facilitating communication with the outside world regarding the rationale behind the final choice. Future evaluations will benefit from the criteria list that was generated through this special conceptual framework.

Further research is needed to gather evidence regarding the interaction between context variables and biotechnology features. Similarly, more experience is required in order to obtain a more detailed clarification of how the outcome (in terms of chances of success) relates to the subjective rating of the projects (per criterion). This will give greater accuracy to the scales of intensity that are used for the hierarchies related to uncertainty. In future applications, more broadly defined criteria need to be developed, to facilitate the joint evaluation of research projects that address different types of end users. A significant field of inquiry for future research would be the incorporation of different scenarios into the decision framework to allow for alternative future developments. Finally, research cost has to be incorporated more carefully into the priority setting process. In the previous chapter, several options for dealing with differences in research cost were presented.

## Methodological Issues

AHP was a suitable approach on which to base the methodological framework used in the case study. Its potential to cope with multicriteria decision problems was confirmed, and its flexibility in modeling the decision problem allowed the working hypotheses to be accommodated. AHP also met the key requirements that were outlined for the tool. Because it is simple and intuitive, AHP does not require special analytical skills, which ensures participation. The way in which complex decision problems are structured and visualized in AHP is straightforward and appealing, making the process transparent. The use of pairwise comparisons to produce relative preferences among alternatives makes it possible to assess qualitative impacts and incorporate a wide range of criteria, even those with conflicting standards of measurement.

At the same time, AHP's ability to incorporate a wide range of criteria was the main shortcoming that was observed in the exercise. A considerable number of pairwise comparisons are required when there are many alternatives to be evaluated, which makes the process time-consuming and somewhat tedious. Various options for dealing with this issue are suggested in the references cited. Future research can assess these options for their potential to save time, their implications for the decision process, and the effect they may have on the quality of the outcome. More research is also needed to examine the optimal point at which to stop decomposing the decision problem, especially in terms of the trade-off between efficiency gains and discrimination potential.

## Procedural Issues

Overall, the procedure that was designed for the Chilean case study worked well. The strong personal and institutional commitment of the Chilean partners in the study contributed greatly to the success of the pilot application. The extensive use of subjective judgments from knowledgeable people helped to overcome the poor information base. The decision to work with two expert groups proved to be reasonable in light of the very diverse tasks that had to be conducted, i.e., weighting the highly political criteria, and assessing the technically demanding project proposals. Collaboration with local consultants was an efficient way to collect and process information, but it would have been useful to link up more closely with subject specialists for the environmental and social issues. Also, more emphasis could have been placed on interaction and communication between the two expert groups and between the members of the strategic group.

The results of the exercise were reasonable. The relative stability of the order of priorities under different scenarios suggests that the decision criteria had sufficient discrimination potential. However, the most relevant outcome for Chile concerns the surprising variation in the experts' weighting of the main criteria, which indicates a potential to generate additional, highly relevant results.

Following the correct sequence of steps in the priority setting process is critical to minimizing the effort required for collecting information. The mutual dependence between criteria relevance and the amount of project information that is necessary illustrates the importance of fine-tuning the sequence of steps. More analysis is needed to optimize the sequencing in order to reduce the volume of information that needs to be collected.

The most serious shortcoming of the procedure was the insufficient representation of the end users, particularly from the private sector and the farming community. Including the end users makes sense not only in terms of stakeholder participation, but also in terms of infusing the process with fresh and different information.

Future applications should explore the benefits of dividing the procedure into two distinct parts: a preselection process to generate a shortlist of research alternatives, followed by a more detailed evaluation of the shortlisted projects. A preselection process option would greatly reduce the number of pairwise comparisons required and allow considerable savings in time. It would also produce additional information about the issues on which the main evaluation will be focused. In any case, the possibility of reducing the required time investment should be explored seriously. Other efficiency gains can also be achieved through improvements in the techniques used to elicit subjective judgments, improvements in the moderation of group sessions, the acquisition of timely and properly processed data, and a sharper focus on the most pertinent parts of the evaluation.

