The Impact of Pesticide Taxation on Pesticide Use and Income in Costa Rica’s Coffee Production

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To Mei and Sophie

Preface

The past three decades have been characterized by growing awareness of the harmful environmental and health effects of excessive pesticide use. However, the discussion of remedial policies such as taxation has often been impeded by limited information on the likely negative effect of such policies on farmers' incomes. As farmers are the lowest-earning income group in many developing countries, it is not surprising that the actual adoption of pesticide taxation policies has not been a very popular step for many governments. Development agencies have thus often met resistance in their attempts to advise on the merits of rational pesticide policies, which operate on farmers' incentives. A preference for difficult-to-enforce regulatory measures has been a common reflection of the discomfort with taxation policies.

It is within this context that the contribution of the research study described in this volume can be appreciated. Using careful econometric analysis, and meticulously collected data, the researcher was able to convincingly demonstrate that taxes on pesticides can be an effective tool in reducing the use of harmful substances while at the same time having a miniscule impact on farmers' income. These results allow a better-informed policy discussion among the various stakeholders, and pave the way to greater use of economic instruments in guiding farmers towards pest management strategies which are more in line with society's concerns for environmentally sustainable agriculture.

Gershon Feder
Research Manager
Development Research Group
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I am grateful to Prof. Dr. Hartwig de Haen for his excellent and prompt comments on the final draft of this thesis.

The field work in Costa Rica was supported by numerous institutions and individuals. I am most grateful to all of them. The field work was conducted while based at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Turrialba, Costa Rica. Thanks are extended to all my colleagues at CATIE and above all to Octavio Ramirez who made my stay at CATIE possible. The Instituto Interamericano de Cooperación para la Agricultura (IICA) as well as the IICA-GTZ project extensively collaborated in the policy research during the first phase of the field work in Costa Rica and in the organization of two workshops on crop protection policies.

The survey on Costa Rica's coffee production was strongly supported by the Costa Rican Coffee Institute (ICAFE) and the Ministry of Agriculture and Livestock (MAG). Most secondary data on coffee production and on agricultural input use were provided by these two institutions. Sincere appreciation is extended to ICAFE's headquarters, its research station in Heredia, to numerous MAG and ICAFE extension agents and to officers of various coffee co-operatives who helped me to plan and organize the survey. Special thanks goes to Luis Guillermo Ramirez from Turrialba for his friendship and for making me familiar with the coffee production in the Turrialba region. Furthermore, I would like to thank a number of coffee co-operatives and agrochemical shops for providing the 1995 input price data.

This survey would not have been possible without the support of the many coffee farmers in Costa Rica who shared their knowledge with me. Their kindness and openness made the field work in Costa Rica an unforgettable experience. In conducting the interviews I was supported by Francisco Casasola, Luis Conejo, Bernardo Meza, Jeannette Montenegro, Gabriel Rodriguez, Ivol Rodriguez, and Christian Zúñiga who at that time were final year students of agriculture. I would like to thank them for their enthusiasm and for their dedication to the field work. Thanks also goes to Doris Cordero who compiled the data as well as to Martin Petrick, Jan Schotz and Andreas Schulte for their support in editing the thesis.

Furthermore, thanks are extended to my colleagues at the Institute of Agricultural Economics of the University of Göttingen for many fruitful discussions, especially to Fritz Feger and Oliver Bode for their comments on the econometric part of this study. I would also like to thank Prof. Dr. Erich Schmidt, Institute of Horticultural Economics of the University of Hannover, for his advice in the field of applied econometrics.

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List of Abbreviations

BCAC	Banco de Crédito Agrícola de Cartago (Bank of Agricultural Credit of Cartago)
BCCR	Banco Central de Costa Rica (Central Bank of Costa Rica)
BCR	Banco de Costa Rica (Bank of Costa Rica)
BNCR	Banco Nacional de Costa Rica (National Bank of Costa Rica)
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Tropical Agricultural Research and Higher Education Centre)
CFC	Chlorofluorocarbon
CES	constant elasticity of substitution
CGE	computable general equilibrium
cif	cargo, insurance, freight
CRC	Costa Rica Colones
CPI	Consumer Price Index
CSCE	Coffee, Sugar, Cocoa Exchange, New York
DGSV	Dirección General de Sanidad Vegetal (Crop Protection Service)
DHL	double hecto-litre (= 200 l)
DM	Deutsche Mark
EPA	Environmental Protection Agency
EU	European Union
fan	fanega (= 400 l)
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration of the United States of America
FEDECOOP	Federation of Coffee Co-operatives in Costa Rica
fob	free on board
FONECAFE	Fondo Nacional de Estabilización del Precio de Café (Fund for the Stabilization of the Coffee Price)
GM	gross margin
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
ha	hectare
ICAFE	Instituto de Café de Costa Rica (Coffee Institute of Costa Rica)
IICA	Instituto Interamericano de Cooperación para la Agricultura (Interamerican Institute of Co-operation for Agriculture)
IPM	integrated pest management
IRM	Integrated Resource Management
IRRI	International Rice Research Institute
l	litre(s)
lbs	pound(s)

kg	kilogram(s)
MAG	Ministerio de Agricultura y Ganadería (Ministry of Agriculture and Livestock)
MB	marginal benefit
MC	marginal cost
MEIC	Ministerio de Economía, Industria y Comercio (Ministry of Economy, Industry and Trade)
MH	Ministerio de Hacienda (Ministry of Finance)
MNB	marginal net benefit
MS	Ministerio de Salud (Ministry of Health)
mz	manzana (0.7 ha)
n.a.	not available
n.c.	not classified
OECD	Organisation for Economic Co-operation and Development
OIT	Organización Internacional del Trabajo (International Labour Organization)
OLS	ordinary least squares
OPS	Organización Panamericana para la Salud (Panamerican Health Organization)
PAN	Pesticide Action Network
PIC	Prior Informed Consent
SEPSA	Secretaría Ejecutiva de Planificación del Sector Agropecuario (Executive Secretariat for Planning in the Agricultural Sector)
t	tons
UCR	Universidad de Costa Rica (University of Costa Rica)
UK	United Kingdom
UN	United Nations
UNA	Universidad Nacional de Costa Rica (National University of Costa Rica)
UPANACIONAL	farmer union in Costa Rica
US, USA	United States of America
USDA	United States Department of Agriculture
US$	United States Dollar
USAID	United States Agency for International Development
WHO	World Health Organization
WTO	World Trade Organization

1 Introduction

The use of high-yielding varieties, chemical pesticides and fertilizers has led to a significant increase in agricultural production. However, indiscriminate use of the latter two inputs and especially of chemical pesticides has caused negative side effects such as resistance to pesticides, outbreaks of secondary pests, poisoning of human beings and pollution of the environment. In tropical countries these side effects occur more frequently and are much more obvious than in temperate regions. Among other reasons, climatic conditions make the utilization of protective gear very uncomfortable. Undesired side effects impose damage costs that have to be borne partly by farmers themselves and partly by the society as a whole.

Recent discussion about the use of economic instruments in pesticide policies as a means to address these problems has been controversial. It is feared that taxes on pesticides would considerably increase production costs and lead to major income losses in the farming community. However, only few quantitative analyses have been conducted on the effects of such taxes.

1.1 Problem Identification and Practical Relevance of the Study

In Costa Rica, the legislation on crop protection and pesticide use has made considerable progress over the last two decades. Like many other countries, Costa Rica has tried to reduce the negative impact of pesticide use through regulations and extension programmes. Costa Rica's government has promoted integrated pest management (IPM) as an alternative to the unilateral use of chemical pesticides. However, IPM has rarely been adopted by Costa Rican farmers. The question, therefore, arises as to how sustainable agriculture can be promoted effectively and how the adoption of IPM can be improved?

So far, in Costa Rica little attention has been paid to the use of economic instruments in pesticide policies as a disincentive to pesticide use and to stimulate the use of non-chemical crop protection methods. A tax on pesticides and/or subsidies for non-chemical crop protection could make IPM more profitable than it is today. Furthermore, a tax would internalize at least some of the external costs of pesticide use.

These obvious advantages have not yet been sufficiently recognized by policy makers. In spite of the world-wide discussion on environmental taxation, pesticide taxes still suffer from a negative image, mostly because it is thought that taxes put an unnecessary burden on the agricultural sector without generating significant improvements in crop protection practices.

This research project deals with pesticide taxation as an additional instrument in pesticide policies in Costa Rica. It provides empirical evidence for the impact of a pesticide tax on pesticide use and income in coffee production and is meant to contribute to a more objective discussion of pesticide taxation as a policy instrument.

1.2 Objectives and Overview of the Thesis

The overall objective of this thesis is to assess the impact of a pesticide tax on pesticide demand and income in Costa Rica's coffee production. At the same time, the following specific objectives are addressed:

- to review the economics of pesticide taxation from the policy and farm-level perspectives,
- to assess the average variable costs of production in Costa Rica's coffee production with a focus on crop protection inputs,
- to compare two different econometric approaches to the estimation of pesticide demand with farm-level data (a single equation panel model versus a system of seemingly unrelated regression equations),
- to examine the practical aspects related to the implementation of a pesticide tax.

Chapter 2 presents the essential features of pesticide policy in Costa Rica with a focus on the institutional and economic factors that influence pesticide use in this country. It gives an overview of the development of pesticide use in Costa Rica and introduces the regulatory framework, the institutional setting, the information environment in crop protection, externalities of pesticide use and input pricing policies.

The economic rationale behind a pesticide tax is discussed in Chapter 3, which looks at the problem of externalities and the options available for society to respond to them. A number of policy instruments that may be used to address market imperfections in crop protection are illustrated, namely regulatory instruments, moral suasion and economic instruments. The two dominant economic approaches to solve the externality problem, namely the use of taxes according to PIGOU (1924) and the property rights approach following COASE (1961) are discussed, showing that pesticide taxation can be an appropriate instrument to supplement current pesticide policies.

The options for pesticide taxation are reviewed based on the experience of various countries.

Whether or not pesticide taxation is a viable policy instrument, depends largely on the effects of a pesticide tax on pesticide use and farm income. Farmers' decision making is therefore analysed in Chapter 4 on the basis of the neoclassical theory of production. However, pesticides do not fit neatly within the standard neoclassical optimization model because they do not increase yields but rather reduce yield variability. Chapter 4 presents attempts to deal with this problem from within the neoclassical approach and outside of it. The chapter formulates hypotheses on the effects of a pesticide tax and presents methods for use in the empirical analysis of this issue.

Chapter 5 portrays the main features of Costa Rica's coffee sector including the commercialization of coffee, characteristics of production from a sectoral perspective and on-farm production technology and pest management. Since the available secondary data on production technology in coffee was not sufficient for an analysis of the impact of a pesticide tax on this crop, it was necessary to conduct a representative survey on input use in Costa Rica's coffee sector.

Chapter 6 gives an overview of the design of the survey, data processing and statistical analyses. Special attention is paid to the problem of aggregation of input prices and quantities, which presupposes identical own- and cross-price elasticities of each aggregate with reference to other aggregates. The use of the Ideal Fisher price- and quantity indexes in the aggregation and the implications of aggregation for the explanatory power of regression models are discussed. Statistics on the evolution of pesticide use from 1993 to 1995 are presented, and the cost structure in Costa Rica's coffee production as well as average partial budgets are examined.

Chapter 7 deals with the econometric analysis of pesticide demand. The sample on input use in coffee production taken in Costa Rica consists of 325 cross-sectional units over 3 time periods, i.e. of a panel data set. For the analysis of panel data, econometric models have been developed that take account of the specific structure of pooled time series and cross-sectional data. Having identified an appropriate panel model for this research, the estimation of pesticide demand functions is discussed concentrating on the choice of the exogenous variables, appropriate functional forms and the two estimation approaches that were used in this study. The results obtained in the empirical analysis of pesticide demand in coffee are presented and discussed.

Chapter 8 assesses the impact of various tax scenarios on farm income and pesticide demand in coffee. Based on these findings, the efficiency and the effectiveness of a potential pesticide tax are discussed. Furthermore, the distributional and equity aspects of pesticide taxation as well as practical questions on the design of a pesticide tax are considered.

In Chapter 9 conclusions concerning the analytical instruments used and the results obtained in this research are presented. Chapter 10 is a summary of the thesis.

2 Crop Protection Policy in Costa Rica

Pesticide use is influenced not only by environmental factors such as the natural conditions for agricultural production and pest pressure but also by institutional and economic factors. Human action and conditions in the field are closely related as exemplified by pest pressure which is often a result of human interference. This policy survey explicitly addresses the question of whether Costa Rica's economic and institutional policy framework encourages exclusive reliance on chemical pesticides or allows for the adoption of non-chemical pest management methods. Section 2.1 introduces the methodology used for the policy analysis and gives a short overview of Costa Rica's crop protection sector. Sections 2.2 and 2.3 discuss the institutional and economic factors which influence pesticide use in Costa Rica and raise the question of whether there is a need for adjustments to Costa Rica's pesticide policy.

2.1 Background Information

2.1.1 Analytical Framework

The point of departure for the pesticide policy analysis in Costa Rica was the "Guidelines for Pesticide Policy Studies" (AGNE, FLEISCHER, JUNGBLUTH, WAIBEL, 1995) which draw on an analytical framework developed by WAIBEL (1994) and the 1994 Göttingen Workshop on Pesticide Policies. The guidelines contain a comprehensive check-list of issues to be covered by pesticide policy studies and emphasize that the entire range of stakeholders of the crop protection sector should be included in the analysis. Institutional and macro-economic factors which influence pesticide use are classified into four groups:

- institutional factors (e.g. legislation),
- information (information provided by extension workers, pesticide retailers, the chemical industry, etc.),
- price factors (e.g. reduced sales tax or tariffs),
- the lack of consideration of external costs of pesticide use.

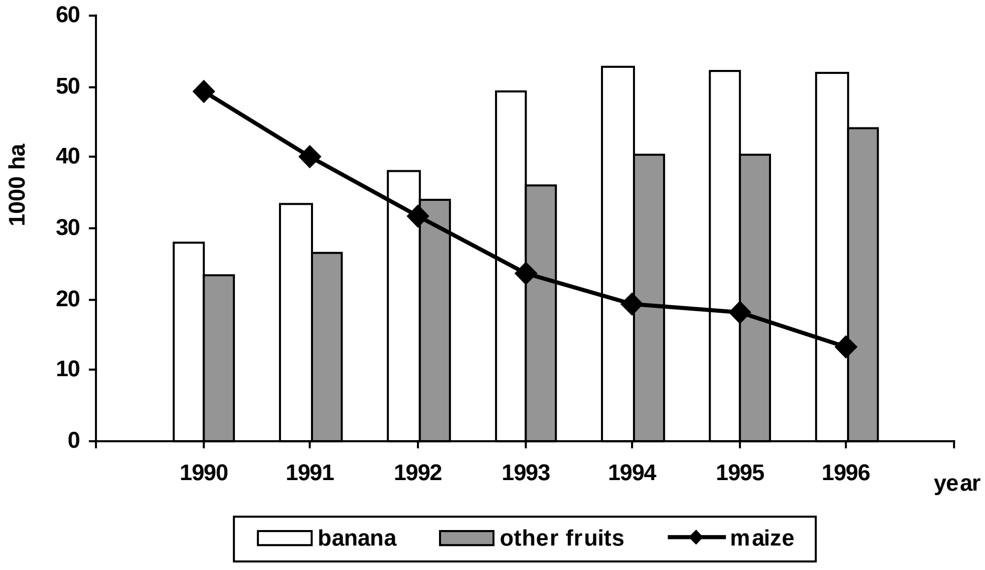
The first task in the policy analysis in Costa Rica was to identify the factors that were relevant for Costa Rica. Information collected in numerous interviews with public and private sector representatives of the crop protection sector led to a preliminary report on pesticide policy in Costa Rica that was presented at a workshop with specialists from different ministries, universities, research centres, industry and the Federation of Coffee Co-operatives (FEDECOOP). The workshop, which took place at IICA's headquarters in San José, Costa Rica in December 1995, was an attempt to include the stakeholders of Costa Rica's crop protection sector in the discussion on pesticide taxation at an early stage of the research. The following sections summarize the major findings of the policy study.

2.1.2 Changes in Costa Rica's Cropping Pattern

In the early 1990s the area dedicated to agricultural export crops in Costa Rica increased significantly. Banana production almost doubled from 28,300 ha to 52,000 ha. The area cultivated with ornamentals expanded from 3,400 ha to 4,500 ha and the production area of melon, mango, orange and pineapple increased by approximately 85%, from 23,282 ha in 1990 to 44,011 ha in 1996 (see Figure 2-1). The coffee area remained almost stable while cotton growing declined. Rice, bean and maize areas decreased; the latter by more than 70% from 49,381 ha to 13,304 ha (SEPSA, 1997).

These developments were related to agricultural trade liberalization and the promotion of horticultural export crops. Border protection for basic grain production in Costa Rica was reduced significantly and this has had a strong impact, particularly on the area under maize. The shift towards cultivation of pesticide-intensive horticultural crops has increased the demand for chemical pesticides in Costa Rica.

Figure 2-1: Changes in area cultivated with banana, other fruits* and maize in Costa Rica from 1990 to 1996



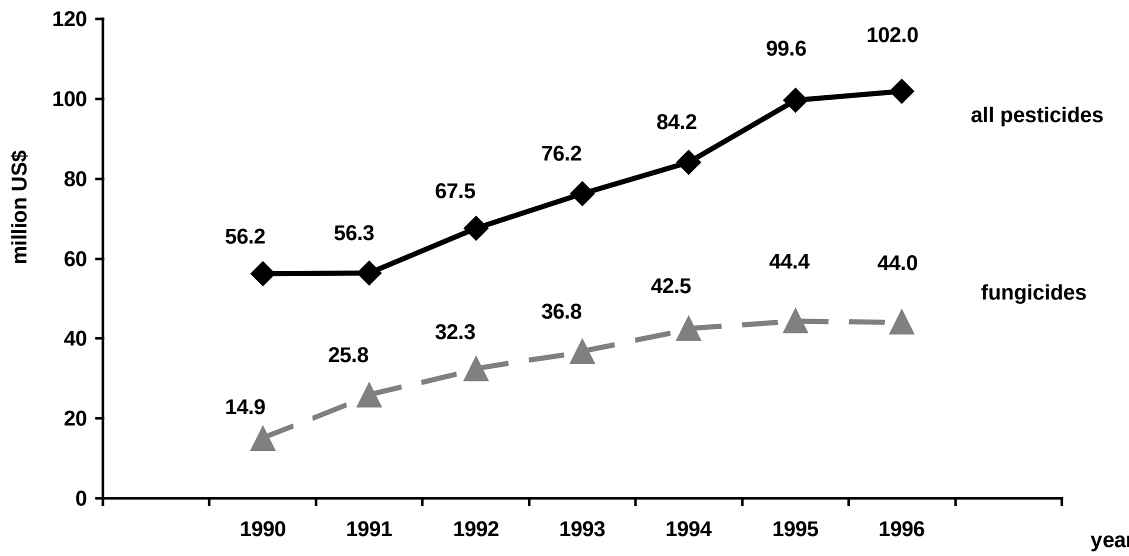
* "Other fruits" refers to melon, mango, orange and pineapple.

Source: SEPSA (1997)

2.1.3 Pesticide Markets in Costa Rica

Costa Rica has a growing market for chemical pesticides, and above all for fungicides. Fungicide imports almost tripled from US$ 14.9 million in 1990 to US$ 44.2 million in 1996. Much of this increase can be explained by the expansion of banana growing between 1990 and 1994, and increased fungicide applications per hectare in banana plantations associated with growing resistance to fungicides of *Mycosphaerella fijiensis* (Sigatoka negra), the most prevalent fungal disease in banana production. The total value of chemical pesticide imports in nominal terms increased from US$ 56.2 million in 1990 to US$ 102 million in 1996, which is equivalent to a shift of over 80% as shown in Figure 2-2.

Figure 2-2: CIF-value of chemical pesticide imports to Costa Rica from 1990 to 1996 (in current US$) [1]



Source: CÁMARA DE INSUMOS AGROPECUARIOS[2], San José, Costa Rica; revised by Dr. Bernal Valverde, CATIE, and by the author

Pesticide formulation also has become increasingly important in Costa Rica, where 21 companies formulate, pack and bottle pesticides. FORMUQUISA, one of the most important agrochemical companies in Costa Rica also

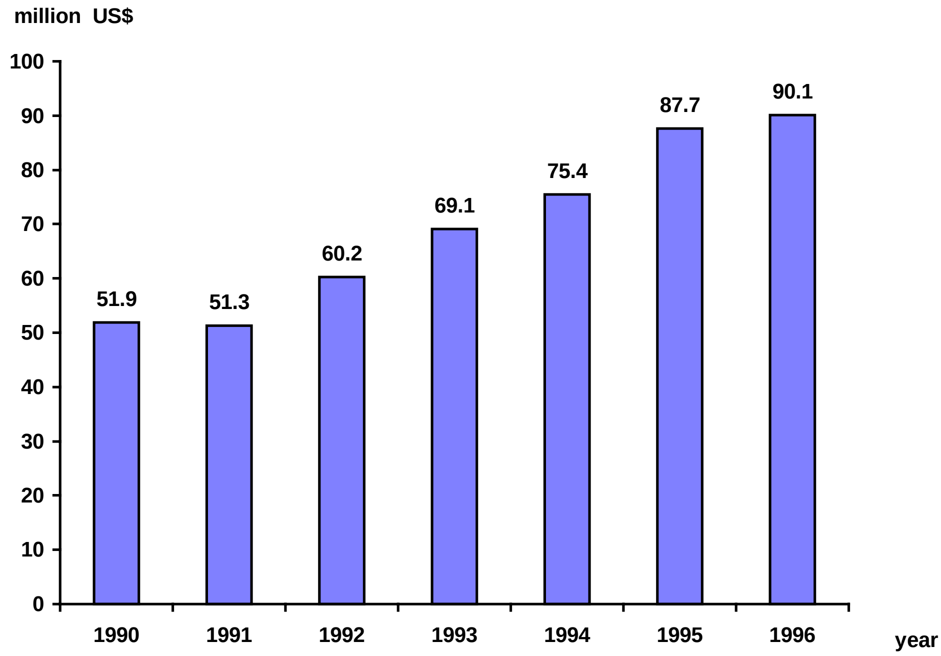
[1] Chemical pesticides include fumigants, fungicides, herbicides, insecticides, mollusquicides, nematicides, etc. as well as coadjuvants. The import data include technical material and formulated products whose proportion may vary between years. Therefore, year to year comparisons should be interpreted with care.

[2] In Costa Rica, *Cámara de Insumos Agropecuarios* is the common abbreviation for *Cámara de Fabricantes, Importadores y Disbribuidores de Insumos Agropecuarios*.

produces two active ingredients: glyphosate and propanyl (CÁMARA DE INSUMOS AGROPECUARIOS, personal communication).

Some firms formulate PIC list[3] or potential PIC list pesticides such as paraquat, aldicarb, methomyl, methyl parathion, monocrotophos, methamidophos, ethoprop, phenamiphos, phorate, mirex, terbufos (DINHAM, 1993). At present no data on the value of pesticides purchased in Costa Rica are available. Therefore, pesticide trade has to be used as an indicator for pesticide use in this country. Figure 2-3 shows that the values of net pesticide imports (value of pesticide imports minus value of pesticide exports) from 1990 to 1996 has increased sharply.

Figure 2-3: Net imports of chemical pesticides to Costa Rica from 1990 to 1996 (value in current US$)



Source: author's calculations based on data provided by the Cámara de Insumos Agropecuarios and the Ventanilla Unica, San José, Costa Rica

The net import data may be used to approximate pesticide expenditures per hectare of agricultural land. Actual expenditures for pesticides in Costa Rica are well above this figure because Costa Rica has a significant pesticide

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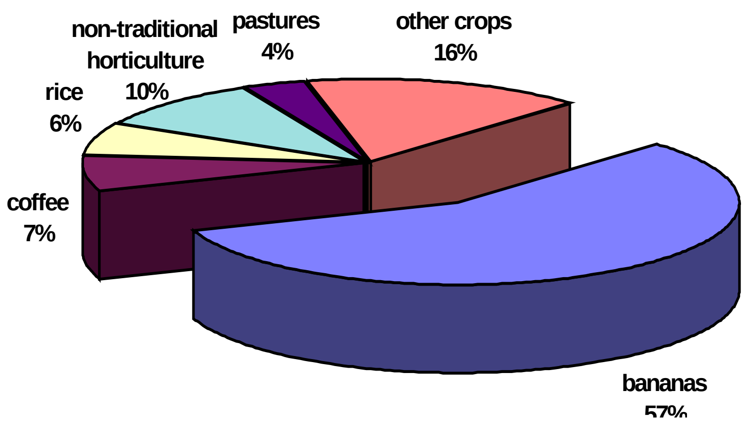
3 The Prior Informed Consent (PIC) list includes pesticides and other chemicals that have been banned or severely restricted in at least one country after 1 January 1992. Chemicals banned or severely restricted prior to this date may be eligible for the PIC-list if control actions have been taken in five or more countries. The PIC procedure is a means to inform participating countries about the characteristics of potentially hazardous chemicals that may be shipped to them.

formulating industry. According to the estimates of net pesticide imports, more than US$ 215 was spent on pesticides per hectare agricultural land in 1996. This is more than the amount spent in any other Central American country.