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# Annex A: Summary of the Project Proposals and Reviewer's Comments

## CHERIMOYA

### *Summary*

The possibility of expanding cherimoya (*Annona cherimola*) markets is seriously limited by the short post-harvest life of this fruit. Chile is one of the main producers of cherimoya in the world, and it is urgently seeking practical solutions for commercialization in international markets. To achieve this, it is crucial to develop cultivars with a better post-harvest life that can also withstand long-distance transportation. Nowadays, genetic-engineering techniques permit the manipulation of key enzymes in the ripening process of the fruit. One aim of this project is to develop suitable methodologies for the genetic transformation of the cherimoya in order to design and express antisense genes that repress the activity of polygalacturonase enzymes and ACC-synthase, which control the disruption of the cellular wall and the ethylene synthesis, respectively.

### *Comments*

In the reviewer's opinion, the project is excellent because the topic is interesting, and its quality and impact will generate development. This is based on the following:

- The experimental proposal is well annotated and supported.
- The work plan is realistic.
- The research group is experienced in transgenic methods.
- The INIA-La Platina laboratory has the facilities and equipment needed to develop the project.
- Achieving positive results will have an important impact on the development and application of new biotechnologies in INIA and in the country.

## GRAPE

### *Summary*

The control of the fungal diseases affecting grape culture in Chile is costly and has a significant effect on the contamination of the environment and the health of agricultural workers. It has been difficult to develop cultivars resistant to powdery mildew and *Botrytis*, the two main fungal diseases affecting crops. There are no resistant cultivars at the commercial level. The genetic-engineering techniques currently available can facilitate the achievement of cultivars that are more resistant, using a series of genes which, when expressed in the host plant, provides a wide resistance to fungi. The primary intention of this project is to develop suitable methodologies for the genetic transformation of the grapevine in order to permit the production of proteins that are capable of anti-fungus activity. It is proposed that work should be done mainly with genes that codify for the production of enzymes that degrade the cellular wall of pathogen, whether alone or in combination, and whether or not in the presence of inactivating proteins of ribosomal activity.

### *Comments*

The reviewer believes this is a project with quality and potential impact and bases his opinions on the following:

- The researchers involved are capable and experienced, therefore good development of the project is forecast for all phases.
- All the necessary facilities and equipment are available to develop the project.
- The achievement of positive results will have an important impact on the development and application of new biotechnology techniques in this country.
- Because of decreased production costs and reduction of pesticide use, the development of the project could have an important economic and environmental impact.

To improve the quality of the proposed project the reviewer suggests:

- An in-depth study of ways to advance the transformation and regeneration of the grapevine; this phase is the most important for the success of the project.
- A more complete analysis of related work developed in other research centers, which would allow the initiation of a better-managed project with a specific combination of fungus-resistant genes.
- Human resource training.

## POTATO

### *Summary*

The golden nematode or potato cyst nematode is one of the most important pests affecting this crop, not only because of yield loss, but also because it is a quarantined pest. The most efficient way to control the cyst nematode is to use resistant cultivars. Resistance is bestowed by a single dominant gene, but selection for nematode resistance by traditional means is a long, costly, and difficult process that has delayed the release of resistant cultivars by INIA's potato breeding program. Molecular markers are powerful tools for selecting resistant genotypes. For potatoes, RFLP-markers have been determined for gene H1 (this gene gives resistance to the nematode). Nevertheless, the RFLP is difficult to use. The main objective of this project is to use existing markers, study their behavior in the Chilean genotypes, and transform them into PCR-based markers, or other cheaper and simpler molecular markers. This tool should then be used routinely in the improvement program for the selection of cultivars that are resistant to the cyst nematode.

### *Comments*

The reviewer believes that the project is good and indicates an advance in the use of markers with the aim of selecting materials containing desirable genes. In the near future, this technology could be applied in other areas for improving this and other crops. Following are some observations:

- The proposed project objectives can be achieved because of the composition and experience of the researchers in their respective areas of work.

- Although the methodology to set up the study is clear, more in-depth bibliographical discussion is necessary.

## TOMATO

### *Summary*

In Chile, *Lycopersicon* germplasm (*L. chilense* and *L. peruvianum*) have interesting characteristics (resistance to disease, drought, and salinity) that could be introduced into commercial tomato cultivars (*L. esculentum*) with a very narrow genetic base. The first step in achieving this objective is to determine the genetic diversity of the Chilean germplasm in order to optimize its conservation, characterization, and future use. In this project, determining the genetic diversity of the Chilean germplasm of the *Lycopersicon* is proposed. This would involve a direct analysis of the genome of these plants, using methods based on PCR markers (RAPD, AFLP), in order to demonstrate the presence of molecular polymorphisms. At the end of this project, information will be available on intra- and inter-specific variability. The material to be analyzed is native germplasm collected in Northern Chile, as well as material stored in a Chilean germplasm bank, which includes numerous other species of Lycopersicon, as well as commercial cultivars.

### *Comments*

The reviewer believes this project is of great relevance to determining whether the native tomato germplasm is a potential source of genes for improving the cultivated tomato. This view is based on the following:

- The experience and training of the research leader and his team.
- The research team is sufficiently familiar with the proposed methodology to be able to obtain useful information that can be applied to a future tomato-breeding program.

However, the reviewer suggests that the time allotted to achieving the proposed goal should be extended because of the importance of the objectives.

It cannot be determined whether or not the total tomato area will be affected, the yield will increase, or the prices will decrease, until the genes present in the native germplasm are known, and the extent to which they can be introduced into the cutivated tomato is determined.

## WHEAT

### *Summary*

Considering the grave damage caused by pathogenic fungal agents to yields of Chilean wheat crops, effective solutions must be proposed to reduce the ever-worsening losses. Through genetic-engineering techniques, there are new alternatives for developing tolerance to fungi in wheat and other plants of commercial interest. One way is to transform plants with genes that express lythic enzymes, which will induce resistance to or tolerance of pathogenic fungi. Another approach is to control pathogenic fungi using transformed nonpathogenic fungi that, when released into the environment, will compete with the pathogenic ones and displace them from the ecological niche. The aim of this project is to create and characterize the response of transgenic plants that over-express hydrolytic enzymes of *Trichoderma harzianum*, as a preliminary means of studying the possible action of *Gaeumannomyces graminis*, through the creation of mutants by using genetic-engineering techniques.

### *Comments:*

This project is interesting and novel, and its development would make a good contribution. Following are some comments related to its formulation:

- There should be more realism regarding the economic impacts generated; even if transgenic plants are obtained, it does not imply that this gene can be incorporated into all the existing crops, or into newly-developed ones.
- The budget, as related to the project's needs, is high. An objective evaluation has been difficult because the budget is not itemized.
- The curricular data submitted by the researchers must be realistic and objective.

## NOTHOFAGUS

### *Summary*

The increasing demand for goods and services derived from the forest is affected by the population's economic and cultural development. This has induced the replacement of complex, autochthonous forests of latifoliante species, with faster-growing coniferous ones that can be cultivated in easily-managed and easily-harvested monospecific forests. In Chile, the native forests have been affected to such an extent that some species and possible ecotypes are becoming extinct. There are some dramatic cases, such as some northern populations of the genus *Nothofagus*, one of the most important in Chile, whose predecessors are suffering severe genetic impoverishment. Because of the fragile environmental balance in most of the ecosystems affected, the land tenure system, and land pressure, it is necessary to learn about the genetic diversity of *Nothofagus*, and relate its characteristics to productive factors, in order to determine conservation policies, management, rational exploitation of native forests and support to future genetic-breeding programs. Genetic studies of the *Nothofagus* species described in the study have not yet been carried out in Chile. The project, therefore, emphasizes the use of biochemical and molecular markers to study the genetic constitution of selected populations, as well as to make a dasometric description of them.

### *Comments*

The reviewer's overall appraisal of this project is that identifying the genetic diversity of the *Nothofagus* is of interest and importance to the country, but that the proposal itself is too ambitious. The most relevant subjects (biochemical and molecular characterization) are treated too generally and are hardly based on the cited literature. The project does not sufficiently explain the methodology to be used. Some points raised are:

- It would be difficult to fulfill the proposed objectives, as neither the isoenzymes nor the "primers," which are polymorphic for this species, have been identified.