Figure 2-4 illustrates the 1993 pesticide market in Costa Rica. Fifty-seven percent of all pesticides were purchased for use in banana plantations although bananas occupied less than 10% of Costa Rica's agricultural area. Pesticide expenses for non-traditional horticultural crops covered 10% of the national pesticide market. Compared to horticultural crops, coffee and rice are less pesticide intensive. In 1993, 6% of all pesticide purchases were used in rice production which covers 13.6% of Costa Rica's total agricultural area, while 7% of all purchases were used for coffee production on 20% of the agricultural land.

Figure 2-4: Pesticide use in selected crops in Costa Rica in 1993 (% of cif-value)



Source: CAMARA NACIONAL DE AGRICULTURA Y AGROINDUSTRIA (1994)

2.2 Role of Institutions and Information in Crop Protection

2.2.1 Institutional Setting

2.2.1.1 Pesticide Policy Formulation

In Costa Rica, public and private institutions are involved in the process of pesticide policy formulation. Two advisory committees play an important role in this field[4], namely the Pesticide Assessory Commission[5] *(Comisión Asesora*

4 see also Table A 2-1 in Appendix 2

5 This commission was established by Ministerial Decree No. 2580 on 11 October 1972.

Nacional de Plaguicidas), and the Commission deciding on tax exemptions *(Comisión Técnica de Exoneración de Insumos Agropecuarios)*.

The Pesticide Assessory Commission, a technical advisory committee to the Ministers of Agriculture, Health and Labour, has responsibility for revising all valid legislation related to pesticides with the aim of proposing necessary reforms. Furthermore, the commission is charged with responsibility for reaching an effective co-operation between institutions to further develop pesticide policy. Its recommendations are expected to follow national and international norms.

An extensive list of agricultural inputs, including agrochemicals and application equipment are exempted from all taxes[6]. Tax exemptions can be granted by the Minister of Finance on the recommendation of the Commission on Tax Exemptions. This commission has a technical secretary, who is based at the government's Crop Protection Service. A representative of the Ministry of Agriculture and Livestock presides over the commission.

Costa Rica's Ministry of Agriculture and Livestock (MAG) and the National Chamber of Producers, Importers and Distributors of Agricultural Inputs *(Cámara de Insumos Agropecuarios)* are the only entities represented on both commissions, and MAG assumes a leadership position. All other institutions are member of only one commission. Pesticide and pest management experts from universities and research institutions are currently not included on either commission[7]. Farmers, farm workers, consumers and environmental groups are also not included in the process of policy formation.

2.2.1.2 Pesticide Legislation

Compared to other countries in Central America, crop protection policy in Costa Rica is advanced. In 1997, Costa Rica's parliament approved the latest revision to the Crop Protection Law *(Ley de Sanidad Vegetal)*, which includes emerging issues such as organic agriculture and biotechnology (MINISTERIO DE AGRICULTURA Y GANADERÍA, 1997). However, as in many other countries, some parts of the legislation are difficult to implement. For example, pesticide misuse is very difficult to control.

Several institutions are involved in pesticide legislation, with the Ministry of Health and MAG taking a leadership role. The Ministry of Health has overall

[6] All legal tax exemptions are specified by Regulation No. 21281-MAG-H-MEIC, valid since April 3, 1992, and are based on Law No. 7293.

[7] This was not true, though, at the beginning of the 1980s when a representative of the University of Costa Rica (UCR) was a commission member (HILJE, L. et al., 1987).

responsibility for legislation and supervision related to toxic substances[8], of which chemical pesticides are an important fraction. Occupational safety has to be determined and regulated by the Ministry of Health in co-operation with the Ministry of Labour. Recommendations developed by the Ministry of Health have to be implemented by the Ministry of Agriculture.

The 1968 Crop Protection Law *(Ley de Sanidad Vegetal No. 4295)*, and its revisions of 1978 and 1997, form the basis for numerous regulations and decrees on pesticide registration and use. CASTRO (1995) gives a good overview of developments in Costa Rica's pesticide legislation until the end of 1994. He suggests that one legal instrument should be developed to regulate all aspects of pesticide use in order to achieve more coherent pesticide legislation. He also emphasizes that public entities involved in pesticide issues as well as private agents often do not adhere to the laws and that sometimes they are not even aware of the legislation.

Costa Rica agreed to the FAO Code of Conduct including the Prior Informed Consent and therefore has an obligation to make efforts to implement these international agreements. Furthermore, US and EU legislation on residues in imported foodstuffs are of vital interest to Costa Rica because agricultural exports are almost exclusively oriented towards the United States of America and to the European Union. The rejection of Costa Rican exports by the US Federal Drug Administration (FDA) has caused significant setbacks.

2.2.1.3 Law Enforcement and Monitoring

The Ministry of Agriculture is the dominant government agency in the implementation and monitoring of pesticide legislation and is responsible for all technical aspects of pesticide use. At MAG, the Agricultural Inputs Department *(Departamento de Insumos)* is in charge of the registration of pesticides and of controlling their appropriate use. This department analyses the technical information provided by the industry and collects import statistics on agrochemicals. At the same time, it is responsible for pesticide residue analyses in foodstuffs carried out by two national laboratories. The Ministry of Health monitors and evaluates toxicity levels of pesticides with respect to human health and the Ministry of Labour is responsible for the supervision of occupational risks related to pesticide use.

[8] Health Law 5395 of 1974, Title III, Chapter 7, Article 345, Item 8, cited in USAID (1992)

Although Costa Rica has made considerable progress in pesticide legislation, implementation of the laws has proven to be difficult mainly because:

- control costs are prohibitively high due to the large number of individuals dealing with pesticides,
- inadequate resources are available for monitoring and these are shared among different government agencies which generally operate independently from each other, and
- penalties are relatively light because the administration feels that farmers and retailers need time to adjust to the relatively new legislation.

CASTRO (1995) states that the legislation involves too many institutions in the monitoring of pesticide use leading to inter-institutional friction and unclear delineation of responsibilities among agencies. Four institutions, for example, are involved in monitoring storage facilities of pesticide retailers, namely MAG, the Ministry of Health, the Ministry of Labour and the Association of Agronomists[9] *(Colégio de Ingenieros Agrónomos)*. To fulfil this task, each institution has inspectors who visit agrochemical shops to examine just those aspects related to the interests of their institution. Resources are scarce and therefore the total number of inspectors is not sufficient to monitor the large number of pesticide distributors. Efficiencies could be achieved by assigning this responsibility to one agency which could then report back to the other Ministries involved.

2.2.1.4 Agricultural Credit

Banks have a strong influence on technological change in agriculture. They give recommendations to farmers who seek loans and, if considered necessary, give technical assistance during the production process.

In Costa Rica, every farmer who seeks credit must submit details on the crops he/she intends to grow, and also on his/her production technology. Credits may be given in shares, obliging the farmer to document his/her expenses during the previous period to make sure that the money provided was used exclusively for production purposes.

THRUPP (1990b) reports that the Banco Nacional de Costa Rica required farmers to use a specific proportion of the credit to purchase chemical pesticides. Several Costa Rican banks interviewed in 1996[10] did not impose

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[9] The Association of Agronomists is the professional association of all agronomists in Costa Rica.

[10] Banco Nacional de Costa Rica (BNCR), Banco de Costa Rica (BCR), Banco de Crédito Agrícola de Catrago (BCAC), Banco de Fomento Agrícola, Banco del Comercio.

such pesticide related credit requirements. However, for every crop a technology package is proposed to the farmer which has been evaluated by an inter-bank-commission *(Comisión Interbancaria)*. The bank guidelines on production technology *(avío bancario)* determine the maximum size of the loan. If the proposed technology package is not used, the farmer must prove that his/her production technology is also viable. In case in which a bank is concerned that the farmer could lose his/her crop, a bank agronomist may assist him/her. At this stage, the agronomist's recommendations are binding.

Even though the technology packages provided by the banks are generally not obligatory the banks have a strong impact on production technology because in many cases, no other information is available to farmers.

2.2.2 The Information Environment in the Crop Protection Sector

2.2.2.1 Public Research and Education in Crop Protection

Research

Public sector agricultural research is executed by MAG, two public universities and via collaborative links between the ministry and the universities. Furthermore, ICAFE, the Costa Rican Coffee Institute - which is a semi-state run organization - has a mandate to conduct research on coffee production. The funds invested in research on crop protection are partly used for research on pesticide use and partly for research on integrated measures.

Education in Crop Protection

In Costa Rica, 44 professional colleges offer a specialization in agriculture. In many of them, it is possible to choose a specific career within the field of agriculture, e.g. agricultural production or agro-ecology. The curricula may or may not contain basic courses on economic and production aspects of major crops of the country and the region in which the college is situated (e.g. Colegio Técnico Profesional Los Chiles, Alajuela) or on farm management, occupational health, ecology and management of natural resources (e.g. Colegio Técnico Profesional de Paquera). A survey of agricultural colleges in Costa Rica revealed that there are no specific courses on crop protection. Phytosanitary measures are only covered in some courses on crop production. Only universities offer special courses on crop protection.

Safe use training

Educational programmes on the safe use of pesticides have been developed for farmers, farm workers, housewives and children by MAG in co-operation with the representatives of the chemical industry (Cámara de Insumos Agropecuarios). The participating farmers are taught the basic techniques of pesticide application and sanitation (washing clothes after spraying, etc.). Protective gear used in northern countries is not recommended because it is not considered suitable for tropical climates. Therefore, safe use recommendations have been confined to judicious application and basic protective clothing such as rubber boots and gloves (CÁMARA DE INSUMOS AGROPECUARIOS, personal communication). Appropriate protective clothing for the tropics has not been developed yet.

Safe use has been taught on a relatively small scale. Since the beginning of the programme in 1986 until 1993 only 10% of the rural agricultural work force and less than 5% of the rural population had been reached[11]. In most cases, information about the safe use of pesticides had been presented in full-day or half-day meetings without follow-up activities. The impact of those seminars has not been evaluated, but, it is likely to have been limited.

2.2.2.2 Extension in Crop Protection: Availability of Information and Methods

The Ministry of Agriculture's extension service and the Crop Protection Service are in charge of extension in crop protection. Extension in crop protection in Costa Rica has changed over the last few years. The extension service now officially promotes integrated pest management.

Availability of information on non-chemical methods in agricultural institutions and on the farm

Theoretically a wide range of information sources is available to farmers from pesticide retail shops, chemical industry campaigns and field advice, neighbours, friends and official extension agents. In reality, the official extension system only reaches a small proportion of farmers; in general, mainly those who live in easily accessible areas. The opposite is true for information from pesticide retail shops and from the chemical industry which can be found all over the country.

[11] Data on the number of people trained were provided by the Cámara de Insumos Agropecuarios, data on the rural and the total agricultural work force were taken from the 1994 Encuesta de Hogares, Dirección General de Estadísticas y Censos, San José, Costa Rica.

In Costa Rica, official recommendations on crop protection were chemical-based for many years. Only recently has there been a change in official policy and the movement towards integrated pest management. Up to now the extension services have been seeking effective methods for farmer training. It has been found difficult to convince Costa Rican farmers of the advantages of IPM, mainly because:

- in many cases the economic incentives for farmers to switch from purely chemical to integrated pest management methods are relatively small,
- information about chemical use is available more easily, in any shop, at almost any time of the day whereas it may be more difficult to contact an extensionist,
- a change to IPM requires an investment in learning while simple methods of chemical treatments are readily available,
- farmers prefer to rely on what they have done previously and what is still promoted by the chemical industry.

This list is far from complete. Throughout the world non-chemical crop protection methods have been developed in agricultural research institutions and in the field[12]. Non-chemical measures include the targeted use of beneficial organisms, cultural measures such as crop rotation to avoid infestation, and the tolerance of pests up to a predetermined level or "economic threshold".

In Costa Rica there are links between research and extension for some specific IPM projects but they do not cover the whole range of options. There is a lack of information on IPM within agricultural institutions that is partly responsible for the fact that few integrated methods have found their way into agricultural practice in Costa Rica.

Extension methods

In Costa Rica IPM extension is relatively new and therefore little experience has been obtained with extension methods. There are two major problems in IPM extension. Firstly, only a small number of farmers are reached by public extension. Secondly, the methods used for educating farmers are not very efficient.

[12] In Costa Rica, for example, a cultural strategy to delay the transmission of the gemini virus to tomatoes has been successfully tested. The gemini virus is transmitted by the white fly *(Bemisia tabaci)* and causes major losses in tomato production.

The most popular method in IPM extension is to invite farmers to field days where the results obtained at demonstration plots are displayed. Integrated pest management is generally understood as a threshold-based chemical control which may be supplemented with some cultural measures. In view of the dynamic nature of pests and the strong influence of farm-specific factors, the effectiveness of this extension approach in convincing farmers about the advantages of IPM is questionable.

IPM training deviates significantly from the concept used in Asia, particularly in Indonesia, where the concept of Farmer Field Schools has proved to be an effective way to transfer IPM technologies (KENMORE, 1996). The overall goal of Farmer Field Schools is to empower farmers by educating them in the ecological principles of production, and enabling them to make decisions on crop protection that are suited to their local conditions.

2.2.2.3 Information Transmitted by the Industry and by Pesticide Retailers

Most farmers in Costa Rica do not receive technical assistance from official extension services. In deciding on crop protection measures they rely on their own experience, on their neighbours' experience and on information obtained when buying pesticides. Pesticide shops cover all regions of Costa Rica. Many farmers prefer to contact a pesticide retailer instead of an official extensionist when problems arise because pesticide shops can be reached easily, quickly and practically at any time.

Advertisements for pesticides can be seen throughout the country. Information transmitted by the industry and by retailers is obviously delivered with the intention of increasing pesticide sales which is not conducive to the dissemination of integrated pest management strategies.

2.3 Tax Exemptions and Hidden Costs of Pesticide Use

2.3.1 Tax Exemptions for Pesticides and other Agricultural Inputs[13]

In Costa Rica pesticides as well as other agricultural inputs are exempted from all taxes and duties. In contrast, agricultural labour is not exempted from taxes. It is interesting to note that crop protection officials do not consider this policy and the government's objective of reducing pesticide use and promoting IPM as contradictory (AGNE, 1996).

For most pesticides a 6% import duty had been originally foreseen[14]. Applying this duty would imply a 6% price increase, a reduction in pesticide use and release of considerable funds that, for example, could be invested in non-chemical crop protection.

2.3.2 Hidden Costs of Pesticide Use

This section summarizes reports and official statistics on external effects of pesticide use in Costa Rica. It provides an overview of the literature to illustrate the dimension of the negative side effects of pesticide use in Costa Rica. In any case, it may be assumed that only a small fraction of the actual injuries have been documented, making it difficult to assess the real external costs incurred by pesticide use.

Health Impacts on Farmers and on Farm Workers

Occupational pesticide poisoning has been a serious problem in Costa Rica for many years. The sterilization of more than 1,000 workers in banana plantations as a side-effect of applying DBCP is well documented and illustrates the hazards related to pesticide use (RAMIREZ and RAMIREZ, 1980; THRUPP, 1989; cited in HILJE, 1991).

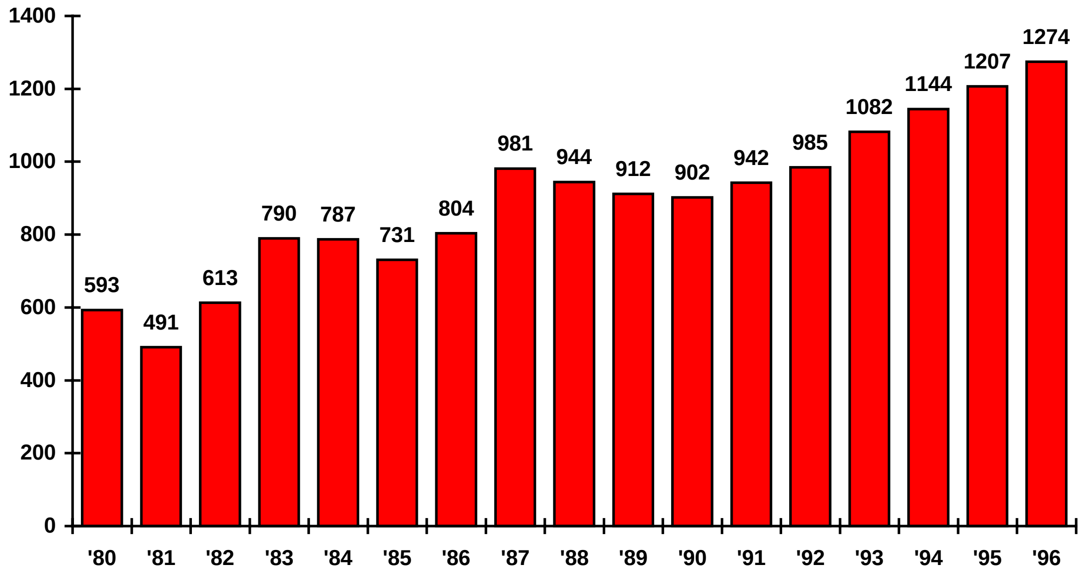
The Centro Nacional de Control de Intoxicaciones, San José, has registered pesticide poisonings since 1980. At present, it relies on information provided voluntarily by physicians who report poisoning cases to the Centre. As this is the only source of information the centre has, it can be assumed that the number of registered cases is lower than the actual number of cases. Cases of

13 This paragraph is based on updates of decrees No. 22593-MEIC-H and 22594-H-MEIC published in Appendix No. 39 of "La Gaceta Diario Oficial" No. 217 del 12.11.1993, Tomo II and on an interview with Mrs. Lina Morera, Ministerio de Economía, Industria y Comerica (MEIC), San José, in 1995

14 Source: updates of decrees no. 22593-MEIC-H and 22594-H-MEIC published in Appendix no. 39 of "La Gaceta Diario Oficial", no. 217, Volume II, of 12 November 1993

poisoning with agrochemicals reported to the Centre increased from 593 in 1980 to 1274 in 1996 (Figure 2-5).

Figure 2-5: Poisonings with agrochemicals in Costa Rica registered at the National Centre for Poisoning Monitoring from 1980 to 1996



Source: Centro Nacional de Control de Intoxicaciones, San José, Costa Rica

In 1996, organophosphates (269 cases), carbamates (169 cases) and paraquat (148 cases) were most frequently associated with registered pesticide poisonings. Forty-eight per cent of the agrochemicals were ingested, most of the rest were absorbed by the skin or inhaled. Of all pesticide intoxications registered in 1996, 38.5% were classified as occupational intoxication, 33% as accidental and 22.5% as suicide attempts. About 70% of all the persons poisoned were male and about 30% were female. Data on fatal intoxications for 1996 are not available. In 1993, 42 fatalities occurred: 18 of those were caused by paraquat, 11 by carbamates and 10 by organophosphates[15].

The data show that the number of pesticide poisonings has increased over time. In this context, it would be worthwhile to examine the impact of the prohibition of the most toxic substances (or of safe use training) from 1988 to 1991 on the number of poisoning cases. Such a study would require additional

[15] This information has been found in the archives of MEDICATURA FORENSE, a judicial government institution in San José, Costa Rica.

information on poisonings at the regional level and monitoring of safe use training activities.

Pesticide Residues and Metabolites in Foodstuffs and in the Environment

Costa Rica's Plant Protection Service analyses pesticide residues in about 400 vegetable samples each year to monitor food quality on the national market. The results of these analyses are not available to the public. VON DÜSZELN, VERENO and WIELAND (1995) published data from Costa Rica's Crop Protection Service on residue analysis in 1992 which showed that 37% of all samples contained pesticide residues, while about 6% of the samples violated Costa Rica's maximum residue limits. In 1993, when the range of compounds analysed was extended, residues were found in 55% of the samples, and 11% of the samples exceeded maximum residue limits (DIRECCIÓN GENERAL DE SANIDAD VEGETAL, personal communication).

The Pesticide Programme at Costa Rica's National University monitored the effects of pesticide use on banana plantations in north eastern Costa Rica. Residues of various pesticides have been found in the surface water of drainage channels. The most frequently detected compounds were the fungicides thiabendazole, propiconazole, and the insecticides, chlorpyrifos and terbufos. CORDERO and RAMIREZ (1979) and THRUPP (1991) documented the existence of copper toxicity in soils that were used by the United Fruit Company for banana production.

Evidence of Pesticide Resistance

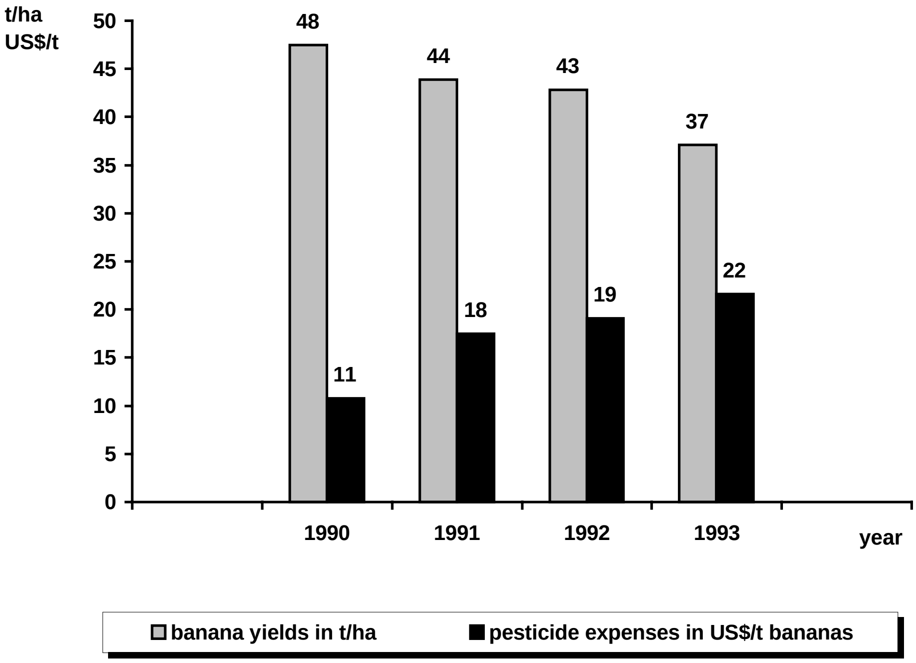
Pesticide resistance is an unintended consequence of pesticide use that has been documented in numerous countries (see GEORGHIOU, 1986, 1990, and FAO, 1991, for insecticide resistance; CASELEY et al., 1991, for herbicide resistance; DEKKER and GEORGOPOULOS, 1982, for fungicide resistance, etc.). In Costa Rica, as in other Central American countries, there is considerable evidence of pesticide resistance. However, only few cases have been scientifically investigated and documented. These include:

- Resistance of *Antichloris viridis* to the insecticide dieldrine (STEPHENS, 1984; cited in HILJE, 1991);
- resistance of the diamond backmoth *Plutella xylostella* to the pyrethroid deltametrine (BLANCO, SHANNON and SAUNDERS, 1990; cited in HILJE, 1991);
- resistance of the whitefly *Bemisia tabaci* to many different insecticides.

Herbicide resistance has been detected in *Echinocloa colona*, an important weed in rice production (GARRO, ET AL., 1991) and in *Ixophorus unisetus* and *Eleusine indica* (VALVERDE and GARITA, 1993).

In laboratory experiments, WILLIAMS (1989) found resistance of *Mycosphaerella fijiensis* (Sigatoka negra) to the fungicides propiconazole and flusilazole. Meanwhile, fungicide resistance has become a fact of life on most banana plantations. Statistics on expenses for pesticides in banana production and on the evolution of average yields reinforce the relevance of these findings. Average total pesticide expenditures per ha in banana production were estimated at US$ 514 per ha in 1990 and at US$ 800 per ha in 1993 (BAYER DE COSTA RICA, personal communication), while average yields declined from 47.5 t/ha to 37.1 t/ha, respectively (author's calculations based on SEPSA, 1993). Consequently, in 1990 one ton of bananas could be produced with approximate pesticide expenditures of US$ 10.8 while in 1993, US$ 21.6 was spent on pesticides in order to produce the same amount of bananas (Figure 2-6).

Figure 2-6: Average banana yields in t per ha versus expenses for pesticides in banana production in US$ per t of produced bananas



Source: SEPSA (1993), BAYER DE COSTA RICA, author's calculations

Although this does not provide conclusive evidence of resistance, these data indicate that fungicide resistance contributes to the declining profitability of banana production and is therefore an important topic for future research.

2.4 Conclusions

The previous section has presented evidence of the negative external effects of pesticide use in Costa Rica. In spite of the progress in modernizing legislation in the crop protection sector, there is scope for improvement in pesticide policy. As outlined in Section 2.2.1, the implementation of some of the laws is a major problem in Costa Rica because of prohibitively high enforcement costs. A pesticide tax, which could be implemented at low administrative cost, might help to improve the current situation by setting economic incentives for judicious pesticide use. Hence, in the context of the government's objective to reduce pesticide use in Costa Rica and to promote non-chemical crop protection, a tax could become an important element.

3 External Effects of Pesticide Use and Policy Measures to Address Them

The existence of external effects of pesticide use indicates that current levels of use may be above the social optimum. This chapter discusses policy measures to address the externality problem.