- The methodology and costs proposed are inadequate in terms of time and funding; this is because the study is extensive, and the prior work that is needed to achieve the results is lacking.
- The realization of the morphologic studies, needed to associate the existing morphologic information (considered scant) with the biochemical and molecular data, has not been taken into account. Furthermore, there is no indication of which morphologic parameters are to be considered in this association.
- The reviewer does not agree with the idea of working with marginal populations, as they are extreme adaptations that do not reflect the true diversity of the species in its natural environment.
- There is no sound basis for the predicted impact.
- It would be necessary to involve a researcher with experience in biochemical and molecular markers for forest species.
- The project should be redefined, restricting it to a single species. First, the genetic structure of the populations should be studied, and, second, all the populations should be taken into account, not only the marginal ones.

## FLOWERS

### *Summary*

Modern agriculture that is open to foreign markets must be highly competitive, stable, and profitable in order to attract investment. For agriculture to be more competitive, it must adhere to the efficient, rational use of productive resources that allows the sustainable development of the sector, the generation of high quality products, and the development of new products and markets. The diversification of our agricultural production will be extremely important.

National agriculture can be diversified in two ways. The first is through products that are not currently produced by the country, but have a market demand. The second is the incorporation of products that are already present in the country, but that the current market does not consume or demand due to ignorance about their existence. The first alternative can be achieved by introducing exotic species, which can then be incorporated into agricultural production through evaluation and selection processes. The second alternative can be done through the productive and economic evaluation of some existing genetic resources, which could have a great impact on national productive diversification policies because of the uniqueness of our genetic resources.

In this country there are many small farmers who could be converted into flower producers, primarily to supply local and regional markets, which could improve their income levels and diversify production. Technical assistance enterprises and other development agencies could participate actively in this work by disseminating, training, and seeking market activities jointly with INIA.

Taking all these factors into account, this project has the following specific objectives: to characterize biochemically and molecularly two types of flowers—different species of *Alstroemeria* and orchids; to evaluate the production of these species technically and economically, in order to widen production alternatives, improve regional agricultural competitiveness and profitability, and aim for the rational and sustainable exploitation of our genetic resources; to help improve the living standards of the small- and medium-scale farmers of the area by disseminating the project's results; to motivate the formation of new enterprises and/or expand current lines of production. The project's aim is to make an important contribution to agricultural diversification using the Central and Southern zones of Chile as a working model.

## *Comments*

Although the general ideas are good, the project itself has several weaknesses:

- The general objective is confusing because the term "evaluate" refers to selected cultivars, while the terms "characterize" and "conserve" refer to types of cultivars. Furthermore, it is unclear whether the species to be used have been identified. If they are known, then it is necessary to indicate which ones they are and the criteria used for their selection, and to outline Chile's position in the international market and the possibility of providing new ecotypes/ cultivars. If there is no prior identification, a wider range of species should be covered. Of the specific objectives, it is only possible to carry out the first within the time proposed, but this objective is not fundamental for the development of the project. Furthermore, the first objective does not contribute directly to the generation of commercial cultivars. Because of this, the project itself is not considered to be biotechnological.
- With regard to the remaining specific objectives, it would appear that none can be achieved by the end of the three-year schedule for the project. Therefore, an evaluation is impossible.
- The description of the methodology is inadequate, especially in relation to the sampling, selection, and cultivation criteria for the evaluation of plants, and how these are related to each phase of the project.
- Relevant bibliographic information was not consulted.
- The analysis of some of the project's impacts is unrealistic or inadequately addressed.
- In the reviewer's opinion, the project could benefit more from the biotechnological techniques available. The way these techniques will be utilized does not, in and of itself, present a comparative advantage over traditional technologies. Furthermore, it would be advantageous to have the initial work completed in terms of, for example, choosing locations for sampling, selecting the most promising species and sub species, and determining propagation parameters, because these are key to adapting the project to the time allocated.

# Annex B: Critera Weights

| Criteria/Subcriteria | Experts | | | | | | | | | | | | | | | | | | | | | Min. | Max. | Standard Deviation | Local Weights | Global Weights |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | | | | | |
| Economic | 12.2 | 51.6 | 51.6 | 51.3 | 41.0 | 23.9 | 11.9 | 10.9 | 33.7 | | | | | | | | | | | | | 10.9 | 51.6 | 17.8 | 32.0 | **32.0** |
| Social | 54.4 | 12.4 | 9.1 | 22.6 | 5.4 | 27.2 | 25.1 | 4.5 | 16.4 | | | | | | | | | | | | | 4.5 | 54.4 | 15.5 | 19.7 | **19.7** |
| Environmental | 27.1 | 15.6 | 25.6 | 19.3 | 22.5 | 41.9 | 57.4 | 26.4 | 40.2 | | | | | | | | | | | | | 15.6 | 57.4 | 13.3 | 30.7 | **30.7** |
| Institutional | 6.4 | 20.4 | 13.8 | 6.8 | 31.1 | 7.0 | 5.6 | 58.3 | 9.7 | | | | | | | | | | | | | 5.6 | 58.3 | 17.4 | 17.7 | **17.7** |
| Net social benefits | | | | | | | | | | 69.6 | 55.9 | 42.0 | 62.7 | | | | | | | | | 42.0 | 69.6 | 11.8 | 57.6 | **18.4** |
| Diversification | | | | | | | | | | 22.9 | 35.2 | 51.1 | 28.0 | | | | | | | | | 22.9 | 51.1 | 12.3 | 34.3 | **11.0** |
| Project cost | | | | | | | | | | 7.5 | 8.9 | 6.9 | 9.4 | | | | | | | | | 6.9 | 9.4 | 1.2 | 8.2 | **2.6** |
| Distribution | | | | | | | | | | 66.7 | 12.5 | 50.0 | 20.0 | | | | | | | | | 12.5 | 66.7 | 25.4 | 37.3 | **7.3** |
| Health risk | | | | | | | | | | 33.3 | 87.5 | 50.0 | 80.0 | | | | | | | | | 33.3 | 87.5 | 25.4 | 62.7 | **12.4** |
| Water | | | | | | | | | | | | | | 20.8 | 8.5 | 25.0 | 12.2 | | | | | 8.5 | 25.0 | 7.6 | 16.6 | **5.1** |
| Soil | | | | | | | | | | | | | | 20.8 | 11.1 | 25.0 | 49.4 | | | | | 11.1 | 49.4 | 16.3 | 26.6 | **8.2** |
| Biodiversity | | | | | | | | | | | | | | 48.7 | 51.2 | 25.0 | 23.9 | | | | | 23.9 | 51.2 | 14.8 | 37.2 | **11.4** |
| Biosafety | | | | | | | | | | | | | | 9.6 | 29.2 | 25.0 | 14.5 | | | | | 9.6 | 29.2 | 9.1 | 19.6 | **6.0** |
| Inst. capacity build. | 25.0 | 33.3 | 75.0 | 75.0 | 16.7 | 50.0 | 16.7 | 33.3 | 66.7 | | | | | | | | | | | | | 16.7 | 75.0 | 23.9 | 43.5 | **7.7** |
| H.R. capacity build. | 75.0 | 66.7 | 25.0 | 25.0 | 83.3 | 50.0 | 83.3 | 66.7 | 33.3 | | | | | | | | | | | | | 25.0 | 83.3 | 23.9 | 56.5 | **10.0** |
| Human resources | 25.8 | 40.0 | 60.0 | 25.8 | 48.1 | 45.5 | 74.7 | 48.1 | 41.3 | | | | | | | | | | | | | 25.8 | 74.7 | 15.4 | 45.5 | **45.5** |
| Characteristics of research | 10.5 | 40.0 | 20.0 | 63.7 | 11.4 | 9.1 | 11.9 | 40.5 | 26.0 | | | | | | | | | | | | | 9.1 | 63.7 | 18.7 | 25.9 | **25.9** |
| Environment of research | 63.7 | 20.0 | 20.0 | 10.5 | 40.5 | 45.5 | 13.4 | 11.4 | 32.7 | | | | | | | | | | | | | 10.5 | 63.7 | 18.3 | 28.6 | **28.6** |
| Qualification | 69.4 | 29.1 | 14.3 | 14.3 | 33.3 | 48.1 | 42.9 | 44.3 | 40.0 | | | | | | | | | | | | | 14.3 | 69.4 | 17.2 | 37.3 | **17.0** |
| Experience | 13.2 | 10.5 | 42.9 | 42.9 | 33.3 | 11.4 | 42.9 | 38.7 | 20.0 | | | | | | | | | | | | | 10.5 | 42.9 | 14.5 | 28.4 | **12.9** |