3.1 The Society's Perspective: Private Versus Social Optimum of Pesticide Use

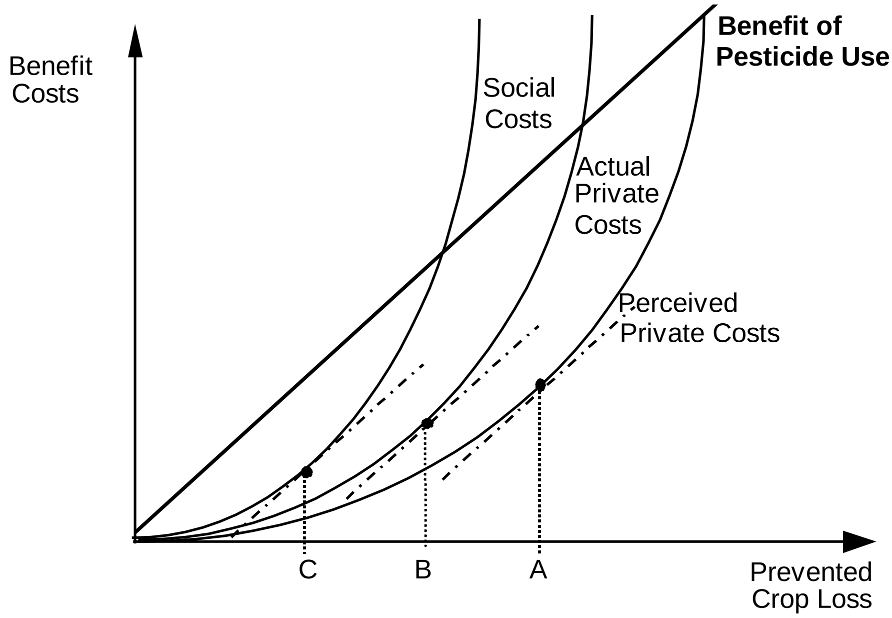
3.1.1 Benefit-Cost Considerations in a Social Context

It is well known that an input is used efficiently when its marginal cost equals its marginal return (e.g. DEBERTIN, 1986). Following this simple rule leads to allocative efficiency. In the case of pesticides, however, there are two difficulties: first to assess the benefits related to their use and second to assess the real costs of pesticide use. This section concentrates on the costs of pesticide use.

Figure 3-1 illustrates how different kinds of costs relate to the optimal intensity of pesticide use. The abscissa shows units of prevented crop loss due to the application of pesticides. The real benefit of pesticide use is a linear function of crop loss. It equals the prevented crop loss times the price per crop unit. This benefit function is contrasted with three different cost functions. The costs of pesticide use are referred to as the amount of farm resources dedicated to crop loss prevention. The cost function labelled *perceived private costs* includes the costs of pesticides plus application costs, which are usually referred to as costs for crop protection. The level of pesticide use according to this cost concept depends on the farmer's subjective assessment of crop loss, the effectiveness of his/her control method and the cost he/she perceives. This may well lead to an overestimation of the benefits of pesticide use and to an underestimation of costs if, for example, actual health hazards are not fully recognized. Relying on distorted information a profit maximizing farmer would increase pesticide applications in order to prevent amount A of crop loss.

Assuming perfect information on the above variables, i.e. knowing the benefit of pesticide use and all the costs incurred by the farmer, leads to a different cost function specified as *actual private cost* inFigure 3-1. In this case B is the optimum level of prevented crop loss at the farm.

Figure 3-1: Private and social optimum of pesticide use



Source: after WAIBEL, 1994

From society's point of view there are additional costs related to crop protection. The external costs of pesticide use arise, for example, through the contamination of ground water or food. Including these costs in the analysis leads to a third cost function, specified as *social costs*. The optimal level of crop loss prevention from society's point of view would be reached at point C.

These considerations are based on the assumption that prevented crop loss is positively correlated to the amount of pesticides used. Hence, greater crop loss prevention implies a higher level of pesticide use. The functional form of the cost functions has been specified exponentially to take account of the decreasing marginal productivity of pesticides.

The optimal level of crop loss prevention and of pesticide use respectively, for society (C) differs from the actual level of pesticide use (A) if there are external costs. Hence, if governments do not intervene in the pesticide market the level of pesticide use is likely to be above the social optimum. The resulting overuse of pesticides causes additional costs, because potential and actual damage caused by pesticides leads to an increased need for government activities which aim at monitoring the implementation of rules and regulations as well as at reducing the environmental and health damage caused by pesticides. Examples of such activities are the establishment of pesticide residue laboratories, residue monitoring programmes and training programmes on the safe use of pesticides. There is no doubt that such activities, which mostly require public funds are necessary in principal. However, the extent of these activities must be decided simultaneously with the level of pesticide use, or else over investment is likely to occur. If activities in pesticide damage mitigation measures come up to the current level of pesticide use, public funds are likely to be wasted. If pesticide use were at the socially optimal level, the induced demand for such activities would be lower (WAIBEL, 1994).

3.1.2 The Real Cost of Pesticide Use to the Farmer: Health and Resource Costs

Health and resource costs may or may not be externalities depending on whether a farmer has to bear them or not. Off-time costs (e.g. of soil erosion) may be external if the land is rented, but are internal on owner-operated farms. Pesticide resistance is a common property problem that mostly affects farmers applying huge quantities of pesticides. In any case, it can be stated that there are off-time and off-site costs, which are usually not considered when different crop protection strategies are compared. Let us call these costs "hidden costs".

In general, when cost comparisons between chemical and integrated crop protection strategies are made, not all on-farm costs of chemical crop protection are taken into account. Only the most obvious and most easily measured costs of chemical crop protection are considered. As shown in Figure 3-2 these are per unit expenses for chemical pesticides, application costs including labour, spray equipment, etc., and, if applicable, transport, storage and disposal costs for pesticides. In addition to these obvious costs there are hidden costs of pesticide use such as health costs for the farmer, production loss through pesticide crop damage, and additional costs through the destruction of beneficials and resistance build-up, as discussed in Section 3.1.2.

Figure 3-2: The costs of pesticide use for the farmer

HIDDEN COSTS

- medical treatment (if paid by the farmer) + opportunity costs of lost working days due to acute and chronic pesticide poisoning
- reduction of self-regulating potential of the agro-ecosystem (e.g. by eliminating natural predators)
- on-farm resistance build-up
- on-farm production loss (crop damage, loss in animal production)

OBVIOUS COSTS

- expenses for pesticides
- transport, storage and disposal costs
- application costs

Source: author's presentation

ROLA and PINGALI (1993) showed that immediate health costs related to insecticide use in Philippine rice production have a significant impact on profitability. They compared the profitability of four different pest control strategies. For all four strategies, they estimated health costs associated with pesticide use on the basis of lost labour days and costs for medical treatment. The mean health cost per season to farmers varied between zero for natural control and 7,450 pesos for calendar spraying (called "complete protection" in the report). Costs for farmers' standard practices and for treatments based on economic thresholds were 623 and 647 pesos in the wet season and 720 pesos and 1188 pesos in the dry season, respectively. Health costs had a significant impact on the farmers' net benefits, which were in fact highest without insecticide use.

3.1.3 External Costs of Pesticide Use

BUCHANAN and STUBBLEBINE (1962) define a (Pareto-relevant) externality as being present when, in a competitive equilibrium, the (marginal) conditions of optimal resource allocation are violated (cited in BAUMOL and OATES, 1988). According to PIGOU (1924) and COASE (1960), this is the case when the private cost of a technology differs from its social cost. Among the many side effects provoked by pesticide use the most important and costly effects are the following:

- acute or chronic health effects,
- build-up of pesticide resistance,
- pollution of the environment (in particular of water resources),
- loss of biodiversity,
- public spending for government agencies involved in pesticide registration and monitoring.

Many studies of the external effects of pesticide use have been undertaken, both in developing and industrialized countries. There are well documented cases of acute intoxication of farm workers who apply pesticides (e.g. THRUPP, 1989) and of pesticide resistance (GEORGHIOU, 1990).

However, only a few systematic economic studies on the external costs of pesticide use have been undertaken. The first comprehensive study on the external costs of pesticide use was conducted by PIMENTEL ET AL. (1992) who estimated environmental and social costs of pesticide use in the U.S.A. at about US$ 8,123 million per year. The pesticide market in the U.S.A. amounts to about US$ 4,000 million which implies that for every dollar spent on pesticides external costs add up to two dollars. Bird losses, groundwater contamination and costs related to pesticide resistance are the most significant factors in PIMENTEL's cost calculations.

WAIBEL and FLEISCHER (1998) calculated the costs and benefits related to pesticide use in Germany[16]. A region-specific sectoral production and factor demand model was used to assess the gross benefits of pesticide use, which were estimated at about DM 2.839 billion[17]. The private costs of pesticide use (expenses for pesticides, pesticide storage and application) were DM 1.689 billion while external costs to society were between DM 252 and DM 312 million, depending on the scenario. This figure does not include chronic effects of pesticides on human health, long-term effects on the sustainability of agricultural production and soil fertility. Expenses for pesticides are equivalent to about DM 1 billion, so that for every mark spent on pesticides in Germany there are 0.25 marks of external costs. Using the lower limit of the external cost estimates the social benefit-cost ratio for pesticide use in Germany amounts to 1.46.

JUNGBLUTH (1996) estimated external costs related to pesticide use in Thailand. Estimations vary between 463 and 5492 million Baht[18] per year

[16] West Germany (before unification)

[17] 1 US$ = 1.7 DM (approximate exchange rate, November 1998)

[18] 1 US$ = 25.6 Baht (exchange rate of 11 December 1996, quoted in JUNGBLUTH, 1996)

depending on the data included. The lower value is attained by using data on side effects of pesticide use which are published in the official Thai government statistics. However, these official figures cover only a small proportion of intoxication caused by pesticides and of residues in food (JUNGBLUTH, 1996). Extrapolating from in-depth case studies on intoxication and pesticide residues leads to much higher costs. If the maximum residue limits were applied rigorously, many vegetables and fruits would have to be taken off the market, which would imply considerable costs to producers (estimated at about 5 billion Baht).

3.2 Pesticide Policy Instruments

Environmental policies are often based on the "principle of damage prevention" and the "polluter-pays-principle". On the basis of these two principles external effects may be addressed through a wide range of policy measures. These can be classified according to the way they influence the behaviour of economic agents (OPSCHOOR and TURNER, 1994a+b).

The first group of instruments includes "direct" regulations such as standards, bans, permits, zoning, use restrictions, etc. which are referred to as *regulatory instruments* or *command-and-control instruments*. Education, extension, training, information transmission in general, and also social pressure, negotiation and other forms of "moral suasion" belong to the second group of instruments. These *persuasive instruments* aim at a change of perceptions and priorities within an agent's decision framework, i.e. at a change of attitude.

The third group of policy measures creates economic incentives or market stimuli for environmentally more appropriate behaviour. This can be achieved by applying charges or levies to polluting technologies and/or subsidies to "clean" technologies. By influencing factor and product prices external effects of specific technologies may - at least partly - be internalized. Instruments that influence prices will be referred to as *economic instruments*.

3.2.1 The Regulatory Approach and Moral Suasion in Pesticide Policies

Regulatory instruments have been the preferred form of all environmental policies including pesticide policy. Direct regulations may be combined with educational programmes or other elements of moral suasion. The most popular regulatory instruments in pesticide policies are standards, bans, permits and use restrictions. They are preferred for a variety of reasons, some of which are:

- Regulatory instruments can be very effective if the transaction costs associated with their enforcement are low. They are particularly important when immediate dangers have to be averted. In such cases the effects of regulation on environmental quality are more certain than the effects of other policy measures.
- Regulatory instruments are more readily accepted by society than economic instruments. The latter are sometimes refused because they might be interpreted as giving a "right to pollute" (OECD, 1989). Furthermore, economic instruments may be rejected because they may have negative distributional effects and may severely affect low-income groups.

Private business seems to prefer regulations because charges might be additional to compliance costs. Furthermore, firms often assume they have more influence on regulations via negotiations, and the implementation of new regulations takes a long time because of such negotiations (BOHM and RUSSEL, 1985). This is a particularly important factor in developing countries.

Within the limits set by the regulatory instruments, utilization of the environment is usually free of charge, whereas any transgression of the limits is considered a legal offence subject to judicial or administrative penalties. Therefore, if the legal provisions are not exceeded, the polluter is not directly confronted with a price for his/her use of the environment (NUTZINGER, 1994).

Moral suasion may be more efficient than regulatory instruments when the monitoring required for economic incentive schemes or regulation is technically unfeasible or prohibitively expensive. It is often used in conjunction with regulatory or economic instruments. Moral suasion instruments are supposed to internalize environmental awareness and responsibility into individual decision-making by applying pressure and persuasion either indirectly or directly, e.g. in negotiations aimed at 'voluntary' agreements or covenants between industry and governments on environmental issues (OECD, 1989). The moral suasion approach uses the threat of possible regulations in order to bring about 'voluntarily' more flexible settlements and behavioural changes which are often supported by economic incentives and disincentives (NUTZINGER, 1994). "In certain cases it may be worthwhile for the government to rely on moral suasion when alternative measures are blocked for political reasons" (BOHM and RUSSEL, 1985). However, moral suasion alone is not likely to be a very effective policy instrument and therefore may rather be used to complement direct policy measures.

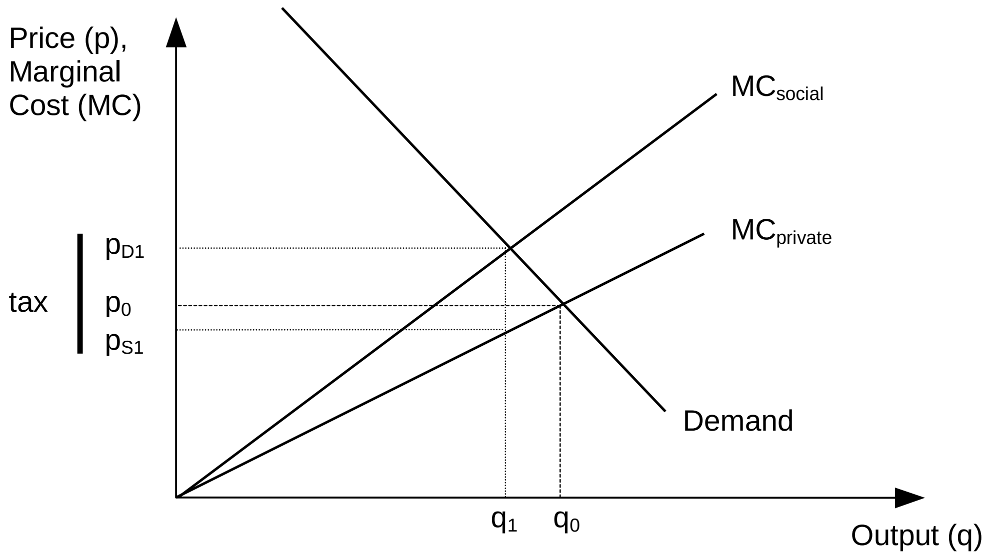
3.2.2 Economic Instruments and the Internalization of External Costs

Fees, taxes, subsidies, tradable permits and deposit-refund systems are economic instruments that may be taken into account in pesticide policy (compare Table A 3-4 in Appendix 3). Among these, taxes are probably the most controversial measures, but at the same time among the most promising. This section gives an introduction to the internalization of external costs through economic instruments.

3.2.2.1 The Pigouvian Tax

PIGOU (1924) explicitly addressed the problem of external costs in a market economy in his famous book "The Economics of Welfare". PIGOU's reasoning is straightforward: his suggestion for solving the externality problem is to implement a tax on products that cause externalities equal to their external cost, the *Pigouvian tax*. Figure 3-3 shows how such a tax influences the production and consumption of goods. In the situation without a tax, the supply and the demand of the good are equal to q_0 units at the price p_0. The tax leads to an upward shift of the supply function. It makes the product more expensive and therefore negatively affects demand of the product. In the new market equilibrium q_1 units of the good are consumed at price p_{D1}. Producers now obtain the price p_{S1}. The tax proceeds, which are equivalent to q_1 times p_{D1}-p_{S1}, are then to be used to pay for the external cost of the activity. Pigou states that this mechanism leads to a Pareto-optimal situation.

Figure 3-3: Effect of a Pigouvian tax on supply and demand of a good



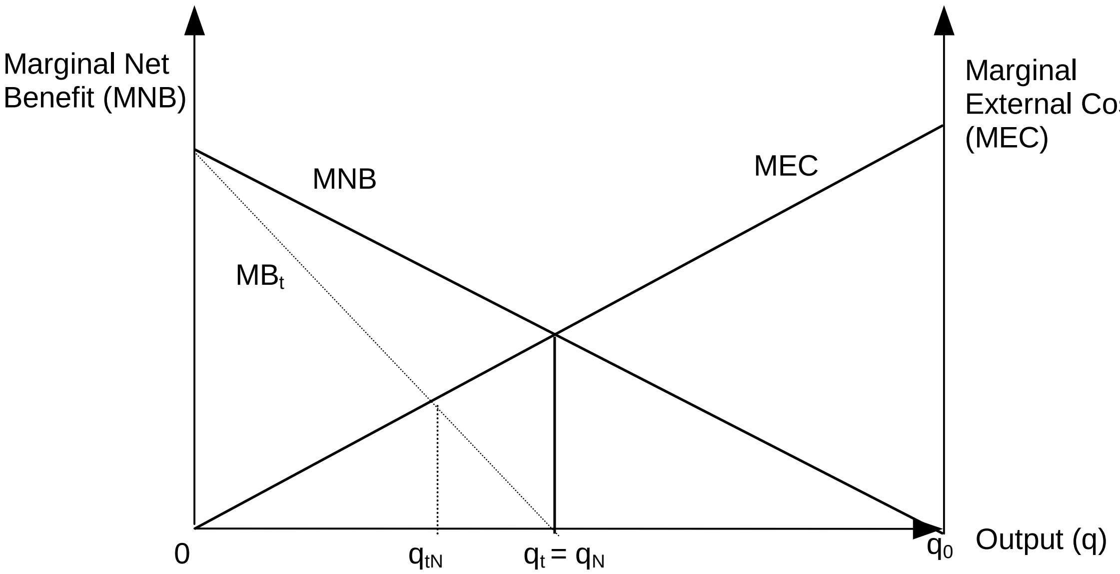
Source: author's presentation

The Pigouvian approach raises both practical and theoretical problems. Practical problems occur when measuring the exact external costs related to an economic activity. A solution to this could be to measure and assess external costs where possible and, based on the empirical findings and their representativeness, to find a societal consensus on the appropriate tax rate. Yet some external costs can only be measured indirectly, reducing the likelihood that a consensus can be found.

A major theoretical problem is that even if all external costs could be assessed, a Pigouvian tax might lead to a sub-optimal solution in cases in which transaction costs are low (COASE, 1960). It is likely that low transaction costs would stimulate negotiation between the concerned parties, with or without a Pigouvian tax (BUCHANAN and STUBBLEBINE, 1962). Figure 3-4 illustrates the consequences of these assumptions. An economic activity with output q causes external effects. MNB represents the marginal net benefit, MEC the marginal external cost related to the activity. Without tax and without negotiation, output q_0 is realized, which causes marginal external costs that are higher than the marginal net benefit of the production activity. Obviously this situation is sub-optimal. In a Pareto-optimal situation, a quantity would be produced such that the marginal net benefit would equal the marginal external cost. This solution, q_N, can be achieved through negotiation between the concerned parties.

A Pigouvian tax would lower the marginal net benefit of the producer and, without negotiation, make him/her produce the Pareto-optimal output q_t=q_N. But, when the transaction costs for negotiations are low, there is an incentive for further negotiation between the producer and the party confronted with external effects. Negotiation between the concerned parties after the implementation of a Pigouvian tax will then result in the suboptimal level of production q_{tN}.

Figure 3-4: The different effects on output of a Pigouvian tax, the negotiation solution and negotiation after implementing a Pigouvian tax



Source: after LERCH (1998)

3.2.2.2 The Property Rights Approach

R. COASE (1960) states that "tradition has not selected the correct taxation principle for the elimination of externalities, and may not even have chosen the right individuals to tax or to subsidize" (quoted in BAUMOL, 1972). COASE suggests the negotiation principle as an efficient solution to the externality problem. A necessary condition is the assignment of property rights and the possibility for private agents to buy or sell them (MANSFIELD, 1985).

Clearly defined property rights create possibilities for using market mechanisms to reach socially optimal solutions. However, only in case of low transaction costs will negotiations take place and a positive result be achieved. Often, e.g. in air or water pollution, a large number of agents are affected, not all of whom can directly negotiate with the firms causing the emissions. This problem is worse when environmental pollution crosses national borders. Furthermore, the intergenerational distribution of wealth is not taken into account because future generations may not take part in today's negotiations.

An often cited example for the negotiation solution is the case of water protection areas in Germany. Water companies that use surface or groundwater for drinking water supplies are obliged to adhere to quality standards. In cases where water resources are polluted by diffuse non-point pollution from agricultural production (e.g. by nitrate or chemical pesticides), the water works bear costs arising from water treatment or the drilling of new wells.

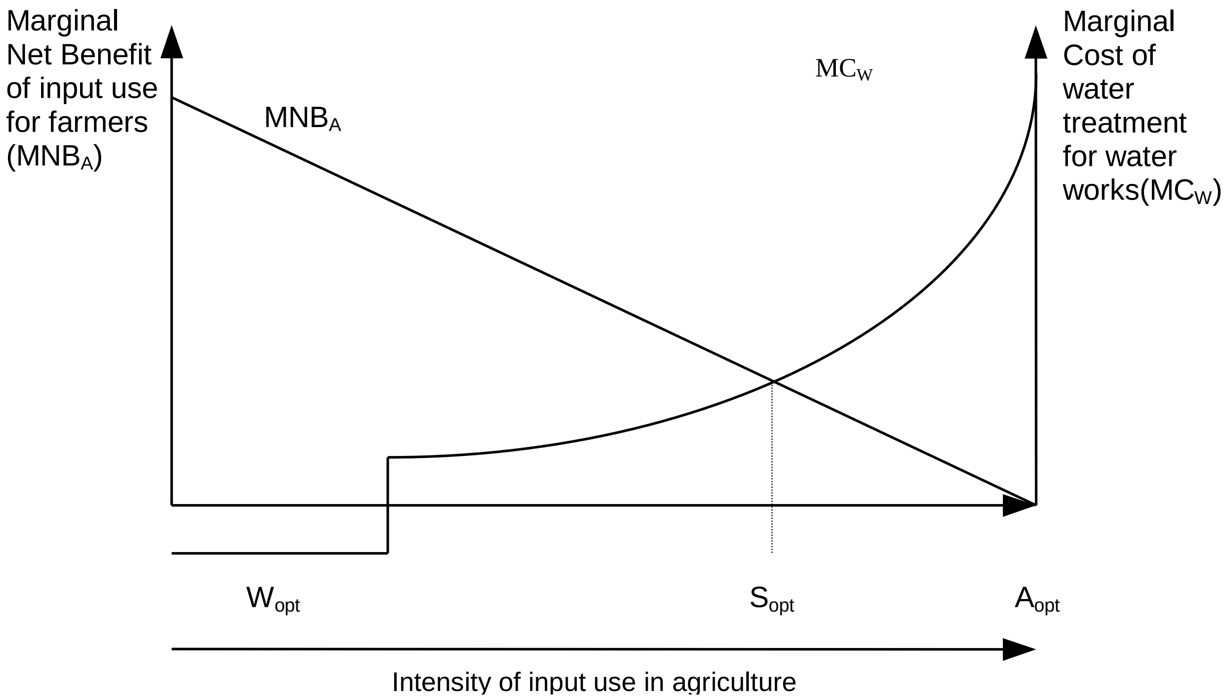
If farmers intensify their production by the use of inputs up to the point where the marginal net benefit is zero, the water works are confronted with marginal abatement costs that are higher than the marginal net benefit from farming. This outcome is inefficient for society as a whole. The socially optimal level of input use is achieved where the marginal net benefit from agricultural production equals the marginal abatement costs for the water supply companies (Figure 3-5).

If transaction costs are low and markets are transparent, an efficient solution will be reached irrespective of the actual distribution of property rights (COASE, 1960). The latter would only determine the flow of the compensatory payments. If farmers own the right to pollute the groundwater, the water supply companies have to pay them for the reduction of their input use. In the case where the water works have the legal right to use uncontaminated water resources, the farmers will have to negotiate for the permission of input use against financial compensation.

However, there are various problems related to this approach. First it is not clear who should be the owner of the property rights - the farmer or the society? In Germany the water works pay compensation to farmers who reduce their input use in water protection areas. This is a practical solution but not in line with the polluter-pays-principle, which is supposed to be one of the most fundamental principles of environmental policy in Germany.

Furthermore, negotiations may be costly and only applicable in areas where economic interests, marginal costs and marginal net benefits are clearly defined, i.e. where transaction costs are relatively low. In most agricultural areas this is not the case and therefore negotiated solutions are less likely to happen.

Figure 3-5: Conflicting interests between agricultural producers and water works related to groundwater use



W$_{opt}$ = private optimum for water works, S$_{opt}$ = social optimum, A$_{opt}$ = private optimum for farmers

Source: after WAIBEL, 1995

Finally, if the farmers do not comply with the agreement, i.e. if they over- or misuse chemical inputs, it is difficult - if not impossible - to prove that a violation of their commitment has occurred. If the nitrate or pesticide concentration in the ground water is higher than it should be, it is virtually impossible to assign this effect to one particular farmer. Nor is it possible to monitor the use of chemical inputs of each farmer.

In view of these shortcomings a number of measures have been proposed to address the nitrate contamination problem which include, among others, research and extension activities as well as economic incentives such as taxes or tradable permits (DE HAEN, 1982)

3.2.3 A Framework for the Evaluation of Pesticide Policy Instruments

Environmental policy is most effective if a combination of different types of instruments designed to address a particular problem is used. Even then it is not always possible to find the optimal policy mix. PEARCE and TURNER (1990) state that "given the inherent uncertainties involved, pollution control in practice is best viewed as an iterative search process. Policy-makers are simply trying to discover and arrive at a set of pollution control arrangements which make enough people better off, so that those circumstances are preferable to current circumstances". The appropriate set of policy instruments required to achieve the environmental quality goals should be based on the criteria of political feasibility, efficiency, cost-effectiveness, flexibility and equity. Similar sets of criteria for the evaluation of environmental policy instruments have been proposed by other authors as summarized in Table 3-1:

Table 3-1: Criteria for the evaluation of environmental policy instruments

	CANSIER (1996)	REUS, WECKSELER and PAK (1994)	TURNER and OPSCHOOR (1994)
ENVIRONMENT	• ecological effectiveness	• effectiveness	• effectiveness in reaching the environmental goal • risk reduction
ECONOMY	• economic efficiency	• efficiency • application of the polluter pays principle	• economic efficiency
EQUITY	• impact on competitive position of an industry	• economic consequences for farmers	• equity / impact on farm income
POLICY	• political acceptance	• feasibility and maintainability • support among farmers	• political feasibility • acceptability by societal groups
IMPLEMENTATION			• administrative simplicity / administrative cost of implementation
INNOVATION POTENTIAL	• incentives for innovation • impact on structural flexibility		

Source: author's presentation

A detailed analysis of policy instruments in the field of pesticide use would be beyond the scope of this dissertation. However, an attempt will be made to classify *regulatory instruments*, *moral suasion instruments* and *economic instruments* with respect to their implementation costs, effectiveness in achieving the environmental objective and societal acceptance of pesticide policies. Each group of policy instruments mentioned above comprises a wide range of measures that differ considerably and, in addition, the impact of each instrument is likely to vary depending on the location. Therefore, evaluating policy instruments as a group carries with it the danger of drawing too general a conclusion. Nevertheless, the following discussion is intended to provide a basis for a more refined evaluation.

The implementation costs of *regulatory measures* may vary greatly. Regulatory measures concerning pesticides may be enforced at a low cost if there is a "bottleneck" in the marketing chain. Otherwise their enforcement is likely to be expensive. Banning a pesticide, for example, can be achieved at relatively low cost by controlling pesticide imports and domestic production. If a substance has to be taken off the market quickly the environmental effectiveness of a ban is high[19]. On the other hand, there are regulatory measures which are difficult to enforce because of prohibitively high enforcement costs such as the restriction of pesticide use on specific crops. It is virtually impossible to control every person that applies pesticides. High enforcement costs may create a divergence between what is written in the law and agricultural management practices. If a law is not applied, its environmental effectiveness, of course, is low.

Regardless of whether enforcement costs are high or low, regulatory instruments have strong support in society. They are preferred to economic instruments by most societal groups ranging from polluters to environmental activists. Surprisingly, enforcement costs do not play a major role in public discussion. This is perhaps because if these costs are prohibitively high there already exists a consensus that legal enforcement is not possible. In such cases regulations are normative measures that set theoretical standards without direct practical implications. If the polluter does not obey there is a threat of punishment which, however, is perceived as being rather theoretical.

Such regulations are close *to moral suasion instruments* which appeal to the polluter's awareness. Moral suasion can be executed at a low cost but the environmental effectiveness and implications for efficiency are also rather low. Some persuasive instruments are costly, for example education and extension programmes which are supposed to influence behaviour in the medium and long run. At the same time, educational and extension measures are reckoned to have a greater impact on the polluter and therefore to be more effective than most other moral suasion measures such as simple awareness campaigns. Persuasive measures are not binding and have no immediate implications which may be a reason for their acceptance by many groups within society.

19 Nonetheless, if border controls are relaxed like in the unified European market, the smuggling of pesticides can be a serious problem.

Economic instruments such as taxes in general have low implementation costs and can be effective in reaching environmental objectives if they are designed appropriately. For example, a targeted tax that discourages the use of pesticides that cause high environmental costs would be environmentally effective. In contrast, a flat tax on pesticides is likely to increase the use of cheap pesticides which, in many cases, are more hazardous than the newer, more expensive ones. Hence, an undifferentiated ad valorem tax could lead to an undesirable environmental outcome.

The implementation cost of subsidies may be relatively high, particularly if extensive monitoring is required. This is the case when subsidy schemes are linked to the fulfilment of environmental standards. In spite of these costs subsidies for environmentally sound farming are quite common and accepted in many industrialized countries. Taxes on pesticides, in general, are more controversial, even if their implementation costs are low.

3.3 Pesticide Subsidies and Taxes in Crop Protection Policies

Many governments in the developing world have directly subsidized pesticide use through preferential access to foreign exchange, tax exemptions or reduced rates, preferential credit, and sales below cost by government-controlled distributors. These mechanisms have often been used simultaneously reaching total subsidies of up to 89% of the retail price (REPETTO, 1985).

In the meantime, direct price subsidies for pesticides in developing countries have decreased though not disappeared. Increasing problems with the negative side effects of pesticide use have led to crop protection policies that aim at reducing pesticide use, mostly through the promotion of Integrated Pest Management (IPM) and non-chemical crop protection measures. Today, economic instruments in pesticide policies are referred to as a means to reduce pesticide use. Therefore, this section will concentrate on pesticide taxation.

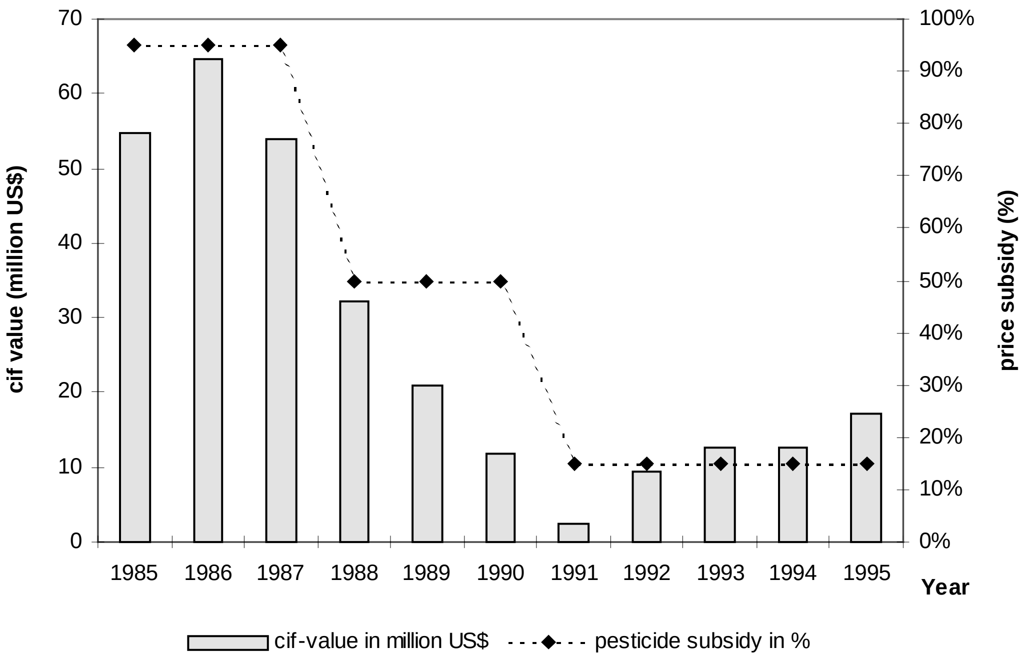
3.3.1 Pesticide Subsidies

Pesticide subsidies were a common tool used to stimulate the adoption of modern agricultural technologies including chemical pesticides. Until the last decade many countries still heavily subsidized pesticide use. REPETTO (1985) studied a sample of nine developing countries (three countries in Africa, Asia and Latin America, respectively), in which price subsidies for pesticides ranged from 15% to 89% of the total retail price. The highest subsidy rates were found in Senegal, Egypt and Indonesia, with 89%, 83% and 82% of the retail cost, respectively. In Latin America, the subsidies ranged between 29% and 44%. FARAH (1993) used the analytical framework developed by WAIBEL (1993) to review pesticide policies in several developing countries on behalf of the World Bank. She found that most of the developing countries reviewed were still providing financial incentives to farmers to use pesticides. At the same time, a number of non-price policies also stimulated pesticide use.

Interestingly, REPETTO (1985) found out that in Honduras, Ecuador and Pakistan "a substantial part of the subsidies provided through government policies is being absorbed by business in high distribution margins, and that these subsidies are not accomplishing their ostensible purpose. Lack of internal competition, import restrictions, and ineffective controls over retail prices make this possible and, indeed, probable."

Nicaragua is a country that under Sandinista rule heavily subsidized pesticide use for its cotton production. When the subsidies were reduced, pesticide imports decreased considerably as shown in Figure 3-6. This was largely due to a breakdown in cotton production in Nicaragua which was highly dependent on pesticide use.

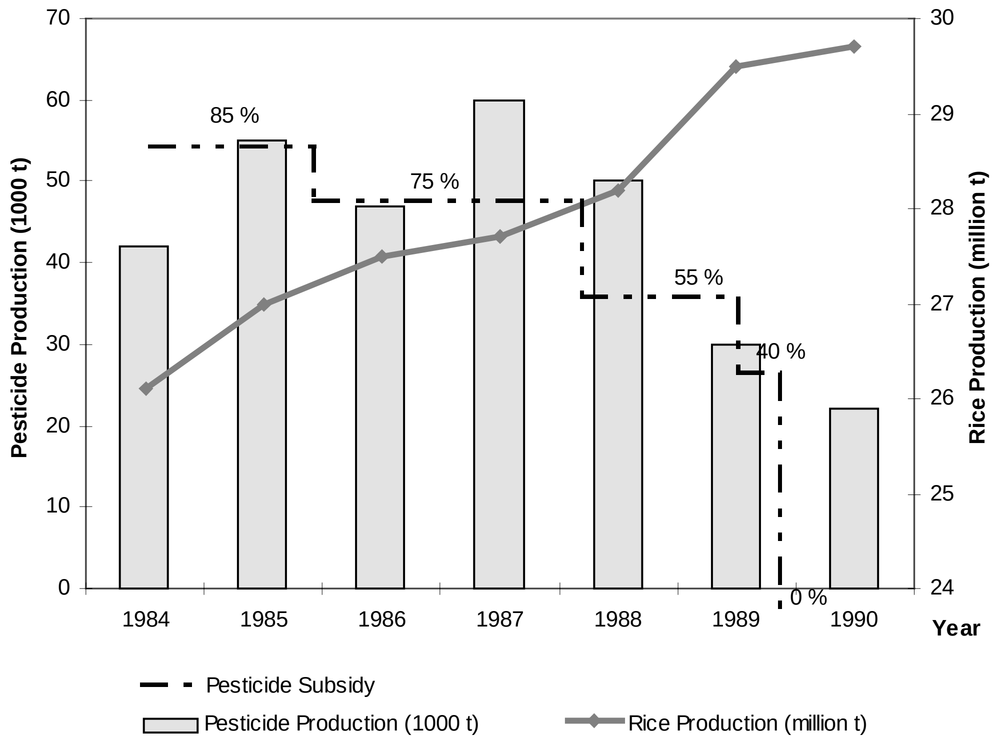
Figure 3-6: CIF-value of pesticide imports to Nicaragua versus pesticide subsidy



Source: BECK, 1996; HRUSKA, Escuela Agrícola Panamericana, Honduras, personal communication

Indonesia is one of the best investigated cases of pesticide subsidization and its impact on pesticide production and agricultural productivity. In 1986, a shift in crop protection policy towards Integrated Pest Management occurred. "Fifty-seven pesticide formulations were banned for use on rice, and a new emphasis was given to field observation and ecological principles. The Finance Ministry responded by gradually reducing, and then eliminating the subsidy on pesticides" (PINCUS, WAIBEL and JUNGBLUTH, 1997). The results of this policy change are shown in Figure 3-7. With the elimination of the subsidy, pesticide production declined dramatically, while rice production was unaffected. In addition to secure food production and the reduction in pesticide application, the government saved an estimated 100 million US$ per year that had previously been spent on the pesticide subsidy (PINCUS, WAIBEL and JUNGBLUTH, 1997).

Figure 3-7: Pesticide Subsidy, Pesticide Production and Rice Production in Indonesia (1984-1990)



Source: after KENMORE, 1991, and PINCUS, WAIBEL and JUNGBLUTH, 1997

3.3.2 Pesticide Taxation

Pesticide taxation is an economic instrument that has only more recently been introduced to pesticide policies. Although taxation has been discussed on many occasions, it has only been implemented in a few countries so far. This section gives a short review of pesticide taxation in several European countries and in India.

3.3.2.1 Pesticide Taxation in European Countries

Three European countries, namely Denmark, Norway and Sweden have introduced pesticide taxes as a component of their national pesticide use reduction plans. Those plans comprise a tool kit of various measures which can be classified as follows:

First, there are *pesticide use restrictions* which mainly aim at reducing the risk and increasing the efficiency of pesticide applications. For example, there are regulations on regular spray equipment inspection and certification programmes.

Second, all three pesticide use reduction programmes enhance the support of *research* and *education* which are considered key components of the reduction plans. In particular the following measures are promoted:

- field trials, courses and demonstrations,
- information campaigns promoting pesticide use reduction and non-chemical methods,
- new, often mandatory, training and education programmes for farmers,
- establishment of regional centres and advisory services to provide forecasting systems and advice in integrated pest control strategies,
- research on resistant varieties, biological control, integrated methods, and other ways to reduce pesticide use.

Third, *economic instruments* are applied as financial incentives to pesticide use reduction. Economic instruments include financial support for farmers making the transition to integrated or organic production, and also taxes on pesticides. The design of the tax schemes as well as the destination of the tax proceeds are summarized in the following table:

Table 3-2: Pesticide taxation in Denmark, Norway and Sweden

	DENMARK	NORWAY	SWEDEN
TAXATION	• a) 35% tax on insecticides and soil disinfectants* • b) 25% tax on herbicides, fungicides, repellents and growth regulators*	• 6% control tax • 13% environmental tax	• SKr 20 (US$ 2.7) environmental levy per kilogram of active ingredient
TAX PROCEEDS	• 80% of the revenues are returned to the farmers through reduced land taxes. • 20% are used to cover research and registration costs.	• No refund. • Control tax proceeds are used for registration and monitoring of pesticide dealers (since 1992). • Environmental tax proceeds fund the national pesticide use reduction programme.	• No refund.

* These tax rates have been valid since 1 November 1998 by Act no. 417 of 26 June 1998. Before November 1998 the tax rates for a) and b) were 27% and 13%, respectively (Act no. 416 of 14 June 1995).

Source: author's presentation based on OECD (1996a+b) and Mai Bjerg, Danish EPA, personal communication

Norway charges a uniform tax on all pesticides which, from an environmental and economic point of view, is not optimal. Ideally, the tax rate should rather be differentiated according to the degree of hazard of a pesticide. Sweden imposes a fixed tax per quantity of active ingredient. This scheme favours low dosage pesticides, which in general are less harmful to the environment. Denmark applies a higher tax rate to insecticides and soil disinfectants than to the other pesticides. Curiously, it was not the potential environmental damage that guided the Danish decision on differentiated taxes but the per hectare application costs which in Denmark on average are lowest for insecticides and soil disinfectants. The tax applied in Denmark was designed as to increase application costs at the same absolute amount for the different types of pesticides.

Although none of these tax regimes are optimal from an environmental point of view, they are interesting examples. The Danish case is particularly interesting, because relatively high tax rates are applied which to a large extent are returned to the farmer in the form of lower land taxes.

3.3.2.2 Pesticide Taxation in India[20]

In many developing countries the exemption of pesticides from duties and taxes is a common practice. In contrast, India, a country that also has an important agricultural sector, does not give preferential treatment to pesticides[21]. In India, pesticides are subject to an approximately 10% excise duty at the factory gate. These tax revenues are shared between the central and state governments based on criteria set by the Finance Commission. The utilization of the tax proceeds is based on the priorities set by the respective governments, which means that the taxes are not necessarily reinvested in the agricultural sector.

In addition to the excise tax collected at the processing plants, local sales taxes may be applied to pesticides, depending on the specific regional regulations. Local sales taxes vary from state to state. Unlike the excise duty, the local sales taxes are utilized exclusively by the respective state government according to its priorities.

3.3.3 Options for the Design of Pesticide Taxes

This section presents various possiblities for pesticide taxation and their likely impact on pesticide use. The design of a pesticide tax depends on the relative importance of the different objectives of the instrument; whether the main aim is to reduce overall pesticide use, to reduce the use of particular products, to raise revenue to fund other expenditures on pesticide reduction, or a combination of these objectives (RAYMENT, BARTRAM and CURTOYS, 1998). As pointed out in Section 3.2.3, the design of a tax should consider environmental effectiveness, economic efficiency, administrative efficiency, equity and any possible side-effects or adverse impacts.

A pesticide tax may be based on sales value, dosage, weight of active ingredient or differentiated according to the environmental impact of different products. All approaches have their advantages and disadvantages. Value-based taxes are more easily administered but may also encourage the use of cheaper products that are often more hazardous, since the price of pesticides is not proportional to environmental impact. Taxes based on the weight or volume of active ingredient can encourage the use of products which require lower weight/volume of active ingredient to achieve a given biological effect, and are therefore more toxic per unit weight/volume (RAYMENT, BARTRAM and

[20] Venugopal Pingali, Centre for Rural Management at XLRI, Jamshedpur, India, personal communication

[21] However, India subsidizes fertilizer production in order to reach self-sufficiency.

CURTOYS, 1998). In conclusion, the approaches discussed so far are not satisfactory.

If reliable data on standard doses of different products can be developed, taxes based on a rate per dose (measured on the basis of the active ingredient) could be an effective means of taxing overall applications without distorting usage patterns. From an economic point of view differentiated taxes based on an environmental hazard index would be preferable, because they would internalize external costs and at the same time encourage a shift to more benign products. The evaluation of the environmental impact could be done following approaches such as the environmental yardstick which was developed in the Netherlands (REUS, 1998). Such a tax is more complex to design and administer, in the first place, because more data on the external costs associated with individual pesticides are needed and at present are not available. However, concurrent with the process of collecting these data, the World Health Organization's (WHO) toxicity classification for pesticides or similar data such as hospital records of pesticide poisonings could be used as a starting point for the classification of pesticides according to their toxicity.

Taxes could be collected at the point of sale. In order to improve acceptance in the farming sector a reinvestment of the tax proceeds in the agricultural sector could be considered.

3.3.4 Conclusions

This brief review reveals that subsidies have been used frequently in pesticide policies while taxes have only recently been introduced in some countries. In the course of the Green Revolution, pesticide use has been encouraged through a range of direct price subsidies and complementary measures. Rising concerns about the environmental effects of indiscriminate pesticide use have changed crop protection policies in many countries. A number of governments have reduced or eliminated price subsidies for pesticides to reduce pesticide use to socially acceptable levels. However, in their survey on pesticide use in 22 developing countries, WAIBEL and FLEISCHER (1993) found that 4 of the countries surveyed still subsidized pesticide prices. The price subsidy in these countries accounted for 10% to 40% of the market price.

FLEISCHER and WAIBEL (1993) further showed that 6 developing countries applied taxes on pesticide imports ranging from 5% to 37%. As in the case of India there is a demonstrated scope for pesticide taxes in developing countries, particularly when the revenues are reinvested in the agricultural sector. If the tax revenues are used to reduce the burden on those directly affected by the tax, societal acceptance and the political feasibility of pesticide taxation can be expected to increase.

Environmental taxes on pesticides are likely to be more effective in reducing pesticide use when used in concert with other measures. Research and extension in non-chemical crop protection measures as well as further regulation of pesticide use are additional measures that have been used in some European countries.

4 The Neoclassical Theory of Production and Pesticide Use

The discourse in Chapter 3 has made explicit that environmental taxes, if used appropriately, can be efficient policy instruments because they internalize external effects and give incentives for the development of environmentally sound crop protection. This conclusion leads to the following question: How would a pesticide tax affect pesticide use and farm income?

Chapter 4 presents the neoclassical approach to the analysis of production with an emphasis on pesticide use. The strengths and weaknesses of neoclassical decision models are discussed and the question is raised as to whether these models represent a suitable basis for the analysis of pesticide demand in Costa Rica's coffee production. This chapter provides the theoretical foundations for the empirical results presented in Chapters 6 to 8.

4.1 Producer Behaviour in Pest Management - a Neoclassical Perspective

Neoclassical decision models for pesticide use in agriculture are briefly discussed in this section emphasizing the specific features of pesticide use. First, a simple decision model for pesticide use is formulated based on the neoclassical static optimization framework. Then the standard model is extended to take account of the specific nature of crop protection inputs. The decision on pesticide use is related to infestation pressure, a pest damage function and the efficacy of the specific pesticides. Furthermore, the dynamic aspects of pesticide use are discussed.

4.1.1 The Neoclassical Standard Optimization Model

4.1.1.1 Optimal Input Use and the Technical Rate of Substitution

For the purpose of this study, a farm is defined as producing a single output[22] *y* at a known price *p*. The production process uses flows of fixed and variable inputs **x** which are purchased at prices **w**. The production function is defined as $y = f(\mathbf{x})$ where *y* is a single output and **x** is a vector of fixed and variable inputs. The production function has the properties of a positive, nonincreasing marginal product from the inputs **x** (HOWITT and TAYLOR, 1993).

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22 For coffee production in Costa Rica, this is a realistic assumption because coffee is usually grown as a monoculture. Since coffee is a perennial crop, cropping patterns hardly vary in the short run.

(4-1) $\frac{\partial f(\mathbf{x})}{\partial x_i} > 0$ and $\frac{\partial^2 f(\mathbf{x})}{\partial x_i^{\ 2}}$

The farm's direct profit function Π can be defined as:

(4-2) $\Pi = pf(\mathbf{x}) - \mathbf{wx}$

where **w** is a vector of factor prices. A profit-maximizing farmer will use each factor x_i until its price w_i equals the marginal value product:

(4-3) $\frac{\partial \Pi}{\partial x_i} = 0$ implies that

(4-4) $p\frac{\partial f(x)}{\partial x_i} = w_i$

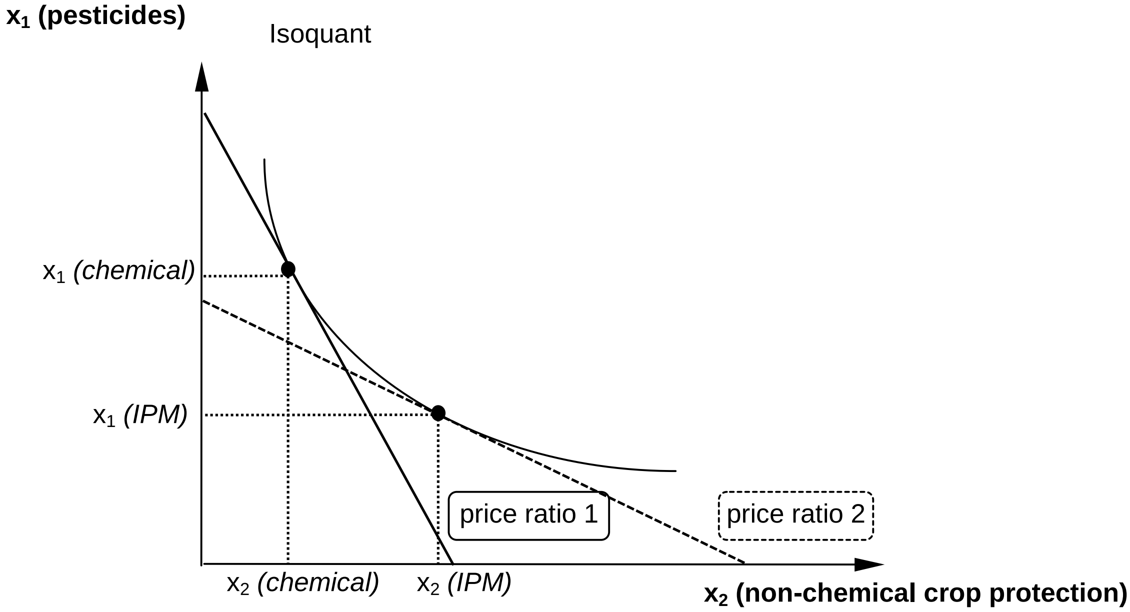
It is assumed that all input levels can be controlled and that the profit maximization conditions (4-4) hold simultaneously for all inputs. Furthermore, it is understood that inputs are available to the farmer at prices **w** sufficient to enable the farmer to use them until the price of a factor (i.e. its per unit cost) equals its value marginal product. Hence, the productivity and the demand of an input are closely related: the demand curve of a factor is identical to its marginal value productivity curve.