| Critical mass | 17.4 | 60.5 | 42.9 | 42.9 | 33.3 | 40.5 | 14.3 | 16.9 | 40.0 | | | | | | | | | | | | | 14.3 | 60.5 | 15.4 | 34.3 | **15.6** |
| Tech. challenge | 63.7 | 11.7 | 40.5 | 25.8 | 33.3 | 14.9 | 35.2 | 29.7 | 28.6 | | | | | | | | | | | | | 11.7 | 63.7 | 15.2 | 31.5 | **8.2** |
| Quality of proposal | 25.8 | 61.4 | 48.1 | 63.7 | 33.3 | 69.1 | 55.9 | 61.8 | 57.1 | | | | | | | | | | | | | 25.8 | 69.1 | 14.6 | 52.9 | **13.7** |
| Regulations | 10.5 | 26.8 | 11.4 | 10.5 | 33.3 | 16.0 | 8.9 | 8.6 | 14.3 | | | | | | | | | | | | | 8.6 | 33.3 | 8.7 | 15.6 | **4.0** |
| Collaboration | 21.8 | 40.0 | 46.0 | 69.4 | 20.0 | 40.5 | 9.4 | 29.1 | 40.0 | | | | | | | | | | | | | 9.4 | 69.4 | 17.6 | 35.1 | **10.0** |
| Infrastructure | 6.7 | 40.0 | 22.1 | 13.2 | 20.2 | 11.4 | 28.0 | 60.5 | 40.0 | | | | | | | | | | | | | 6.7 | 60.5 | 17.2 | 26.9 | **7.7** |
| Project management | 71.5 | 20.0 | 31.9 | 17.4 | 60.2 | 48.1 | 62.7 | 10.5 | 20.0 | | | | | | | | | | | | | 10.5 | 71.5 | 22.9 | 38.0 | **10.9** |
| Situation of the end users | 16.5 | 26.0 | 16.2 | 7.5 | 9.6 | 9.7 | 6.5 | 5.8 | 11.7 | | | | | | | | | 6.5 | 13.0 | 12.7 | 7.2 | 5.8 | 26.0 | 5.7 | 11.5 | **11.5** |
| Interst of the end users | 28.5 | 8.0 | 48.7 | 50.8 | 39.4 | 40.4 | 51.3 | 53.4 | 44.0 | | | | | | | | | 16.3 | 46.5 | 41.1 | 51.8 | 8.0 | 53.4 | 14.2 | 40.0 | **40.0** |
| Process of development and transfer | 49.4 | 29.5 | 12.7 | 26.5 | 28.7 | 38.0 | 30.5 | 11.2 | 15.6 | | | | | | | | | 55.9 | 33.5 | 39.6 | 21.4 | 11.2 | 55.9 | 13.4 | 30.2 | **30.2** |
| Public acceptance | 5.7 | 36.5 | 22.3 | 15.1 | 22.3 | 11.9 | 11.6 | 29.7 | 28.7 | | | | | | | | | 21.2 | 7.0 | 6.5 | 19.6 | 5.7 | 36.5 | 9.7 | 18.3 | **18.3** |
| Quantity | | | | | | | | | | | | | | | | | | 83.3 | 16.7 | 12.5 | 25.0 | 12.5 | 83.3 | 33.0 | 34.4 | **4.0** |
| Organization | | | | | | | | | | | | | | | | | | 16.7 | 83.3 | 87.5 | 75.0 | 16.7 | 87.5 | 33.0 | 65.6 | **7.5** |
| Privat benefits | | | | | | | | | | | | | | | | | | 62.7 | 45.5 | 28.0 | 67.4 | 28.0 | 67.4 | 17.9 | 50.9 | **20.3** |
| Concrete demand | | | | | | | | | | | | | | | | | | 28.0 | 45.5 | 62.7 | 10.1 | 10.1 | 62.7 | 22.6 | 36.6 | **14.6** |
| Participation | | | | | | | | | | | | | | | | | | 9.4 | 9.1 | 9.4 | 22.6 | 9.1 | 22.6 | 6.7 | 12.6 | **5.0** |
| Time of maturity | | | | | | | | | | | | | | | | | | 16.2 | 8.5 | 20.0 | 13.6 | 8.5 | 20.0 | 4.8 | 14.6 | **4.4** |
| No. of phases | | | | | | | | | | | | | | | | | | 7.0 | 9.5 | 7.8 | 13.6 | 7.0 | 13.6 | 2.9 | 9.5 | **2.9** |
| Program of research | | | | | | | | | | | | | | | | | | 40.5 | 24.8 | 20.0 | 55.2 | 20.0 | 55.2 | 16.0 | 35.1 | **10.6** |
| System of transfer | | | | | | | | | | | | | | | | | | 36.3 | 57.1 | 52.2 | 17.6 | 17.6 | 57.1 | 17.8 | 40.8 | **12.3** |
| Transgenics | | | | | | | | | | | | | | | | | | 50.0 | 25.0 | 16.7 | 50.0 | 16.7 | 50.0 | 17.2 | 35.4 | **6.5** |
| Chem. residues | | | | | | | | | | | | | | | | | | 50.0 | 75.0 | 83.3 | 50.0 | 50.0 | 83.3 | 17.2 | 64.6 | **11.8** |

# Annex C: Project Priorities

| Criteria/Subcriteria | Weight | Cherimoya | | Grapes | | Potato | | Tomato | | Wheat | | Nothofagus | | Flowers | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (%) | potential | **final** | potential | **final** | potential | **final** | potential | **final** | potential | **final** | potential | **final** | potential | **final** |
| Impacts | | **14.7** | **6.06** | **26.5** | **9.22** | **16.0** | **5.47** | **10.0** | **5.57** | **9.6** | **3.28** | **11.7** | **3.65** | **11.6** | **2.73** |
| **Economic** | 32.0 | 17.9 | 5.0 | 46.1 | 15.2 | 18.1 | 5.7 | 6.6 | 4.0 | 3.9 | 1.9 | 2.4 | 0.5 | 4.9 | 0.8 |
| Net social benefits | 57.6 | 12.6 | 3.2 | 50.1 | 15.9 | 23.5 | 5.0 | 5.2 | 1.8 | 2.7 | 0.5 | 2.1 | 0.3 | 3.8 | 0.3 |
| Diversification | 34.3 | 29.4 | 7.5 | 48.0 | 15.3 | 6.8 | 1.5 | 3.0 | 1.1 | 3.0 | 0.6 | 3.0 | 0.4 | 6.8 | 0.6 |
| Project cost | 8.2 | 6.8 | 6.8 | 9.4 | 9.4 | 27.7 | 27.7 | 32.1 | 32.1 | 16.7 | 16.7 | 2.1 | 2.1 | 5.1 | 5.1 |
| **Social** | 19.7 | 14.1 | 3.6 | 31.0 | 9.8 | 18.2 | 3.9 | 9.2 | 3.2 | 9.2 | 1.8 | 9.2 | 1.3 | 9.2 | 0.8 |
| Distribution | 37.3 | 19.2 | 4.9 | 27.0 | 8.6 | 30.1 | 6.4 | 5.9 | 2.1 | 5.9 | 1.2 | 5.9 | 0.9 | 5.9 | 0.5 |
| Health risk | 62.7 | 11.1 | 2.8 | 33.3 | 10.6 | 11.1 | 2.4 | 11.1 | 3.9 | 11.1 | 2.2 | 11.1 | 1.6 | 11.1 | 1.0 |
| **Environmental** | 30.7 | 5.9 | 2.5 | 12.9 | 4.7 | 15.1 | 6.4 | 13.3 | 7.7 | 5.2 | 1.3 | 26.5 | 9.3 | 21.0 | 5.7 |
| Soil | 31.9 | 11.1 | 2.8 | 33.3 | 10.6 | 11.1 | 2.4 | 11.1 | 3.9 | 11.1 | 2.2 | 11.1 | 1.6 | 11.1 | 1.0 |
| Biodiversity | 44.6 | 3.0 | 2.0 | 4.0 | 2.3 | 14.1 | 6.8 | 10.1 | 6.7 | 1.9 | 0.7 | 39.7 | 15.1 | 27.4 | 8.5 |
| Biosafety | 23.5 | 4.5 | 3.1 | 2.2 | 1.3 | 22.5 | 10.9 | 22.5 | 14.9 | 3.4 | 1.3 | 22.5 | 8.6 | 22.5 | 7.0 |
| **Institutional** | 17.7 | 24.6 | 16.8 | 9.5 | 5.5 | 11.0 | 5.3 | 11.0 | 7.2 | 28.1 | 10.8 | 5.8 | 2.2 | 10.0 | 3.1 |
| Institutional capactiy building | 43.5 | 30.8 | 21.0 | 12.5 | 7.3 | 20.8 | 10.1 | 20.8 | 13.7 | 5.7 | 2.2 | 7.0 | 2.7 | 2.4 | 0.7 |
| H.R. capacity building | 56.5 | 19.9 | 13.6 | 7.1 | 4.1 | 3.4 | 1.7 | 3.4 | 2.2 | 45.3 | 17.5 | 4.9 | 1.9 | 15.9 | 4.9 |