The neoclassical marginality conditions underlie most quantitative analyses of production. Rearranging equation (4-4) for the two factor case gives that the rate of technical substitution between two factors is equal to the ratio of their prices:

(4-5) $$\frac{\dfrac{\partial f(x_1, x_2)}{\partial x_1}}{\dfrac{\partial f(x_1, x_2)}{\partial x_2}} = \frac{w_1}{w_2} = -\frac{\partial x_2}{\partial x_1}$$

The concept of factor substitution is particularly important for this research because it is hypothesized that chemical pesticides to some extent can be substituted by other production factors, e.g. by labour. Figure 4-1 illustrates the technical rate of substitution between two different crop protection technologies.

Figure 4-1: The rate of technical substitution between pesticides and non-chemical measures for crop protection



Source: author's presentation

There are two factors or factor-bundles to produce a given output. X_1 represents the chemical-based crop protection technology, while x_2 represents non-chemical crop protection. Depending on the prices of each technology, different quantities of the respective factors are used. Price ratio 1 ($-w_2/w_1$) favours the use of pesticides. An increase in pesticide prices, a decrease in prices for non-chemical crop protection measures or simultaneous changes may lead to price ratio 2, which implies an increased use of non-chemical crop protection. "IPM" is an integrated pest management strategy, while "chemical" refers to chemical pesticide based crop protection.

This figure shows that if a factor can be substituted, price ratios play an important role in the decision on input use.

4.1.1.2 The Dual Approach to Applied Production Analysis

The dual approach to production economics is particularly suited for the analysis of a pesticide tax on input use, because it uses prices as exogenous variables to define a production technology. The key to derive dual functional forms from primal production functions is the profit maximization criteria. Theoretically, a correspondence between the production function and the profit function may be established for any functional form. However, for complex functional forms this correspondence is complicated and, as stated by SADOULET and DE JANVRY (1995), may not always be established analytically.

Therefore, the Cobb-Douglas production function, which is easy to handle, is used to exemplify how a dual profit function can be derived. In production economics, the Cobb-Douglas production function has been used frequently because of its computational ease. However, it is very restrictive as regards the functional relationship between the exogenous and the endogenous variables. For example, the Cobb-Douglas function in its standard form restricts the elasticity of substitution to one for any combination of inputs.

As outlined in SADOULET and DE JANVRY (1995), the primal Cobb-Douglas production function, $q = ax^{\alpha} z^{\beta}$, and its primal profit function, $\Pi = pax^{\alpha} z^{\beta} - wx$, may be transformed into a dual profit function by applying the profit maximization criteria. Profit maximization is given by the first-order condition:

(4-6) $$\frac{\partial \Pi}{\partial x} = pa\alpha x^{\alpha-1} z^{\beta} - w \equiv 0$$

where; q is the output; x is a variable input; z is a fixed factor; Π is the profit; p is the output price; w is the input price; α and β are parameters that specify the partial productivity of each input. Transforming this equation yields the optimum level of input use:

$$x_{opt} = \left(a\alpha z^{\beta} \frac{p}{w} \right)^{\frac{1}{1-\alpha}}$$

Substituting x_{opt} into the production function yields the supply function (= optimum level of output):

$$q = a^{\frac{1}{1-\alpha}} \left(\alpha \frac{p}{w} \right)^{\frac{\alpha}{1-\alpha}} z^{\frac{\beta}{1-\alpha}}$$

Substituting both x_{opt} and the supply function to the primal profit function gives the dual profit function:

$$\Pi = a^{\frac{1}{1-\alpha}} \alpha^{\frac{\alpha}{1-\alpha}} (1-\alpha) z^{\frac{\beta}{1-\alpha}} p^{\frac{1}{1-\alpha}} w^{\frac{-\alpha}{1-\alpha}}$$

Hence, primal and dual functions are connected through the profit maximization criteria. In other words, the profit function is the mathematical representation of the solution to an economic agent's optimization problem (CHAMBERS, 1988).

4.1.1.3 The Profit Function and Derived Supply and Factor Demand Functions

A dual profit function $\Pi(\mathbf{p},\mathbf{w})$ is homogenous of degree one in all prices and has the following properties (CHAMBERS, 1988):

1. $\Pi(p,w) \geq 0$;
2. if $p^1 \geq p^2$, then $\Pi(p^1,w) \geq \Pi(p^2,w)$ (nondecreasing in p);
3. if $w^1 \geq w^2$, then $\Pi(p,w^1) \leq \Pi(p,w^2)$ (nonincreasing in w)
4. $\Pi(p,w)$ is convex and continuous in (p,w) ; and
5. $\Pi(tp,tw) = t\Pi(p,w)$, $t > 0$ (positive linear homogeneity);

where Π is the profit, **p** is a vector of output prices and **w** is a vector of input prices. Most of these properties are self-evident. Further elaboration of them can be found in CHAMBERS (1988).

Two interesting properties of the profit function are important for this research: its derivative with respect to the price of a product is equal to the supply function of that product; and its derivative with respect to the price of an input is equal to the negative of the demand function of that input. This relationship, known as Hotelling's Lemma, "is proved by differentiating the profit function and taking advantage of the first-order conditions of the maximization problem" (SADOULET and DE JANVRY, 1995).

(4-7) $$\frac{\partial \Pi}{\partial p_i}(\mathbf{p},\mathbf{w},\mathbf{z}) = y_i \quad \text{and} \quad \frac{\partial \Pi}{\partial w_i}(\mathbf{p},\mathbf{w},\mathbf{z}) = -x_i$$

These output supply and input demand functions are homogenous of degree zero in all prices and, if production display constant returns to scale, homogenous of degree one in all fixed factors. Furthermore, the second-order derivatives of the profit function are symmetric which implies that (SADOULET and DE JANVRY, 1995):

$$\frac{\partial y_i}{\partial p_j} = \frac{\partial y_j}{\partial p_i} \quad \text{and} \quad \frac{\partial x_i}{\partial w_j} = \frac{\partial x_j}{\partial w_i}$$

4.1.1.4 Flexible Functional Forms

"In specifying functional forms for applied production analysis, it is advantageous to have estimable relationships that place relatively few prior restrictions on the technology. To some extent, the last sentence is self-contradictory since specifying an estimable form that does not restrict the technology is usually difficult (if not impossible). Estimability typically implies a choice of form, and once the form is parameterized in accordance with received economic theory (homogeneity, convexity, etc.), duality guarantees the existence of a unique dual function." (CHAMBERS, 1988)

Various authors have defined flexible forms as functions that are able to closely approximate arbitrary technologies in a particular point. CHAMBERS (1988) states that it is not useful to think of a general linear form in terms of approximating the unknown, but true, structure because flexible forms do not have this property. He further argues that it seems more productive to recognize that estimation requires the specification of some functional form and that the most likely contribution of the flexible forms "lies not in their approximation properties but in the fact that they apparently place far fewer restrictions prior to estimation than the more traditional Leontief, Cobb-Douglas, and CES technologies. In most instances, they let measures like the elasticity of size and elasticities of substitution depend on the data. Hence, they can vary across the sample and need not be parametric as they are for most of the more traditional forms."

4.1.2 The Special Nature of Crop Protection Inputs and the Analysis of Pesticide Productivity

In neoclassical models, the productivity of and demand for an input are closely related. As pointed out in Section 4.1.1, a profit-maximizing farmer will use each factor x_i until its price w_i equals the marginal value product (see equation 4-4). Hence, as long as a factor's marginal productivity is positive, it is profitable to increase the use of this factor.

However, pesticides and other damage control inputs are different from standard inputs. The assessment of pesticide productivity is difficult, because pesticides do not increase output but help to realize a bigger proportion of the potential yield. The magnitude of this increase, i.e. the marginal productivity of pesticides, depends on a wide range of factors that are usually not taken into account in production function analyses. Such factors include infestation pressure, epidemiology of a pest and of the damage caused by an individual pest (CARLSON and WETZSTEIN, 1993). This section presents approaches that to some extent take account of the specific nature of pesticides.

4.1.2.1 Models that Take Account of the Specificity of Pesticides

Decision models on optimal input use extend the usual decision framework by incorporating various sources of information such as pest density, potential crop loss and efficacy of a pesticide. These *economic threshold models* are short-term decision models which help to decide on pest management measures within a crop. Pesticide use is recommended when crop loss without treatment is more costly than a pesticide application. Economic thresholds neglect long term cropping strategies to avoid pest incidence such as the adjustment of the cropping pattern. Economic thresholds are derived through partial analyses assuming that a crop protection measure has no influence on other production costs.

The economic threshold decision model recognizes the importance of potential crop loss in the farmer's decision to use a pesticide. HEADLEY (1972) introduced the concept of marginal pest control costs, marginal pest damage, and timing of the pest damage. HALL and NORGAARD (1974) further divided the threshold problem into determining both the optimal time and the optimal dosage of a treatment (quoted in CARLSON and WETZSTEIN, 1993).

The simplest version of the economic threshold models distinguishes a treat and a not-treat option. The decision whether or not to apply a pesticide depends on the treatment cost, the expected product price *(p)*, the expected yield without crop loss *(A)*, the level of infestation *(N)*, the crop damage per pest unit *(a)* and on the efficacy of the pesticide *(b)* which is measured in percent reduction in pest number per treatment (CARLSON and WETZSTEIN, 1993). Hence, the model includes important components in a two-stage process: the pesticide kill rate *b*, and the resulting reduction of pest levels which has an effect on the yield. This separation is important for economic and statistical reasons (LICHTENBERG and ZILBERMAN, 1986).

Setting all other production costs constant, profit without treatment can be written as

(4-8) $$\Pi = p(A - aN) - \mathbf{wx}$$

where **wx** stands for all other production costs. N is the pre-treatment pest density. Profits with treatment are:

(4-9) $$\Pi = p[A - a(1-b)N] - r - \mathbf{wx}$$

in which *r* is the cost of the crop protection measure including material and application costs.

The threshold pest population *(N^*)* is found by equating (4-8) and (4-9) and solving for N^*:

(4-10) $$N^* = \frac{r}{pab}$$

At N^* the marginal value of crop saved *($pabN^*$)* is equal to the treatment cost *(r)*. This concept is able to model (include) pest control action at different infestation levels with, in the case of pesticide application, different levels of dosage per hectare as requested by WAIBEL (1986).

Up to now a linear relationship between pest density and crop loss has been assumed, which is a simplification of the actual situation. MARRA and CARLSON (1983) state that "damage per pest (a) usually differs by crop stage and may not remain constant over pest densities. Pesticide efficacy (b) can change with the stage of development of the pest or under various weather conditions. Also, potential yield and future pest densities for the season may not be known at the time the pesticide use decision must be made. These complications may make threshold estimates impractical. However, slight elaborations of (4-10) with sensitivity analysis for changes in economic and biological parameters may provide useful starting points for recommendations, especially for weeds and some insects (TALPAZ and FRISBIE, 1975)".

The threshold model poses additional problems when several pests occur simultaneously because the sum of damage thresholds computed for individual pests may not be equal to the damage caused by two or more pests at the same time. Therefore a "common" damage function that considers the interaction of the considered pests has to be estimated, e.g. in a multiple regression (WAIBEL, 1986):

(4-11) $Y = A - a_1 N_1 - a_2 N_2 \pm a_3 N_1 N_2$, where *Y* stands for actual yield.

In terms of the above specified profit function this relationship yields:

(4-12) $$\Pi = p[A - (a_1 N_1 + a_2 N_2 \pm a_3 N_1 N_2)] - \mathbf{wx}$$

Pesticides may affect beneficials and provoke the expansion of a secondary pest. The effect of pesticide use on a target pest, its effect on a beneficial, subsequent build-up of a secondary pest and the pesticides required to control the secondary pest may be modelled in a simultaneous optimization framework (CARLSON and WETZSTEIN, 1993). The more pests, pest control options and secondary effects are included in the model the more data is required for modelling. In many cases the data needed are not available.

The data required for threshold models are usually obtained at agricultural research stations where production conditions differ from those in the field. In particular, potential yield *(A)*, the probability of infestation and pest epidemiology may vary greatly within a region and between farms. Furthermore, management practices such as selection of a variety, fertilization, and cultural measures influence the pest pressure (THURSTON, 1992).

More generally speaking, the question is whether or not pest threshold models can help the farmer to make a right decision. Threshold models may orient the farmers and serve as a basis for on-farm trials. There are situations in which threshold models can go beyond that, but it has to be kept in mind that even complex models can hardly take account of all interactions and biological processes that occur in a specific field. Even when multiple infestation and secondary effects on beneficials are treated in economic threshold models, they remain incomplete because the dynamic effects of pesticide use such as the increase of pesticide resistance - which is not evident ex ante - are not included. TÜTTINGHOFF (1991) reached the conclusion that for Thai rice farmers the threshold concept as it used to be applied was not a suitable decision aid. In general, these farmers did not base their decision on the infestation level with a single pest but on pest complexes, i.e. on the occurrence of all the pests observed in the field.

Hence, it can be concluded that actual pesticide use may only partly be explained by economic decision models. Even sophisticated models developed to support the farmer's decision-making have their limitations[23].

4.1.2.2 A Literature Review on Pesticide Productivity

An economic threshold model that incorporates profit, yield, and abatement functions is biologically more realistic, but requires a simultaneous determination of pest control intensity and pest density (MOFFITT, BURROWS, BARITELLE, and SEVACHERIAN, 1984). This approach allows to determine:

[23] Nevertheless, DUBGAARD (1991) has used a linear programming based threshold model to derive the own-price elasticity of pesticides.

(4-13) $\Pi = py - rz - F$ (returns net of pest management costs)

(4-14) $y = A - an$ (yield function)

(4-15) $n = Ne^{-bz}$ (abatement or kill function)

where y and z are output and pest management (or pesticide) input. This approach allows the calculation of different optimal pesticide dosages for each possible pre-treatment pest level *(N)* (CARLSON and WETZSTEIN, 1993). Various functional forms may be considered as abatement functions (LICHTENBERG and ZILBERMAN, 1986) depending on the data from experimental trials. LICHTENBERG and ZILBERMAN (1986) state that the standard production function specifications overestimate damage control agent productivity. They found "overwhelming consensus opinion of the theoretical, normative, empirical, and casual empirical studies [...] concerning pesticide use [...] that pesticides are overused rather than underutilized as the econometric literature suggests". In order to obtain better estimates of pesticide productivity they suggest the incorporation of a damage abatement function in standard production functions. In their analysis, an exponential abatement function considerably improved the pesticide productivity assessment.

CARRASCO-TAUBER and MOFFIT (1992) used the LICHTENBERG-ZILBERMAN framework to analyse 1987 cross-sectional data. The objective of their analysis was to find out if the inclusion of an abatement function in the Cobb-Douglas production function as used by HEADLEY (1968) could help to improve estimates on pesticide productivity, i.e. to achieve lower econometric estimates of pesticide productivity that correspond better with the empirical findings mentioned above. CARRASCO-TAUBER and MOFFIT compared four different specifications of the abatement function (Cobb-Douglas, Weibull, logistic and exponential). Estimates of marginal pesticide productivity varied between 0.11 (exponential function) and 7.53 (logistic function) as compared to 5.94 for the Cobb-Douglas case. The exponential specification was the only one that yielded a lower estimate of marginal pesticide productivity than the Cobb-Douglas technology. In fact, the exponential specification suggested that the marginal productivity of pesticides is negative, i.e. that pesticides are overused. However, the statistical evaluation of the four functional forms provided little support for the exponential specification. The authors concluded that the "explanation of the magnitude of the pesticide productivity estimate obtained by HEADLEY seems to lie somewhere other than with the functional specification of damage control in his econometric model". It is probable that the functional form of the production function itself plays an important role.

CHAMBERS and LICHTENBERG (1994) developed a dual representation of the LICHTENBERG-ZILBERMAN (1986) damage control technology which allowed a considerable increase in the ability to model the production technology flexibly. CARPENTIER and WEAVER (1997) estimated pesticide productivity in French cereal production based on the LICHTENBERG-ZILBERMAN (1986) approach. The estimates presented in both papers indicated a smaller marginal productivity of pesticides than reported by past studies. SAHA, SHUMWAY and HAVENNER (1997) showed that misspecification of the stochastic element in the production function can lead to overestimates of the marginal physical productivity of pesticides and to gross underestimates of the responsiveness of demand to increases in pesticide prices.

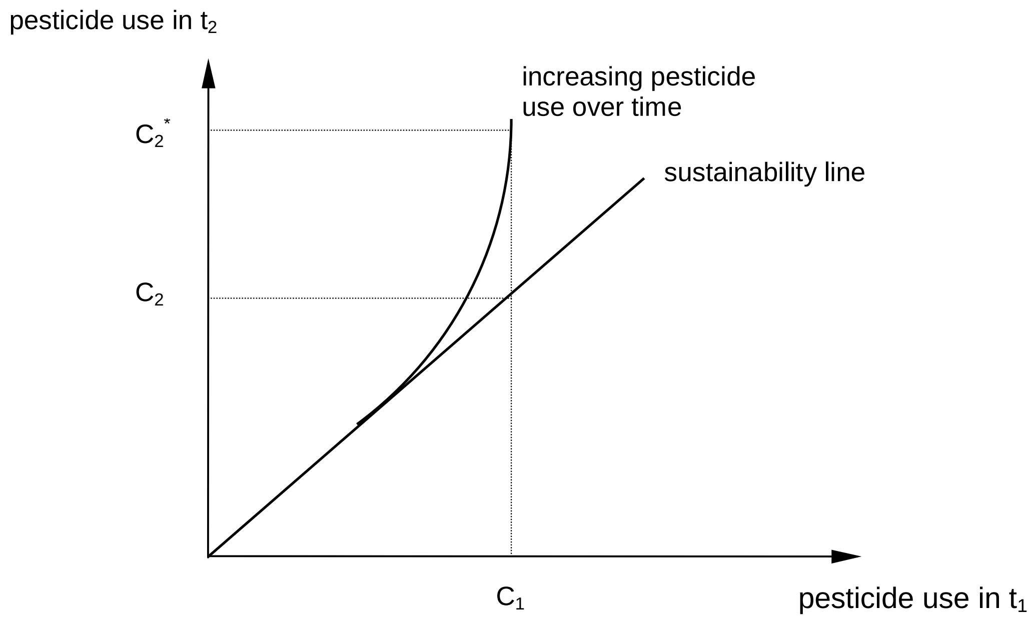
Aside from the econometric analysis there are numerous other approaches to estimate pesticide productivity. In many cases, research station experiments are used to assess the productivity of a pesticide by comparing a treated plot with an untreated plot. The productivity of pesticides measured in such trials in general is lower than econometric estimates of pesticide productivity. However, trials at research stations most likely still overestimate pesticide productivity because they do not take account of non-chemical pest control options which might be used instead of a pesticide. Hence, the reference "no treatment scenarios" in classic research station trials do not consider the possibility that pesticides may be at least partly substituted by non-chemical crop protection.

4.1.3 Dynamic Considerations

Pest management decisions in a production period may have an influence on pest management options in subsequent periods. This becomes very clear in the case of pesticide resistance. Once a pest has developed resistance to a pesticide, it is necessary to increase the dosage per hectare, to use other pesticides or to switch to other crop protection measures, in general at an increased cost. If a farmer wishes to maximize long-term profits he has to take into account these additional costs. In fact, the economic preconditions for a control measure remain the same irrespective of whether a single or a multi-period approach is used. In the multi-period decision situation, the entire planning period would be considered and the strategy resulting in the maximum discounted overall returns would be chosen (WAIBEL, 1986). The discount rate applied depends on the individual's preferences and on the intertemporal production possibility curve (ZILBERMAN, WETZSTEIN and MARRA, 1993).

WAIBEL and SETBOONSARNG (1993) show that increasing depletion of beneficial organisms and monocropping stimulates pest development and increases the probability of pest attack and augments the dependence on pesticides. A high level of pesticide use in a set period may further increase pesticide use in the subsequent period as shown in Figure 4-2. The sustainability line defines levels of pesticide use that do not lead to resistance resource depletion and therefore remain stable over time (C_2=C_1). In contrast, unsustainable pesticide use will provoke resistance build-up or decrease the population of beneficials which in turn makes higher dosages necessary in the following period (C_2^*=C_1).

Figure 4-2: The resource costs of pesticide use



where C_1 is pesticide use in period 1, C_2 is pesticide use in period 2 under sustainable conditions and C_2^* represents pesticide use in period 2 when the dosage per ha has to be increased

Source: after WAIBEL and SETBOONSARNG (1993)

This leads to a situation where the use of pesticides appears to become more economical over time. Due to an increase in both the probability of pest attack and average pest population levels, the yield difference between 'treated' and 'untreated' plots increases. This difference is further augmented by technological progress which increases the crop's yield potential. On the other hand, increasing resistance to pesticides causes the costs of control to increase as well because the pesticide dosage levels have to be adjusted upward. However, as long as the difference in revenues rises faster than the cost of control, pesticide use will continue to increase. This process is stopped when the gross margin of the current crop falls below the gross margin of an alternative, less pesticide intensive crop (WAIBEL and SETBOONSARNG, 1993).

ARCHIBALD (1988) studied pesticide productivity in cotton production with and without taking account of pesticide resistance. Results from an econometric model suggest that excluding the costs of resistance in cotton pest control, the returns to a dollar invested in chemical insecticides equal 3.5 dollars. The competing IPM-technology in cotton (including chemical use at lower levels) produced a lower short-term return to the individual producer of US$ 2.5 per dollar invested. However, in a dynamic model that internalizes the costs of pesticide resistance the producer returns to chemical pest control drop to one dollar for every dollar invested.

FLEISCHER (1998) showed that continuous atrazine applications in intensive maize cropping systems, have led to a considerable increase in weed control costs and, in addition, to water contamination. Resource costs were estimated at between DM 211 and DM 470 per ha, depending on the extent of atrazine use.

4.2 Approaches to Explain Suboptimal Behaviour of Farmers

4.2.1 Uncertainty in Pest Management and Risk Aversion

Production risk and the farmer's risk attitude have received a lot of attention in the literature on the economics of pest control in agriculture. In his literature overview, PANNELL (1991) states that there is "widespread consensus [...] that, in many circumstances, risk considerations influence pesticide use". A risk neutral farmer would maximize expected utility - which for this analysis is equal to the expected profit - irrespective of the variability of profits. A risk averse farmer would sacrify a part of the expected profit for less income variation. An extreme case of risk aversion is the maximization of the minimum profit under uncertainty (maximin criterion).

Uncertainty has often been defined as an event with unknown probabilities while risk has been characterized by random events with known probabilities (e.g. BRANDES and ODENING, 1992). According to ANTLE (1988) "modern decision theory makes this distinction unnecessary by assuming that individuals have subjective beliefs about the distributions they are choosing. The 'subjective' distributions need not correspond to the objective ones. It is often argued that decision makers learn over time about the objective distributions which generate observed phenomena, and that they update their subjective beliefs over time according to their observations." Following this reasoning, risk and uncertainty are used as synonyms in this section.

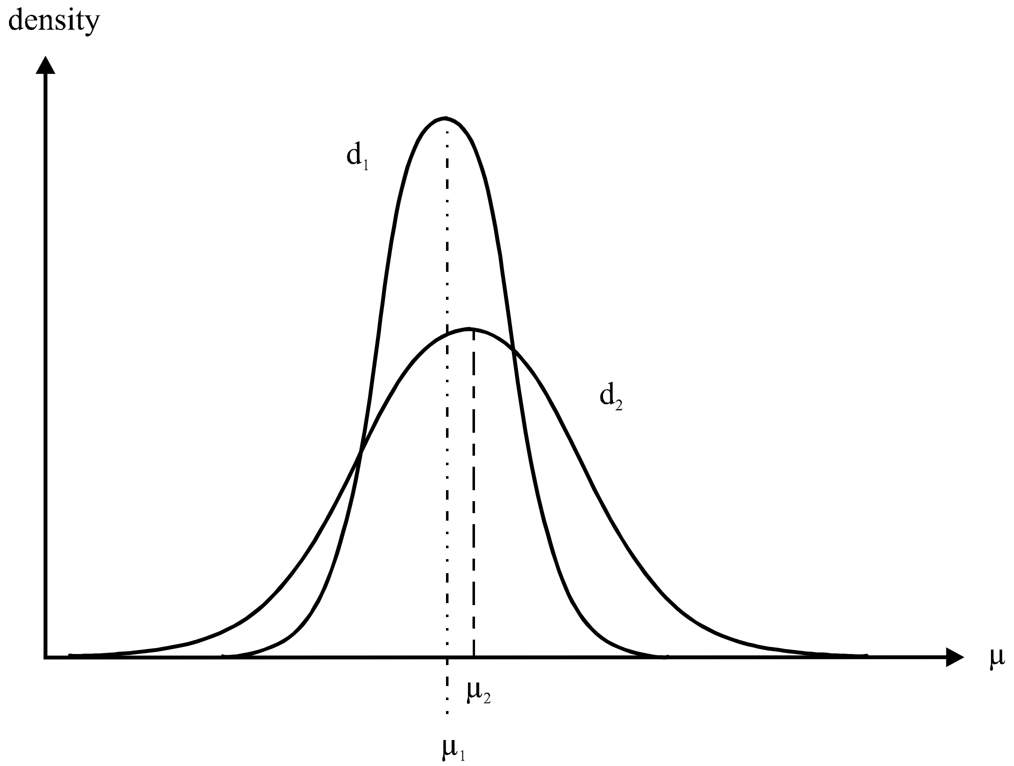
Most authors find that farmers are risk averse and that pesticide use reduces risk so that if risk is included in a model, risk aversion will cause the optimal treatment rate to increase (PANNELL, 1991). For example, FEDER (1979 developed the following model for risk averse farmers:

(16) $$\underset{z}{Max}\, EU\{(\Pi) - aN[1-k(z)] - rz\}$$

where *E* denotes the expectations operator, *U(·)* is a concave utility function from a risk averse agent, Π denotes profits realized if no pests were present, *a* represents the damage caused by a single pest, and *N[1-k(z)]* represents the damage function where *k(z)* is the kill function.

FEDER (1979) argues that risk averse farmers prefer crop protection strategies which guarantee a low variability of yields even if the expected value of yields of such a strategy is below a competing strategy with higher yield variations. Figure 4-3 illustrates two distributions d_1 and d_2. The distribution d_2 has higher average returns than d_1, but also a higher mean variation. Hence, a risk averse farm may prefer the distribution d_1 although average returns μ_1 are lower than μ_2.

Figure 4-3: Distribution of net returns of two different crop protection technologies



Source: after FEDER (1979)

According to CARLSON and WETZSTEIN (1993) the critical assumption in this model is that pesticides have to be applied prior to knowing random variables such as the pest level *(N)*. In fact, the conclusion that pesticides are risk reducing inputs is mainly based on analyses which only consider uncertainty about the level of pest infestation or chemical efficacy. But there are numerous other sources of uncertainty in the pest/pesticide/crop system which may or may not result in reduced risk as pesticide use is increased (PANNELL, 1991). The threshold model introduced in chapter 3.1, for example, contains various stochastic parameters. Recall equation (4-9):

$$\Pi = p[A - a(1-b)N] - r - \mathbf{wx}\,.$$

On unregulated agricultural markets the output price *p* of agricultural commodities is variable; price fluctuations are particularly pronounced in the coffee market. Furthermore, the pest-free yield *A*, the damage caused by a pest individual *a*, the pesticide kill rate *b* and the pest density *N* are also likely to be uncertain. PANNELL (1991) concludes that for some sources of uncertainty such as pest density, yield loss per pest and pesticide effectiveness, pesticide application acts to reduce risk. For other factors like the output price, the pest-free crop yield or the damage of pesticide applications to crops, pesticide application may increase risk. Hence, "the validity of the usual assumption that pesticides reduce risk depends on the relative importance of these different sources of uncertainty" (PANNEL, 1991).

In the light of the highly variable output prices in coffee production it is not clear if pesticides can be considered as a risk reducing, risk neutral or even risk increasing input in this crop.

4.2.2 Path Dependence

The farmer's decision on the best crop protection strategy may be influenced by several factors among which path dependence is likely to be an important one. Over the last decades chemical crop protection has become the dominating crop protection method. COWAN and GUNBY (1996) argue that this trend has been self-reinforcing and led to a locked-in situation in crop protection. Different aspects of path dependence apply to pesticide use:

1. Chemical crop protection is a technology that has *externalities in use*, such that the net benefit of using it increases with the number of agents currently using it. Few agents are willing to adopt a technology without knowing that (many) others will also adopt it, since such a move would mean leaving a large network to join a small or non-existent one (FARREL and SALONER, 1985, FARREL 1986). "Thus a system can become stranded on a, possibly inferior, technology unless some co-ordinating device appears" (COWAN and GUNBY, 1996).

2. Chemical pesticides are a technology that is improving, either through *learning* by using or learning by doing. Therefore, experience with this technology will increase the benefits of adopting it (ARTHUR, 1989). Thus a competition between two new technologies, a lead in market share will push a technology quickly along its learning curve, thereby making it more attractive to future adopters than is its competitor. "A snow-balling effect can lock a market of sequential adopters into one of the competitors" (COWAN and GUNBY, 1996).

3. Learning about payoffs is a form of *reduction of uncertainty* regarding which of the possible technologies is preferable from the user's point of view. As experience with the competing technology accumulates, estimates about their properties and relative merits become sharper. As a consequence, the incentive to use a technology thought to be less than the best, 'just to learn something about it' declines, and the market locks in to one technology (COWAN, 1991).

Under these conditions a path once chosen has a tendency to become entrenched. Hereby it is possible, that self-reinforcing mechanisms drive a system to an inefficient outcome. The change to an alternative technology in a locked-in situation in many cases is uneconomic because of the (often prohibitively) high costs of adjustment.

Since the advent of the Green Revolution, investment in chemical crop protection and in the dissemination of pesticide use has been far higher than investment in non-chemical crop protection. This has even reached a point at which crop protection and pesticide use are used as synonyms. Following this reasoning, information on crop protection is limited to information on which pesticide to use, and so forth. Furthermore, high yielding varieties in combination with chemical pesticides attained spectacular increases in production. Under such conditions, it is clear that chemical pesticides have gained an initial advantage over any competing technologies such as resistance breeding. Accordingly, path dependence has helped to sustain the chemical paradigm.

4.2.3 The Pivotal Role of Information in Crop Protection

The previous sections in this chapter have shown that many different factors influence the farmer's decision on pesticide use. On the one hand, information on the type of pest in his field, infestation pressure and pest epidemiology help the farmer to determine the damage that may be caused by a pest without treatment. On the other hand, the farmer needs to know how to control a pest. Ideally, crop protection decisions should be made based on information about pest pressure, damage potential and on the pest control measures available.

In fact, much of the information mentioned above is not available to the farmer. He/she has to make his/her decision based on his/her experience and on the information obtained from different sources. Theoretically, a wide range of information sources is available to farmers such as pesticide retail shops, chemical industry campaigns and field advice, neighbours, friends, and official extension. In reality, official extension often only reaches a small proportion of farmers, in general those not living in remote areas. The opposite is true for information obtained from pesticide retail shops and from the chemical industry, which often can be found all over the country. Since more pesticide sales imply more profits for private business, it can be assumed that information from these sources is biased towards the use of chemical pesticides. Pesticide retailers, industry publicity campaigns and industry advisers have an economic interest in recommending their respective chemical products. Promotion often magnifies the productivity of a chemical product which leads to an overestimation of its effectiveness. Messages from the chemical industry are also attractive because, in general, they are easy to understand: 'Apply on a regular basis the recommended quantities and you will not need to care about pests' (GTZ, 1994).

The information environment influences the farmer in two respects: first, on what measure of pest control can be relied on and second, on how profitable such a measure is. WAIBEL (1996) points out that crop loss, and hence the productivity of pesticides, are often overestimated. A study by ROLA and PINGALI (1993), for example, indicates that insecticide use in rice is uneconomical, which is counter to the widespread opinion on the profitability of insecticide use in rice.

4.2.4 Can the Profit Maximization Assumption Hold?

Pesticide use is often discussed as an area which does not fit in the neoclassical optimization model because it is influenced by a number of factors that are difficult to consider in neoclassical models. Some of these factors such as biased information, path dependence or risk aversion have been discussed in the sections above. In this context, the more general question of whether farmers are profit maximizers or not must be raised.

The profit maximization hypothesis is a fundamental assumption of neoclassical economics which in agricultural economics has rarely been tested. FOX and KIVANDA (1994) define homogeneity, monotonicity, curvature and symmetry as being the four categories of "falsifiable hypotheses" incorporated within the theory of production. They analysed 70 papers that use econometric techniques to estimate cost functions, profit functions or systems of factor demand functions published in the principal international journals on agricultural economics from 1976 to 1991. In most papers, the refutable hypotheses employed were referred to as "theoretical restrictions which are 'imposed in order to obtain efficient estimates'". By doing this the "writers give the impression that the validation of the theory has been established elsewhere" (FOX and KIVANDA, 1994). However, the authors point out that from their point of view there would (for a Popperian economist) be no basis to claim that any sensible cost or profit function possesses the above-mentioned properties.

Although it has rarely been validated that the assumptions of the neoclassical theory are met in real life, the analytical tools based on this theory have been widely used. For many economists this is not contradictory because in their view applied economics should be evaluated according to its ability to formulate empirically significant predictions (KROMPHARDT, 1981). According to

Milton FRIEDMAN, for example, (1953, cited in KROMPHARDT, 1981) the ultimate objective of a positive science is the development of a theory or hypothesis "that yields valid and meaningful (i.e. not truistic) predictions about phenomena not yet observed." FRIEDMAN (1953) further emphasizes that "the only relevant test of the validity of a hypothesis is the comparison of its predictions with experience". MARGGRAF (1985) supports this view by stating that empirical economic research can hardly satisfy the Popperian criteria because in general it does not deal with clearly defined causal relationships as they prevail in the natural sciences.

The author of this research rather shares the instrumentalist interpretation of economic science. Analytical instruments can be useful to predict changes in economic behaviour even if the fundamental hypothesis cannot be taken for granted. This is of utmost relevance in the field of policy analysis. Nevertheless, it should be understood that the results of such analyses have to be interpreted with care and that they "can never provide objective truth in its fullness" (STENT, 1994).

It is important to point out that the dual analysis is based on the correspondence between primal production functions and dual functions which is given when the profit maximization assumption is fulfilled. As we have seen, this need not be the case in crop protection where, besides prices, many other factors are important. In his book on the limitations of "armchair economics", BRANDES (1985) states that economic models may only assess the behaviour of farmers under quite restrictive assumptions.

However, even if profit maximization cannot be guaranteed, the dual analysis of production is still viable. BAPNA, BINSWANGER and QUIZON (1984) stress that systems of output supply and factor demand equations can exist independent of profit maximization behaviour, "as long as the behaviour of individual agents is sufficiently stable over time and can be aggregated over farmers. This implies that estimated systems are useful for economic analysis regardless of whether the theoretical restrictions of profit maximization hold. However, if profit maximization does not hold, no inferences can be made from the supply and demand equations about the production function underlying them, since behavioural and technological relationships are then confounded in those equations."

4.3 Hypotheses and Methods

The quantitative methods applied in the analytical part of this thesis have their foundations in the neoclassical theory of production. Having discussed the various aspects of the economics of pesticide use in agriculture, the following sections derive hypotheses for the empirical part of this research project, give a systematic overview of the methods for quantitative analyses of pesticide use and introduce the methods used in this study.

4.3.1 Hypotheses

Although there are few quantitative analyses on the impact of pesticide taxation, it is a common belief that a tax on pesticides would have a limited impact on pesticide use, mainly because of the lack of substitutes for pesticides in agricultural production[24] and because "the share of pesticides in total production costs is, in general, rather low so that significant changes in usage rates can reasonably be expected only at very high (and politically unacceptable) tax rates" (NUTZINGER, 1984). Challenging this assumption, the first hypothesis of this research is that the substitution principle applies to crop protection in Costa Rica's coffee production and, consequently, that there is no reason to assume that pesticide demand is price inelastic.

The second hypothesis of this research is related to the controversy about the income effect of pesticide taxes. It is hypothesized that a tax on pesticides would not significantly affect income from coffee production and therefore would not hamper the competitiveness of Costa Rica's farmers with reference to other coffee producers in the world.

4.3.2 A Typology of Standard Methods for the Assessment of the Impact of a Pesticide Tax on Pesticide Demand and Farm Income

Various approaches may be used to assess the demand for pesticides and income effects resulting from a tax on pesticides or other inputs. Table 4-1 classifies these approaches as normative and positive methods which both can follow a primal or a dual approach. All methods, whether normative, positive, primal or dual may be applied to sectoral analyses or to farm-specific analyses of production. They may be conducted in a static or in a dynamic analytical framework.

[24] In fact, the degree of substitutability has an impact on the demand elasticity of a product or product group. If a product may easily be substituted, demand for this product is likely to be elastic, whereas if no substitutes are available demand is likely to be inelastic.

Table 4-1: Classification of methods for the assessment of the impact of a pesticide tax on pesticide demand and income

	NORMATIVE	POSITIVE
PRIMAL	**partial budget model**	not used in this study
DUAL	not used in this study	**pesticide demand models**

Source: author's presentation

Normative methods draw on expert knowledge and existing information to specify the production technology for a crop or a cropping system. Normative methods derive the farmer's behaviour from optimal factor allocation under given restrictions and pay-offs. Under these assumptions, farmers are supposed to use a "representative" production technology and to maximize profits.

Mathematical programming models in general, and linear programming in particular, are widely used normative methods[25]. Primal linear programming maximizes an objective function (which in most cases represents the total gross margin or the total profit) subject to technological and economic restrictions. The combination and extent of activities realized must not violate any of the fixed resource constraints or involve any negative activity levels. Dual linear programming minimizes a cost function with respect to a given output. This approach identifies the shadow price (which is equivalent to the marginal productivity) of each resource (HAZELL and NORTON, 1986).

When analysing the effects of a policy change with linear programming models the question arises of how to find a production technology set which is representative of a whole sector. Often policy analyses are carried out with models based on farm data which are then projected on a whole sector. Obviously there is an aggregation problem and the reliability of such projections depends on the quality of the empirical data on which it is based. The same sort of problems apply to policy analyses with partial budget models which presuppose fix proportions between factors and therefore do not at all take account of factor substitution.

Positive methods do not ex ante postulate a specific behaviour. They use empirical data to test hypotheses on the production technology. There is a

[25] For this study, linear programming is not adequate because coffee is a perennial crop which in Costa Rica in most cases is grown as a monoculture. Hence, as coffee is the only economic activity no classical linear programming optimization can be conducted.

variety of econometric approaches to conduct positive economics research. The primal approach to the positive analysis of production departs from a set of physical and technological production possibilities which are described by a production function. Factor demand functions may be derived from the production function.

In contrast, the dual approach to positive methods in the first place does not use quantities of products and inputs as explanatory variables but mainly output and input prices. These are supposed to explain profits, costs and physical quantities of inputs or outputs as outlined in Section 4.1.1.2.

4.3.3 Methods Used in this Study

This research uses both a normative and a positive static model for the empirical analyses. First, based on the statistical analyses of the production technology a representative cost structure is defined for Costa Rica's coffee production. In a later stage of the analysis, this model is used to assess the impact of various pesticide tax regimes on production cost and, eventually, on the gross margin. Negative income effects of a pesticide tax are overestimated when using partial budget models because these presuppose that production factors cannot be substituted. Hence, according to a partial budget model, a pesticide price increase affects neither pesticide demand nor pesticide productivity but simply increases production costs. The elasticity of factor substitution is assumed to be zero. If factor substitution takes place, the income effect will be less than predicted with partial budget models. In spite of these deficiencies, the partial budget approach is a useful tool for the analysis of the effect of a policy change on farm income because it is pragmatic and easy to handle.

Taking account of factor substitution is an important issue in the assessment of pesticide demand. This is done in the positive part of the analysis when estimating a demand function for pesticides. As mentioned earlier, the effect of price changes on input demand may best be assessed by using dual demand functions, because these explicitly define the production technology and behavioural relationships (such as derived demand functions) as a function of prices. The specific structure of the data collected allows the use of panel data models which take into account any individual-specific effects. The degree of risk aversion, knowledge and path dependence are examples of individual specific-effects that influence the farmers' decisions on pesticide use.

5 The Coffee Economy in Costa Rica

This chapter introduces Costa Rica's coffee sector and describes the context in which the empirical research was carried out. Secondary data are presented from the period of 1989 to 1995 to show the impact of a long-lasting period of very low coffee prices on other variables of interest. Section 5.1 provides an overview of coffee's place in the Costa Rican economy, of coffee marketing and pricing and of coffee research and extension. Considerable space has been dedicated to the marketing and pricing system for coffee in order to justify the specification of the coffee price in the econometric model. Section 5.2 presents coffee production in Costa Rica from a sectoral perspective. It introduces the natural conditions of coffee production in Costa Rica, production and productivity at a national scale, and the various coffee production systems. Section 5.3 familiarizes the reader with the management of coffee in Costa Rica focusing on pest management and agrochemical use at the farms. The data presented focus on the period from 1993 to 1995 and serve as a reference for the empirical information presented in the subsequent chapters.

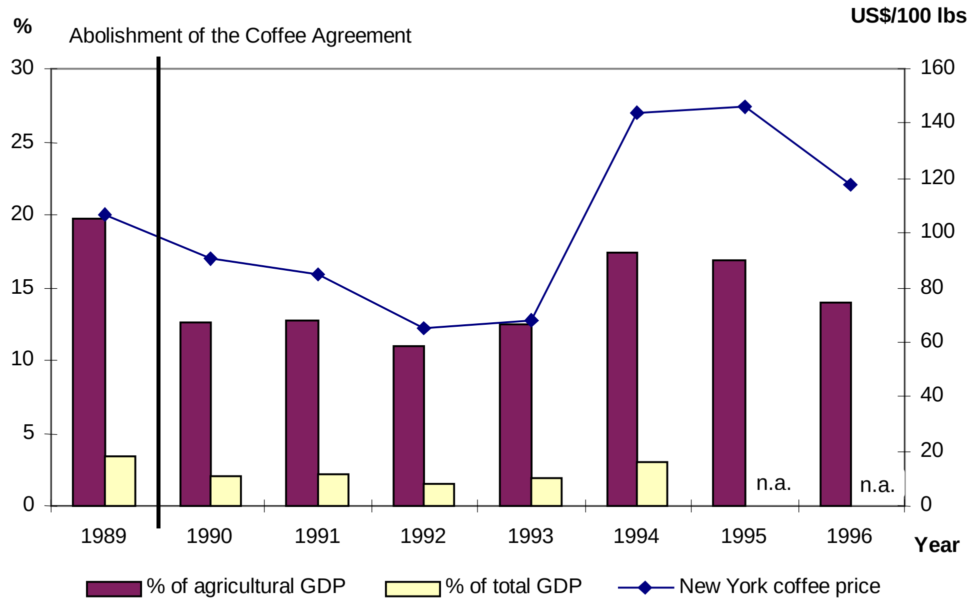
5.1 The Organization of Costa Rica's Coffee Sector

Commercial coffee production in Costa Rica began in 1832 in the Central Valley which offered excellent natural conditions for coffee and a good infrastructure (HALL, 1976). From 1890 to 1935 coffee growing expanded to the regions of Tilarán, Puriscal, Acosta, Tarrazú and Turrialba, which are all situated around the Central Valley. After 1935, the coffee area was extended to more peripheral regions, namely to the Península de Nicoya, San Carlos, Valle del General and Coto Brus (HALL, 1976). Until now, the Central Valley has remained the core area of Costa Rica's coffee production with the highest intensity and highest yields on a nation-wide and also on an international scale. Coffee has been one of the most important activities in Costa Rica's economic development and until 1900 coffee earned almost 100% of Costa Rica's foreign exchange (HALL, 1976). Since then, the agricultural sector and the economy as a whole have both undergone considerable changes so that at present coffee is just one important commodity among others. The agricultural and grassland areas have been extended, and bananas and beef have become major agricultural export commodities.

5.1.1 Coffee in the National Economy

In Costa Rica, coffee production contributes substantially to agricultural GDP and is a major source of employment in rural areas. In 1996, coffee represented about 14% of the gross value of agricultural production (ICAFE, 1997c). This figure varied between 19.8% in 1989 and 11% in 1992 (ICAFE, 1994d and 1997c), partly due to fluctuations in the world market coffee prices (compare Figure 5-1). After the breakdown of the coffee agreement in 1989 coffee producing countries had to face a decline in the world market coffee price which subsequently recovered in 1994.

Figure 5-1: World market coffee prices and coffee's contribution to the agricultural and total GDP in Costa Rica



Source: author's presentation based on data from ICAFE, 1994d, 1997c; CSCE, 1998

In Costa Rica, coffee production generates considerable employment in the maintenance of coffee plantations, the coffee harvest and in coffee processing. ICAFE (1997c) estimated that in the year 1995/96 17.8 million mandays were used in coffee production and processing in Costa Rica. Calculating an average of 300 days per year per person this figure is equivalent to about 60,000 permanent jobs, which represents employment for about 23% of Costa Rica's agricultural labour force, or 4.9% of the total labour force (ICAFE, 1997c). These numbers do not reflect the total impact of coffee production on the Costa Rican labour market because coffee indirectly generates employment in input industries and trade.

5.1.2 Coffee Marketing and Coffee Pricing

Private agents and public institutions with well-defined functions participate in the process of coffee marketing. Coffee producers, processing plants and exporters are the most important private agents. ICAFE, FEDECOOP (Federation of Coffee Producer Co-operatives), the Ministry for Economy, Industry and Trade (MEIC), and the Ministry for Agriculture (MAG) are public institutions that are involved in coffee marketing (MORALES and VILLALOBOS, 1985). Although conducted by private agents, coffee exports and sales on Costa Rica's national market are strictly controlled by ICAFE, Costa Rica's national coffee institute. ICAFE authorizes and registers all of the coffee traded on the national market and also for export. Each transaction has to be documented in a contract. Besides this, there are additional requirements of the Central Bank of Costa Rica (Banco Central de Costa Rica) and of the Costa Rican customs office (Dirección General de Aduanas). Finally, ICAFE hands over a certificate of origin for the exported coffee. This process is supervised by inspectors at the national ports. Coffee sales for export take place at authorized coffee markets or directly between processors and exporters.

Every year, ICAFE analyses coffee supply and demand on the national market, and international commitments like export quotas. It then fixes a percentage of the coffee harvest for export, a percentage for national consumption and, if considered necessary, a retention quota. Once the export quantity has been fixed the coffee processing plants have to export their share during a given period. They have the option of selling coffee to national exporters or selling it directly to international buyers.

In 1995/96, 90% of the coffee harvest was exported and the remaining 10% was sold on the local market. Twenty-two per cent of all exports went to the United States of America, 18% to Germany, 10% to the United Kingdom, 9% to France, 8% to the Netherlands and 36% to other countries. In this period, exported coffee equalled about 2.54 million 60-kg sacks, which were sold at US$ 393.4 million. The average fob-price for coffee was US$ 154.97/60 kg, i.e. about US$ 2.58/kg. On the national market, coffee was sold at CRC 341.75/kg, which in 1995/96 was about US$ 1.69/kg or 64.9% of the fob-price for exported coffee (ICAFE, 1997c). The domestic market price for coffee in Costa Rica is considerably lower than the export price as a result of a government market intervention.

International prices have fluctuated considerably over the last few years. Figure 5-2 shows coffee prices on the New York market between January 1989 and February 1997.

Figure 5-2: New York Coffee, Sugar and Cocoa Exchange (CSCE) prices for coffee from January 1989 to February 1997 *

* CSCE nearby prices, contract high

Source: CSCE (1998)

In 1989, after the abolition of the quota system implemented by the International Coffee Agreement, coffee prices sank to just a little above US$ 50/100 lbs (CSCE, 1998). Prices remained at a low level until May 1994, when a drought in Brazil's coffee regions caused prices to shoot up to more than US$ 240/100 lbs (CSCE, 1998). Brazil is the major coffee producer world-wide supplying about 20% of world production (FAO Agrostat). Whenever drought or frost seriously damages coffee plantations in Brazil, coffee prices on world markets react strongly.

It is important to note that world market price fluctuations have a direct impact on prices received by coffee farmers in Costa Rica. In contrast, neither exporters nor processors have to bear significant price risk because profit shares for exporters and processors are set by regulation. Table 5-1 shows how the price received by the farmers is calculated from the fob-price in US dollars per 46 kg. First, marketing costs are deducted including transport costs, insurance and the exporter's profit. By law, the exporter's profit on average must not be more than a fixed percentage of the fob-value of all coffee transactions in a marketing year. This percentage is 1.5% for traders that act as simple intermediaries without bearing a price risk and 2.5% for traders who bear a price risk (ICAFE, 1992). In case the fob-price exceeds US$ 92, a 1% export tax has to be paid[26].

Table 5-1: Price paid for coffee at different marketing stages*

FOB PRICE *(precio fob)*
- transport cost to harbour
- crop insurance
- contribution to ICAFE (1.5% of the fob price)
- export tax *(if applicable)*
- exporter's profit (fixed by ICAFE, 1992)
= PRICE RECEIVED BY THE COFFEE MILL *(precio rieles)*
- profit margin of the coffee mill (fixed by ICAFE, 1992)
- processing cost (assessed by ICAFE)
- contribution to FONECAFE *(if applicable)*
= FARM GATE PRICE FOR GREEN COFFEE *(precio de liquidación final)*

* compare also Table A4-1 in Appendix 4

Source: various regulations elaborated by the author

Subtracting the marketing costs, the contribution to ICAFE and, if applicable, the export tax, gives the price paid to the coffee mill. The coffee mill takes its processing cost, its profit margin, the tax to be paid by the farmer and, if the fob-price exceeds a certain limit, a contribution to FONECAFE, which is a stabilization fund established in 1992. FONECAFE accumulates resources when coffee prices are above US$ 92 and supports coffee farmers when the world market coffee price falls below a specified limit.