| Success of research | | | **0.68** | | **0.58** | | **0.49** | | **0.66** | | **0.39** | | **0.38** | | **0.31** |
| **Human resources** | 27.4 | | 0.63 | | 0.26 | | 0.63 | | 0.26 | | 0.26 | | 0.33 | | 0.57 |
| Qualification | 50.0 | | 0.26 | | 0.26 | | 1.00 | | 0.26 | | 0.26 | | 0.13 | | 0.13 |
| Experience | 50.0 | | 1.00 | | 0.26 | | 0.26 | | 0.26 | | 0.26 | | 0.52 | | 1.00 |
| **Characteristics of research** | 10.2 | | 0.08 | | 0.08 | | 0.17 | | 0.35 | | 0.08 | | 0.35 | | 0.35 |
| Technological challenge | 66.7 | | 0.06 | | 0.06 | | 0.13 | | 0.26 | | 0.06 | | 0.26 | | 0.26 |
| Regulations | 33.3 | | 0.13 | | 0.13 | | 0.26 | | 0.52 | | 0.13 | | 0.52 | | 0.52 |
| **Enviornment of research** | 5.4 | | 0.83 | | 0.83 | | 0.63 | | 0.33 | | 0.63 | | 0.44 | | 0.47 |
| Collaboration | 35.1 | | 0.52 | | 0.52 | | 0.52 | | 0.26 | | 0.52 | | 0.06 | | 0.06 |
| Infrastructure | 26.9 | | 1.00 | | 1.00 | | 0.26 | | 0.52 | | 0.26 | | 0.13 | | 0.26 |
| Project management | 38.0 | | 1.00 | | 1.00 | | 1.00 | | 0.26 | | 1.00 | | 1.00 | | 1.00 |
| **Quality of proposal** | 57.1 | | 0.80 | | 0.80 | | 0.46 | | 0.94 | | 0.48 | | 0.41 | | 0.16 |
| Consistency with literature | 24.4 | | 0.52 | | 0.52 | | 0.26 | | 1.00 | | 0.52 | | 0.26 | | 0.26 |
| Feasibility of Hypothesis | 62.9 | | 1.00 | | 1.00 | | 0.52 | | 1.00 | | 0.52 | | 0.52 | | 0.13 |
| Gap between resources and activities | 7.9 | | 0.52 | | 0.52 | | 0.52 | | 0.52 | | 0.13 | | 0.13 | | 0.13 |
| Prior results | 4.8 | | 0.06 | | 0.06 | | 0.52 | | 0.52 | | 0.26 | | 0.13 | | 0.13 |
| Success of adoption | | | **0.37** | | **0.55** | | **0.44** | | **0.53** | | **0.51** | | **0.38** | | **0.29** |
| **Situation of the end users** | 11.5 | | 0.14 | | 0.67 | | 0.33 | | 0.14 | | 0.33 | | 0.14 | | 0.14 |
| **Interest of the end users** | 40.0 | | 0.34 | | 0.34 | | 0.34 | | 0.34 | | 0.34 | | 0.34 | | 0.12 |
| **Process of development and transfer** | 30.2 | | 0.28 | | 0.65 | | 0.28 | | 0.65 | | 0.65 | | 0.15 | | 0.15 |
| **Public acceptance** | 18.3 | | 0.76 | | 0.76 | | 1.00 | | 1.00 | | 0.76 | | 1.00 | | 1.00 |

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