Exporters have to pay a 1% export tax in case the fob-price exceeds US$ 92 per 46 kg (ICAFE, 1997c). Previously the export tax used to increase progressively with the coffee price, often resulting in much higher export tax revenues. Government earnings by taxing coffee exports decreased from 6.6% of the total government budget in 1989 to about 0.3% in 1996 (ICAFE, 1997c).

26 The export tax has been lowered considerably. In early 1995, it ranged from 1% to 12% of the fob-value, progressively increasing with the coffee price (Decree No. 23974-MEIC-MAG-H, published in the official journal "LA Gaceta No. 25, 3 February 1995).

Coffee cannot be consumed without processing. It is a typical "bottleneck" product which has to be processed before it can enter the market. Coffee mills collect coffee at the farm level or at local assembly points. The payment for coffee is determined both by volume[27] and quality[28]. After processing, coffee is marketed throughout the year.

The farmer receives various share payments for his produce according to sales over the year. Shortly after handing over the coffee, the farmer receives a first payment; further shares follow every three months and a final payment is made when the last share of the coffee delivered is sold. The amount paid in every share depends on the amount of coffee sold and on the fob-price of each transaction as outlined in the previous paragraph. Consequently payments may be highly variable.

In the context of this study, it is important to note that farmers do not know the price they will eventually receive for their produce at the time they make decisions on input use, nor at the time they deliver their produce. Therefore, it is assumed in this study that the farmers make their decisions on a basic technology package based on average price expectations over several years. In addition to this, it is hypothesized that farmers will adjust the intensity of coffee production within a cropping season according to current prices due to the expectation that these will hold in the future. Farmers, in general, are aware of the coffee prices through radio and TV news or newspapers and from their quarterly payments. This assumption is also reasonable because some farmers relate their input decisions to the availability of cash. When coffee prices are high, and, consequently quarterly payments are high, the farmers have access to money that they may then use for inputs. If payments are low, less money is available for production purposes (see also Section 7.2.1.3).

In Costa Rica, the per unit farm-gate price is subject to taxation whenever it exceeds the per unit production cost as assessed by ICAFE. Hence, the farmer's net profit depends on coffee prices, on the marketing and processing margins, on contributions to FONECAFE, and ICAFE's assessment of the average agricultural production costs. Each quarter, ICAFE estimates the average production and processing costs for coffee on the basis of an average model farm or an average model coffee mill, respectively. Thus, farmers are

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[27] The measure used is *fanega* which equals 400 litres. This is approximately the amount of coffee berries necessary to produce one 46-kg sack of dry coffee (café oro), which is the international trade unit for coffee.

[28] There are different qualities of coffee which mainly depend on the altitude where the coffee is grown. The best qualities are obtained in the higher altitudes. Furthermore, the price for a certain quality may be lowered, if it contains too many unripe green berries.

not taxed according to their real costs of production but according to estimated average profits per hectare.

Table 5-2 shows how the income tax to be paid by farmers is computed. When the coffee price is low, production costs per unit as estimated by ICAFE exceed the farm gate price so that no tax is to be paid.

Table 5-2: Computation of the income tax on coffee production

FARM GATE PRICE PER UNIT
- per unit production cost (assessed by ICAFE)
= PER UNIT NET PROFIT
per unit net profit x 0.2
= PER UNIT INCOME TAX

Source: author's presentation based on various regulations

In all other cases the government charges a 20% tax on the coffee producer's net profit *(impuesto sobre la renta)* which is collected at the coffee mill and directly transferred from the coffee mill to the Ministry of Finance (ICAFE, 1997c).

5.1.3 Research and Transfer of Technology

Costa Rica's coffee institute (ICAFE) is in charge of research and extension for coffee. Research is mainly undertaken and co-ordinated by ICAFE's coffee research centre. Until recently, the research agenda has followed the classical external input oriented approach to agricultural production. Research activities are subdivided according to technical discipline including plant nutrition, entomology, phytopathology, etc. ICAFE's research report for 1996 (ICAFE, 1997b) shows that research in crop protection, which is of special interest to this study, is mainly research on pesticide use, i.e. on optimal application frequencies and pesticide efficacy. In 1996, integrated pest management had only been investigated for *Picudo* and *Cochinilla*, two insect pests which are of minor importance in Costa Rica. The research done is not consistent with the official objective of sustainable coffee production, which aims at sustainable coffee production by using Integrated Pest Management (IPM) methods. ICAFE officially promotes integrated resource management (IRM), a concept that goes beyond IPM as far as the minimization of pesticide use and sustainability are concerned.

Extension consists of farm visits, presentations, demonstration plots, seminars, field days and different types of publications (leaflets, articles, booklets). Extension is conducted in co-operation with the regional agencies of the Ministry of Agriculture and Livestock, by coffee co-operatives and by private business related to the coffee sector (ICAFE, 1997c).

5.2 Coffee Production Systems in Costa Rica

This chapter introduces the biophysical environment, production on a national scale, and systems of coffee production in Costa Rica.

5.2.1 Biophysical conditions for coffee production in Costa Rica

In Costa Rica, coffee is grown at altitudes between 500 m and 1700 m above sea level. Above 1700 m, the development of the coffee plant is not satisfactory and below 500 m, the quality of coffee beans is inferior, especially in regions with high precipitation. A suitable quantity and distribution of rainfall is essential for a good development of the coffee plant. Between 1000 mm and 3000 mm of precipitation per annum is required for coffee production, the more equally distributed the better. A long drought period can cause defoliation or, in extreme cases, death of the coffee plant. On the other hand, heavy and continuous rainfall increases the infection pressure of some important fungal diseases and provokes considerable losses during the harvest period, mostly because the workers cannot enter the fields when necessary and because the ripened coffee berries drop to the ground. Temperatures should not fall below 10 degrees centigrade, otherwise chlorosis and paralization of plant growth are likely to occur (ICAFE, 1989). Costa Rica's volcanic soils and temperate climate in its upper regions provide excellent conditions for coffee growing.

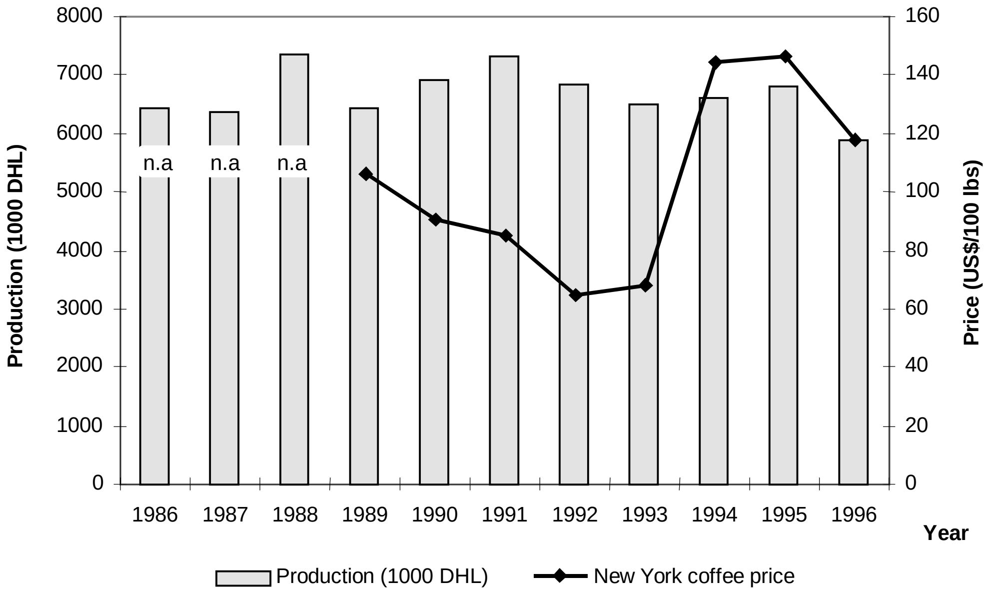
5.2.2 Coffee Production and Productivity

Coffee has a biannual production cycle, i.e. production differs considerably between two successive years. After a good harvest, coffee bushes are exhausted and often damaged from the harvest which has a strong impact on the harvest of the following year. The biannual cycle is an important feature of coffee production. First, because it makes productivity estimates difficult and second, because it limits the potential for raising coffee production in the short term, e.g. as a reaction to a price increase in the coffee market.

Figure 5-3 contrasts coffee production over the last decade with prices on the New York market. The time series is too short to draw conclusions about the relationship between world market prices and production. However, it does illustrate that they show little correlation. Hence, coffee production in the short run is not linked to price fluctuations on the world market for coffee.

It is difficult to find data on per hectare coffee yields over time. At the national level, yields can hardly be calculated because no sound data on the coffee production area are available[29]. The most recent data on area cultivated with coffee are taken from the 1984 agricultural census. In that year, Costa Rica's coffee area amounted to about 90,181 hectares. Using this figure as a reference for the last decade, the productivity of coffee has changed in the same way as production.

Figure 5-3: Coffee production in Costa Rica from 1986 to 1996*



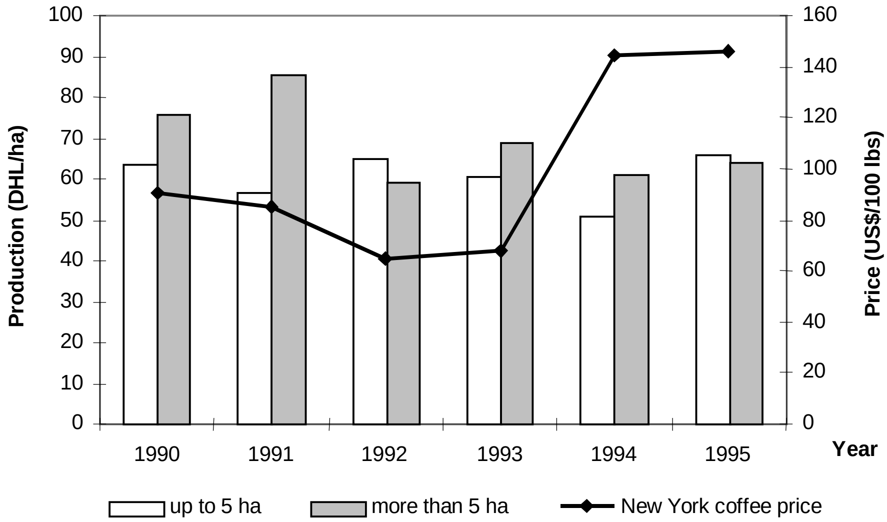
* DHL *(doble hectolitros)* = 200 litres.
In Costa Rica, the coffee year lasts from 1 October to 30 September of the following year. The values indicated refer to coffee years, i.e. 1986 implies the 1986/87 period.

Source: author's presentation based on data from ICAFE (1994d, 1997c) and CSCE (1998)

ICAFE has estimated the development of per hectare yields on farms with up to 5 ha of coffee and farms that have more than 5 ha of coffee between 1990 and 1995 on the basis of its annual surveys. These estimates suggest that productivity changes have been more significant on large farms than on small- and medium-scale farms (compare Figure 5-4). For both farm types, there is little evidence of a correlation between productivity and world market coffee prices in the 1990 to 1995 period.

29 FAO offers statistics on coffee yields in Costa Rica which are based on the data available in Costa Rica. Therefore these data can only be considered as estimates.

Figure 5-4: Productivity in Costa Rica's coffee production between 1990 and 1995*



* DHL *(doble hectolitros)* = 200 litres

Source: author's presentation based on ICAFE (1994d) and ICAFE (1997c)

It is difficult to estimate the impact of increased input use on the productivity of coffee production from cross-sectional data or from a short time series mainly for two reasons. First, coffee is a perennial crop with limited possibilities for increasing productivity through higher levels of input use within one cropping year. It takes two to three years for production to increase substantially as a result of improved management. Second, this problem is further aggravated by the fact that coffee has a biannual production cycle.

5.2.3 Coffee Production Systems

This section gives a short overview of coffee production systems in Costa Rica. It concentrates on production systems that use chemical inputs which cover close to 100% of the total coffee production. Organic coffee production has only recently been introduced by a few innovators. Nevertheless it is included in this chapter to show that from a technological point of view, it is possible to produce coffee in Costa Rica without chemical inputs.

Commercial coffee varieties grown in Costa Rica belong to the arabica species[30]. The most important varieties are *Caturra*, *Catuaí* and, the more recently introduced *Catimor* (ICAFE, 1997c).

[30] Coffee belongs to the genus *Coffea*, Rubiaceae, and originates in Africa. The most important cultivated species are *Coffea arabica*, arabica coffee, which accounts for 74% and *Coffea canephora*, robusta coffee, which accounts for 25% of world coffee production. *Coffea liberica*, liberica coffee, *Coffea stenophylla*, highland coffee, and others supply the remaining 1% (REHM and ESPIG, 1991:248).

5.2.3.1 Conventional Coffee Production in Costa Rica

Coffee production systems in Costa Rica differ considerably and it is difficult to find one single criteria on which to classify them. There are extreme cases like the highly intensified systems in pure stand without shade trees on the one hand, and low input agro-forestry systems on the other hand. But between these two extremes there are numerous variations concerning the degree of shade coverage, planting density, management of the crop, especially pruning techniques, use of agrochemical inputs, etc. that make it difficult to classify coffee production according to a single variable.

Although coffee production systems have often been subdivided into with or without shade systems (e.g. ESPINOZA, 1985) there is no information on the relative importance of each of these production systems available. As a rough orientation, it can be said that coffee growing under full exposure to sunlight is the dominant production system in the Central Valley, while coffee production under shade predominates in the surrounding areas like Turrialba.

The productivity of coffee under full sun exposure in general is higher than under shade (RAMIREZ, 1997). Physiological studies have shown that there is a trade-off between productivity and quality of coffee. Experiments conducted in Costa Rica demonstrate that under full sunshine the photosynthesis rate of coffee may be up to 35% higher than under shade (CARVAJAL, 1984, cited in HERNÁNDEZ, 1995), while the quality is inferior to the quality of shaded coffee (MUSCHLER, 1997a+b).

In Costa Rica, little research has been conducted on IPM in coffee, and, consequently, few IPM practices can be found in the field (see Section 5.1.3). Integrated weed management is most advanced, as will be presented in Section 5.3.2.1.

5.2.3.2 Organic Coffee Production in Costa Rica

In principal, coffee can be produced on organic standards in coffee regions all over Costa Rica. It is interesting to note that the elimination of pesticides from the production system has not proved to be a serious limitation for organic coffee production. Proper shade management allows the control of fungal diseases which are the most important threat to coffee in Costa Rica. Direct exposure to sunlight stresses coffee plants and makes them susceptible to some fungal diseases, while excessive shade leads to a high degree of humidity which stimulates the growth of other fungal diseases. Therefore, organic coffee is usually produced with an intermediate shade coverage which supposedly is a valid solution to the management of fungal diseases.

A more significant problem in organic coffee production is fertilization which, in organic farming is restricted to the use of manure and various other well-defined types of organic and inorganic material. In Costa Rica, most coffee farms cannot provide this material and therefore have to purchase it elsewhere. Transportation may considerably increase the cost of such fertilization.

The most serious limitation to organic coffee production in Costa Rica is the access to special marketing schemes for organic produce. Firstly, farmers need to be certified by an independent body, and secondly only a few coffee mills process organic coffee separately. None of the other mills are prepared to pay an extra premium for organic coffee (BOYCE, FERNÁNDEZ, FÜRST and BONILLA, 1994). For a long time, the *Beneficio Tres Volcanes* was the only coffee mill that processed organic coffee in Costa Rica. In 1995, it paid a premium of 1000 CRC per fanega to organic coffee farmers, which at that time was equivalent to about 5 US$ or 6% of the price paid for conventional coffee. Taking into account the lower yields and additional production costs for organic coffee, this premium is relatively low.

Nonetheless, world market prices for organic coffee are significantly higher than the prices paid for conventional coffee. LUTZEYER, PÜLSCHEN, COMPART and SCHOLAEN (1994) report that for organically grown coffee, farmers can receive a price bonus of 20% to 50%, and in some cases, even more than twice the price for conventional coffee. They stress that the access to a marketing organization for organic coffee is the essential condition for achieving a price premium. To make sure that the standards for organic production are met, certification schemes have been set up world-wide. Only certified coffee will receive the price premium that is paid for organic produce on the European and North American markets. In the future, the price premiums paid for organic coffee in Costa Rica may increase when larger quantities of organic coffee are available and its marketing is better organized.

5.3 Production Technology and Pest Management

This section introduces the management practices in Costa Rica's coffee production with a focus on pest management and input use. It does not include activities such as land preparation and planting, which are part of the establishment of coffee fields. For each task presented in this section a variety of techniques and inputs are available which cannot be discussed in detail.

The objective of this section is to familiarize the reader with the main features of the annual coffee production cycle in Costa Rica. Sections 5.3.1 to 5.3.3 will make it apparent that the management of coffee plantations is a relatively simple process.

5.3.1 Overview of the Production Process

The management of coffee plantations basically consists of six tasks which are repeated every year at about the same time: pruning of the coffee bushes, shade management, fertilization, weed management, pest and disease management and harvesting. Coffee is a robust plant that naturally resists unfavourable conditions and many pests. However, the better the environmental conditions and management, the higher the potential production.

On coffee plantations with shade, the annual production cycle usually starts with the first pruning of the shade trees which is done shortly after the harvest. Often these branches are cut completely off in the first cycle and then cut back only partially in subsequent cycles.

The pruning *(poda)* of the coffee bushes and the first fertilization then follow. In the traditional and still widespread selective pruning technique, the exhausted branches are cut back from every plant. More recently "total pruning", i.e. snipping the whole plant at about 30 - 40 cm above the soil (ICAFE, 1989), has been promoted. This type of pruning can be done individually, by selecting and cutting only the exhausted plants in a plot or in more rigid systems that trim down complete rows or plots in a three- to five-year rotation.

Fertilizer is the most important external input in coffee production. Fertilizer applications are made one to four times a year. Most plantations carry out the first application, while subsequent applications depend on rainfall, growth and, in some cases, on coffee prices. Fertilization may be used to a certain extent to adjust productivity in the short run.

Weeds can be managed chemically or mechanically (ALVARADO and ROJAS, 1994). Weeds are usually controlled two to four times per year, depending on the region. The humid regions such as Turrialba require more weed control than the semi-arid regions (e.g. the Central Valley). Some farmers rely exclusively on chemical control, while others also use manual/mechanical techniques. The first herbicide application is usually made just before pruning; the last application before the coffee harvest begins.

Depending on the weather conditions and other environmental factors specific to each location, fungal diseases may represent a problem in coffee production in Costa Rica. Farmers who use fungicides usually apply them two to four times a year, whenever they expect the fungal diseases to occur. In most cases, protective inorganic copper-based fungicides are applied in mixture with micro-elements and/or foliar nutrients.

Insect pests are not a significant problem in Costa Rica and therefore need not be controlled. In some regions, however, nematodes may affect plant growth and, consequently, production. Nematicides are rarely applied more than once a year.

In Costa Rica, coffee is harvested manually two to three times a year within a period of two to four months. Coffee berries mature at different times and they have to be harvested shortly after ripening, otherwise they drop to the soil. The coffee harvest is labour intensive and therefore among the most expensive tasks in coffee production.

5.3.2 Pests and Pest Management

Costa Rica is a very favourable country for coffee production, not only due to its climate and soils, but also because it has few pests that threaten coffee production. This section discusses the key pest problems and management methods available for pest control.

5.3.2.1 Weed Management in Coffee Production

Coffee production is adversely affected by grasses, vines and climbing plants, all hosts of coffee pests, and other plants which, because of their growth-form, root systems, or germination biology might compete with coffee in some way (COMPART, 1994; MATA PACHECO, 1993). Sunshine strongly favours weed growth and therefore shade, both from trees or from coffee bushes, is one of the prime measures to suppress weed growth. Weeds in coffee plantations can be controlled by agricultural, chemical and mechanical measures. Chemical control is the most popular approach, which, however, is often used in combination with the other methods available.

Preventative agricultural measures include the planting of shade trees and increased planting density of coffee bushes. A relatively new technique is selected weed management which concentrates on removing just those weeds that compete with coffee. So-called "noble-weeds" which are generally characterized by a low, creeping growth habit and shallow root systems do not substantially affect coffee production and are therefore left in the fields. They may be used as cover plants to suppress the growth of prejudicious weeds

(AGUILAR, SOMARRIBA, STAVER and AGUILAR, 1996). Such cover crops also reduce erosion.

Chemical control is often carried out using mixtures of different herbicides depending on the weed population. *Paraquat* and *glyphosate* are the most commonly used active ingredients. *Atrazine*, *2,4 D* and *oxyfluorfen* are other popular active ingredients.

Different techniques for the mechanical control of weeds are implemented among which cutting down weeds with a machete is the most popular *(chapia, lumbrea)*. Some farmers also use a spade to turn over the soil *(palea)* or to rake *(raspa)*. Digging the coffee field is very laborious and costly, but at the same time the most effective mechanical control option.

5.3.2.2 Management of Fungal Diseases

The most important fungal diseases in Costa Rica are brown eye spot[31] *(Cercospora coffeicola)*, South America leaf spot[32] *(Mycena citricolor)* and coffee rust[33] *(Hemileia vastatrix)*. *Cercospora coffeicola* is particularly virulent when coffee plants grow under scarce nutrient conditions and are exposed to solar radiation. Contrary to *Cercospora*, *Mycena citricolor* thrives under high humidity and excessive shade. Yield loss is mainly caused by leaves dropping off which weakens the plant, and also by coffee berries dropping off when *Mycena* attacks are severe (REHM and ESPIG, 1991). In Costa Rica, *Hemileia vastatrix* (coffee rust) is the most serious fungus which, in severe cases, may lead to total defoliation.

All of these fungi can be controlled using fungicides. In most cases, preventive copper-based fungicides are applied for coffee production. If fungal diseases are prevalent, systemic curative products may also be used, which, however, are much more expensive than protective fungicides. Fungicides are usually applied in mixtures with micro-elements and/or foliar nutrients. In some regions, however, fungicides, foliar fertilizers and minor elements are not used at all in coffee production.

Disease infestation pressure can be lowered considerably through shade management. Excessive exposure to sunshine which weakens the coffee plant takes place when there is no shade. If the tree canopy is too dense, humidity in the coffee field will increase and favour fungal growth. Therefore, in every

[31] brown eye spot = *Chasparria*

[32] South America leaf spot = *Ojo de gallo*

[33] coffee rust = *Roya del cafeto*

location a shade system has to be found that protects the coffee bushes from sunshine without increasing humidity too much. This requires regular pruning of the shade trees.

5.3.2.3 Other Pests

Insect pests do not affect coffee production in Costa Rica. The coffee berry borer *(Hypothenemus hampei)* for example, the most important coffee insect pest, has not yet been introduced to Costa Rica. However, insecticides sometimes are applied on some spots in coffee fields to control ants. Ants are controlled in order to facilitate the harvest, not because they threaten production.

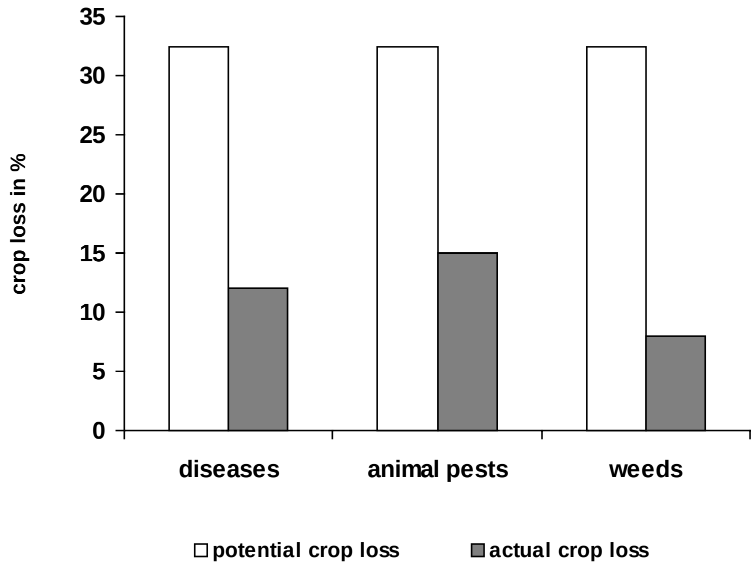
Some regions are infested with nematodes *(Pratylenchus spp., Meloidogyne spp.)*. It is not clear to what extent nematodes weaken the production potential of adult coffee plantations. However, it has been shown that nematicides may have a stimulant effect on production, even when there are no nematodes in the soil.

Young plants are susceptible to nematodes and therefore are more often treated with nematicides than adult plants. Usually nematicides are applied immediately after planting and, if judged necessary, in the second and the third year after planting.

5.3.2.4 Crop Loss Estimates

OERKE, DEHNE, SCHÖNBECK and WEBER (1994) have estimated potential and actual crop loss in Central American coffee production. Potential crop loss is defined as crop loss that would occur without pest management, actual crop loss defines the difference between the potential yield and what is actually harvested. In Central America, OERKE et al. (1994) distinguish three types of countries according to their productivity level in coffee production. Figure 5-5 shows yield loss estimates for Costa Rica, which belongs to the group of highly productive countries. For Costa Rica, these estimates seem to be too high, mostly because Costa Rica is almost free of insect pests.

Figure 5-5: Estimates of potential and actual crop loss in Costa Rica's coffee production



Source: author's presentation based on OERKE, DEHNE, SCHÖNBECK and WEBER (1994)

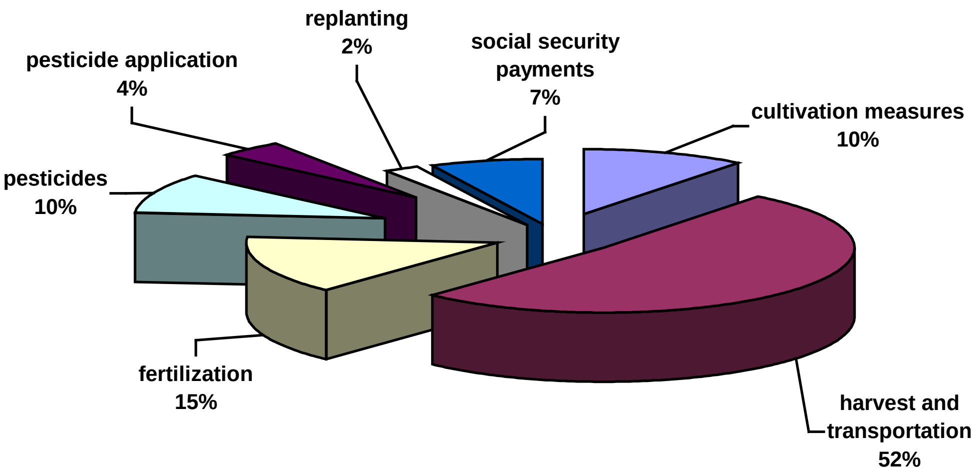
5.3.3 Production Costs and Input Use in Costa Rica's Coffee Production

5.3.3.1 Production Costs

There are few empirical studies on input use in Costa Rica's coffee production that specify the products used and the per hectare dosages. Studies that reach such a level of detail have only been carried out on experimental stations or on a few selected farms.

ICAFE has elaborated a standard technology package which is used to assess average production costs in coffee farming (compare Section 5.1.2). In September 1995, average variable costs in Costa Rica's coffee production were estimated at CRC 388,068 (approximately US$ 2087) per hectare. This amount refers to a model farm with 10 ha of coffee in production and an average yield of 80 DHL. Production costs were distributed among the various inputs as shown in Figure 5-7.

Figure 5-6: Shares of variable production cost as assessed by ICAFE



Source: author's presentation based on ICAFE (1995e)

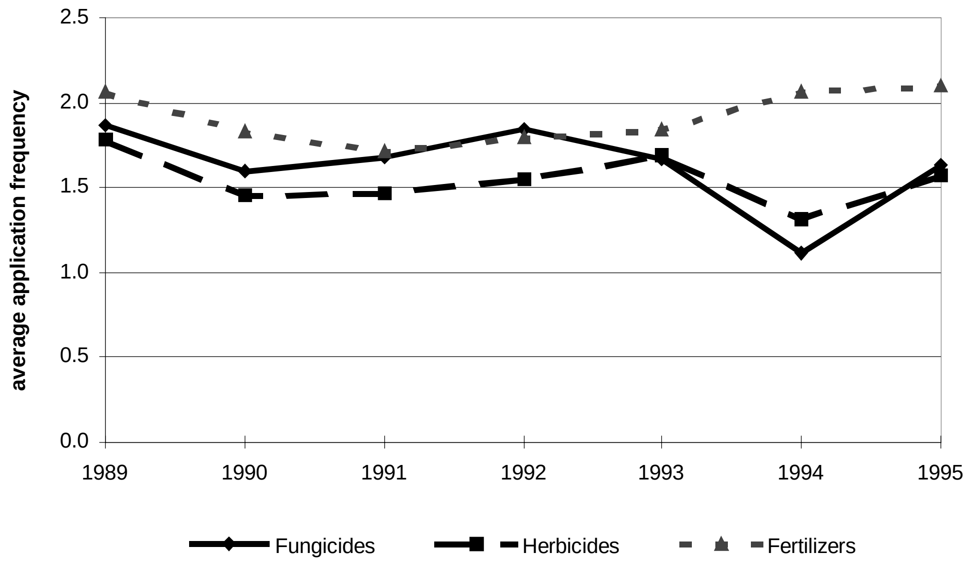
Pesticides account for 10% of variable costs and pesticide applications about 4%. Cultivation measures include all labour costs related to pruning of coffee bushes and of shade trees as well as manual weed control. Manual weed control is assumed to represent less than 1% of the variable production costs. It should be emphasized that these data are not based on empirical findings but on the technology package recommended by ICAFE.

5.3.3.2 Input Use

Over the last few years, ICAFE has interviewed about 100 farmers every year to obtain quantitative information on production technologies. Unfortunately, production costs cannot be derived from these data, because for most inputs they do not specify the quantities used. As far as pesticide use is concerned only the application frequency has been recorded. Neither the name of the product applied nor the per hectare dosages have been registered. Despite this, the data collected can be used as a rough estimate for changes in crop protection intensity between years. In order to facilitate the comparison of application frequency between years a weighted average of the number of applications was computed (number of applications times the percentage of farmers belonging to the respective class).

Looking at Figure 5-7, it is remarkable that the average application frequency of fungicides[34] and herbicides fell considerably in 1994, while the frequency of fertilizer applications increased. Knowing that the average world market coffee prices shot up in May 1994 after a low price period over several years, it is surprising that fungicide and herbicide applications were dropping. The data collected for this research suggests a continuous increase in the application frequency for these inputs from 1993 to 1995 in the northern Central Valley and in the Turrialba region. The differences between the data presented in Figure 5-7 and the findings shown in Chapter 6 are possibly due to differences between the two regions sampled for this study and the overall average in Costa Rica.

Figure 5-7: Average application frequency of fungicides, herbicides and fertilizers



Source: author's computations based on ICAFE (1995d) and ICAFE (1997c)

Table 5-3 shows that the average intensity of fertilizer use in Costa Rican coffee production lies considerably below ICAFE's recommendations. The increase in nitrogen applications in 1994 supports the hypothesis that nitrogen fertilizer is used as a means to adjust short term production intensity to price movements in the coffee market.

[34] Table A 4-2 in Appendix 4 contains the complete data set which shows that a considerable amount of farmers did not apply fungicides at all.

Table 5-3: Average intensity of fertilizer use in Costa Rica's coffee production from 1989 to 1995

	Quantity of Nutrients in kg/ha				
Year	*Nitrogen*	*Phosphorus*	*Potash*	*Magnesium*	*All Fertilizers*
1989	203.2	36.2	88.0	31.5	370.1
1990	198.0	43.8	69.0	22.5	341.1
1991	153.6	24.9	62.5	22.7	271.5
1992	171.3	31.8	77.7	29.1	319.8
1993	175.1	30.6	78.6	27.0	320.5
1994	202.2	39.8	88.4	28.7	369.9
1995	188.9	34.7	32.4	38.9	309.3
ICAFE recom-mendation	300.0	75.0	150.0	50.0	575.0

Source: ICAFE (1994d) and ICAFE (1997c)

Based on the secondary data on production technology presented in this chapter it seems, that the coffee price has a significant impact on the use of nitrogen fertilizer, whereas the correlation between the frequency of pesticide use and coffee prices is not clear.

5.4 Conclusions

Coffee is a suitable crop to study the impact of price changes on input use, for several reasons. Firstly, over the sampling period there were significant price changes in the coffee market to which coffee farmers were directly exposed. Economic theory suggests that coffee farmers adjust their input use accordingly. Secondly, the production technology in coffee is relatively simple and can easily be recorded. This was a precondition for the realization of the survey presented in the following chapter. And thirdly, coffee is one of the most important agricultural crops produced in Costa Rica providing employment for more than 23% of Costa Rica's agricultural working force. Coffee also earns a substantial share of Costa Rica's revenue from agricultural exports. Hence, a policy analysis that focuses on coffee production covers a large share of Costa Rica's agricultural sector.

6 A Survey on Input Use in Coffee Production

In Costa Rica, detailed empirical information on input use in coffee production is scarce. The most important secondary data relevant for this research have been presented in the previous chapter. Since these data are not detailed enough for the quantitative analysis of a pesticide tax, it was necessary to conduct a formal survey on production technology and input use on Costa Rica's coffee farms.

This chapter introduces the design of the survey, explains the data transformations that were necessary in preparation for the quantitative analyses, and gives an overview of the sample using descriptive statistics. The last section discusses the cost structure in Costa Rica's coffee production sector and presents average partial budget computations.

6.1 The Design of the Survey

The overall objective of the survey on input use in Costa Rica's coffee production was to obtain quantitative information on input use and input prices that may be used to assess the impact of price changes on pesticide use and farm income. This section explains how the study areas were selected, how the sample was taken and how the interviews were conducted.

6.1.1 Selection of the Study Areas

After consultation with ICAFE experts, the northern part of the Central Valley (a highly productive area) and the surroundings of Turrialba (intermediate coffee locations) were both included in the survey. These two major coffee producing areas represent a considerable portion of Costa Rica's coffee production and the predominant production technologies. A more detailed plan was then worked out with local agricultural extension officers who assisted in selecting the districts where the survey was carried out.

In the Central Valley, where ideal conditions for coffee production and the highest productivity can be found, interviews were conducted in five cantons (Sto. Domingo de Heredia, Barva de Heredia, Sta. Barbara, Grecia, Naranjo). Sto. Domingo de Heredia, Barva de Heredia and Sta. Barbara are small neighbouring cantons with similar environmental conditions and therefore may be considered as one sampling unit. Naranjo is one of the most productive cantons in Costa Rica where almost exclusively coffee is cultivated. In Grecia quite a few farms grow coffee and sugar cane. In Turrialba, a canton which is close to the Central Valley, some coffee farmers specialize in coffee while others also grow sugar cane.

Most of the farms visited produce only coffee. Those farmers who also grow other crops do not intercrop with coffee, i.e. coffee is always grown in monoculture. Consequently, it was possible to analyse coffee without considering any other production system. Coffee is a perennial crop and therefore short-term decision making does not depend on the other crops. The planting of coffee represents a considerable investment and therefore changes in the cropping pattern can only be made with a medium to long-term perspective.

As the main concern of this study is the influence of prices on the use of pesticides and other inputs, data were collected on input use between 1993 and 1995, a period during which the coffee price fluctuated considerably (see Figure 5-2 in Chapter 5).

6.1.2 Sample Selection

Costa Rica has a huge number of small-scale coffee producers, many of whom grow coffee as a side-business and produce very small quantities. On the other hand, there are many medium-scale farms and a few large-scale farms which make a large contribution to national coffee production. The most recent data on the distribution of coffee farm land are from the 1984 agricultural census. In view of the unequal distribution of coffee farms among the various strata, it is appropriate to draw a stratified sample from the population of coffee farmers. LEVY and LEMESHOW (1991) state that "stratified sampling [...] combines the conceptual simplicity of simple random sampling with potentially significant gains in reliability." They suggest a two-step strategy for constructing strata: firstly the determination of the population parameter to be estimated, and secondly, the stratification of the population with respect to another variable that is thought to ensure that the strata are homogeneous with respect to the variable under consideration. At the same time they consider that "in most practical situations, it is difficult to stratify the population with respect to the variable under consideration, primarily for reasons of cost and practicality" (LEVY and LEMESHOW, 1991). Therefore, the population is often stratified in the most convenient manner, which is reasonable "since it is not common for modern surveys to estimate a single parameter. [...] Clearly, what might be an optimal stratification strategy for one variable providing relatively homogeneous strata, may provide very heterogeneous strata with respect to another variable. It is important for the statistician to consider the scope of the data to be collected before deciding on an appropriate criterion for stratification" (LEVY and LEMESHOW, 1991).

Hence, stratification is useful, even if done in a pragmatic manner. The second important question to be addressed is the size of the sample. In theory, the sample size may be determined by specifying the level of reliability needed for the resulting estimates. This procedure refers to cases in which one single or a few parameters are to be estimated and where variances of the variables are known; which is the exception rather than the rule. As the survey conducted in Costa Rica is very complex and the number of parameters to be estimated is great, it was not possible to completely satisfy the requirements elaborated by statistical science. For this research project a solution had to be found that takes into consideration the information required, their reliability and the resources available.

With regard to Costa Rica's coffee production the sample selection came from two sources of information: firstly, from the up-to-date information on all coffee producers in Costa Rica managed by ICAFE's statistics department; and secondly, from information provided by the 1984 census (see Table 6-1).

The first attempt in the sample selection was to draw a stratified random sample from a computerized data base of all coffee producers in Costa Rica, which is administered by ICAFE. ICAFE collaborated in subdividing the data base of coffee producers into four strata and provided the names of coffee producers belonging to each stratum in the various locations of interest. With this information, stratified random sampling could be conducted that satisfied the major statistical requirements. Unfortunately, ICAFE's data base did not contain the exact addresses of the farmers, but only the district they lived in. In addition, in Costa Rica there are about three times as many coffee deliverers as coffee producers, because during the cropping season, different family members may deliver coffee under their respective names. This made it impossible to identify the individuals selected in the random sampling process.

Consequently, a different strategy had to be followed. Coffee extension officers helped to identify communities that were representative for a sampling district or canton. Within these communities, farmers were randomly selected from the lists of coffee producers provided by the Ministry of Agriculture's local extension agencies and by the coffee mills. These lists contained the names (and sometimes phone numbers) of the farmers and specified the community. In those cases where no information was available for a community, the coffee farmers were selected ad hoc by way of accidental selection after arrival in the community. This selection attempted to adequately represent the various strata of coffee producers as outlined in Table 6-1.

In conclusion, the sample was selected in a three-stage process by identifying firstly the representative cantons, then the representative communities and eventually by randomly selecting coffee farmers from different strata. The approximate size of the total sample drawn from each stratum was determined with the help of the above-mentioned information on production volumes per location and by information originating from Costa Rica's 1984 agricultural census which represents the most recent comprehensive statistics on coffee production. The census contains detailed information on the distribution of farm sizes, area planted and coffee production in the seven provinces[35] of the country.

Table 6-1: Coffee farming in Cartago Province and in the Central Valley according to the 1984 agricultural census

CARTAGO PROVINCE (incl. Turrialba)

Stratum	**No. of Farms**		**Coffee Area**		**Production**		**Productivity**
Farm Size (ha)	*no.*	*in % of total*	*ha*	*in % of total*	*tons*	*in % of total*	*tons/ha*
>0 to <2	2 067	45.63	1 148	6.77	6 655	6.22	5.80
2 to <5	1 132	24.99	2 065	12.18	10 703	10.00	5.18
5 to <10	613	13.53	1 564	9.23	8 046	7.52	5.14
10 to <50	514	11.35	2 932	17.29	16 304	15.24	5.56
50 and above	204	4.50	9 243	54.53	65 305	61.03	7.07
TOTAL	**4 530**	**100.00**	**16 952**	**100.00**	**107 013**	**100.00**	**6.31**

CENTRAL VALLEY

Stratum	**No. of Farms**		**Coffee Area**		**Production**		**Productivity**
Farm Size (ha)	*no.*	*in % of total*	*ha*	*in % of total*	*tons*	*in % of total*	*tons/ha*
>0 to <2	5 807	47.47	3 789	10.05	24 615	9.30	6.50
2 to <5	2 984	24.39	6 390	16.95	41 094	15.52	6.43
5 to <10	1 589	12.99	5 930	15.73	37 980	14.34	6.41
10 to <50	1 526	12.47	11 460	30.41	77 255	29.18	6.74
50 and above	327	2.67	10 119	26.85	83 828	31.66	8.28
TOTAL	**12 233**	**100.00**	**37 687**	**100.00**	**264 772**	**100.00**	**7.03**

Source: Dirección General de Estadísticas y Censos (1984)

35 A province is the second administrative level in Costa Rica.

During the field work in Costa Rica, 346 farmers were interviewed; 128 in the Turrialba region and 218 in the Central Valley. A few interviews could not be completed because the farmers or farm administrators were not willing to give the quantitative information required. Additionally, some farm administrators had only recently been in office and therefore could not give the information, and in a number of other cases, farmers did not remember how they had managed their farms. Therefore, 21 questionnaires had to be excluded from the quantitative analysis. A total of 325 observations were used for the quantitative data analysis as shown in Table 6-2.

Table 6-2: Overview of the sample

CARTAGO PROVINCE (incl. Turrialba)			
Stratum *Farm Size (ha)*	**Population** *no. of farms*	**Sample** *no. of farms*	**Coverage** *farms sampled / all farms*
>0 to <2	2067	43	2.08%
2 to <5	1132	46	4.06%
5 to <10	613	19	3.10%
10 to <50	514	7	1.36%
≥ 50	204	9	4.41%
TOTAL	4530	124	2.74%
CENTRAL VALLEY			
Stratum *Farm Size (ha)*	**Population** *no. of farms*	**Sample** *no. of farms*	**Coverage** *farms sampled / all farms*
>0 to <2 ha	5807	50	0.86%
2 to <5 ha	2984	67	2.25%
5 to <10 ha	1589	36	2.27%
10 to <50 ha	1526	38	2.49%
≥ 50 ha	327	10	3.06%
TOTAL	12233	201	1.64%

Source: Dirección General de Estadísticas y Censos (1984) and field survey

It can be assumed that the amount of coffee produced and total expenditure for inputs are positively correlated. Thus, the decision on the input use of a large farmer has a stronger impact on the market than the input decision of a very small farmer. For this reason big farms are slightly over-represented in the sample.

6.1.3 Data Collection Method, Structure of the Questionnaire and Interview Technique

The surveys were conducted immediately after the 1995/96 harvest when the farmers were aware of their total production in the 1995/96 cropping season. The period following the harvest is a good time for visiting coffee farms because at that time the crop does not require much attention. The interviews were conducted from mid-December 1995 to May 1996, beginning in Turrialba and then moving on to the Central Valley.

Data Collection Method

There are various ways of collecting data on input use in agricultural production, namely recall interviews, on-farm surveys with regular monitoring of the production process and scientific experiments on farms or on research stations. Each of these methods has its advantages and disadvantages, which are briefly discussed below.

Scientific trials provide the most exact data, but in general are not representative for production conditions in the field because they include only a relatively small number of plots with specific environmental conditions.

The second option is regular monitoring on farms, which although not as accurate as experiments, also provides highly reliable data which usually represents a larger proportion of environmental conditions and actual farming practices than scientific trials. However, it is expensive and therefore often limited to smaller sampling areas and fewer farms than recall surveys.

Recall surveys are the third possibility. Such surveys may be conducted on a large number of farms at relatively low cost, which implies that the data gathered are more representative than data obtained through the data collection methods mentioned above. The disadvantage of recall surveys is that the data obtained are likely to be less accurate than data obtained by repeated farm visits or from research station trials. The quality of the information, therefore, depends a lot on the complexity of the survey as well as on the knowledge of the informants and on their willingness to co-operate.

Among these three methods there is an obvious trade-off between accuracy and representativeness. The decision on which method to use depends on the scope of the survey, on the resources available and on the complexity of the production system to be assessed. Highly complex production systems can hardly be documented in a single recall interview, at least not without bearing the risk of collecting incomplete or misleading information.

The production technology in Costa Rica's coffee production is relatively simple with standard activities such as pruning, fertilization, weed management, fungus control and, in a few cases, nematode management. All of these activities are realized at about the same time every year and therefore are easy to remember (see Section 5.3.1). A pre-test of the questionnaire used for this research showed that farmers do remember their input decisions over the year, namely product names, quantities applied and labour used. Some farmers had detailed notes on input use and production, others provided the information on a recall basis.

Input prices could not be obtained at the farms but at the nearest agrochemical shops in the respective regions. Farmers were aware of the quantity of coffee produced over the years, because the entire harvest is delivered to coffee mills, where it is registered and certified by a receipt.

Structure of the Questionnaire

The survey questionnaire was subdivided into various sections focusing on input use in 1995 and the two previous years, as well as on the general aspects of crop protection (see questionnaire in Appendix 5). Three types of data were collected:

- socio-economic information on the farmer and general information on the farm and farm income (including production system, varieties, etc.)
- data on production volume and production technology in 1995 which then was compared to the two previous years
- information on decision making in crop protection and use of non-chemical crop protection

Collection of the Price Data

The most important local agrochemical retailers supplied information on the prices of the various inputs used in coffee production. While the 1995 prices were readily available, it was more difficult to find input prices for 1993 and 1994 at the agrochemical shops. Therefore, much of this information was taken from statistics compiled by Costa Rica's Ministry of Agriculture and Livestock, which conducted semestrial surveys on input prices in all major agricultural regions of the country. The last survey was conducted in mid-1994. These data were used to complement the 1993 and 1994 prices provided by the agrochemical retailers.

Training of Interviewers and Interview Technique

Interviewers were trained during a two-day period which began with an introduction to the objectives of the survey and to the structure of the interviews. Thereafter, a practical exercise took place, in which each enumerator interviewed a farmer in the presence of the whole group. This made a comparison of the different interviews possible and necessary adjustments to the interview technique could be discussed after each interview.

The interview itself first concentrated on the 1995 production technology which was then compared to the two previous years. After collecting data on production technology for 1995, the farmer was reminded of the coffee prices in the two previous coffee years: 1994, when the prices shot up and 1993, with its extremely low prices which had persisted since 1990. It was explained that the main scope of the survey was to compare management practices under different price scenarios. Although most farmers remembered the differences in production technology between these three years very well, such a recall interview bears the danger of incipient errors. However, in view of the simplicity of the coffee production system in Costa Rica and the experience gained when the questionnaire was tested in the field, this data collection method has proved to be suitable for the requirements of this research project.

6.2 Data Processing and Aggregation

The quantitative analysis of this research focuses on input use, production costs and coffee production under various price scenarios. Section 6.2.1 briefly describes the data processing that was necessary to allow the computation of production costs and gross margins. For the estimation of a pesticide demand function further data transformation was necessary. In order to be tractable in the econometric model, the prices and quantities of the various inputs had to be aggregated to indexes.

6.2.1 Initial Steps of Data Processing

This research looks at changes in the average intensity of pesticide use in coffee production which is determined by the dosage per application, the application frequency and the area treated with chemicals. All these factors were considered in the data analysis by dividing the total amount of input use in coffee at each farm by the hectarage under coffee. In other words, input use has been expressed on an average per hectare basis.[36] Average yields were computed in a similar way by dividing the total coffee production per farm by the area planted with adult coffee.

Expenditure for Agrochemicals

The data obtained at the farms and the price data from agrochemical shops had to be transformed in standard measures, in order to be compatible and to allow the computation of expenditures per hectare. Most information provided on the farms referred to 1 manzana (mz), which is equivalent to 0.7 ha. The farmers usually indicated quantities of agrochemicals applied in ounces per backpack sprayer or in ounces per barrel and in numbers of backpack sprayers or barrels applied per manzana. In some cases the quantities of chemicals applied were indicated in litres or kilograms per manzana or per hectare. All of this information was transformed into kg/ha or into litres/ha. At the same time agrochemical prices (CRC/unit) were transformed into CRC/kg or CRC/litre.

With this standardized information at hand, expenditures per ha for the various inputs could be easily computed by multiplying quantities of agrochemicals applied per hectare with the respective prices. Prices provided by the nearest major agrochemical shop were used to estimate production cost as accurately as possible. When a price for a specific product was not available in a location, the respective product price of the neighbouring location was taken. In a few cases, where no price at all was available, the price of a substitute for the pesticide with the same active ingredient was used. This procedure ensured that approximation of the real price paid by the farmer to be as accurate as possible.

Labour Cost

The farmers provided information on wages paid for hired labour and on the labour requirements for the different tasks in coffee production. In most cases, there was a difference between the wages for hard labour such as pesticide application and ordinary labour such as pruning. In general, this wage differential was expressed in a 6-hour work day for hard labour versus an

[36] This analysis does not take into account the overall changes of the area cultivated with coffee which of course have an impact on pesticide use in the coffee sector. However, this would only make sense in a medium- to long-term analysis where changes in the area cultivated under coffee can be explicitly measured. Coffee is a perennial crop and therefore changes in the area cultivated with coffee cannot be considered in a study covering only a period of three years.

8-hour work day for regular labour, with both types being paid the same daily wage. Labour requirements for specific tasks were always indicated in man days presupposing that a man day lasts from 6 to 8 hours, depending on the task. Therefore, it was not necessary to differentiate between different types of work and different rates per hour in the cost calculations.

Harvesting is not paid on a daily basis but depends on the quantity harvested. The unit for payment is one basket with a volume of about 20 litres *(canasta)*.

In the cost analysis no difference was made between family labour and hired labour. This was necessary to make a comparison of small, medium and large farms possible. The bigger the coffee farm the more hired labour is used. For small farmers it can be assumed that the wage is the real opportunity cost for family labour, because small farmers often work on other farms as day labourers in periods when coffee requires little attendance or when coffee prices are very low[37].

6.2.2 Aggregation

According to economic theory, all input prices relevant for coffee production as well as the price for coffee may have an impact on pesticide use in coffee[38]. For practical reasons several inputs have to be aggregated in order to make econometric techniques applicable and operational. Although, as outlined in Chapter 5, the production process is relatively simple and the number of chemicals used per farm is limited, over the whole sample a considerable number of chemicals was used which made it virtually impossible to estimate a demand function for every single product. Issues related to the aggregation of agricultural inputs are discussed in this section.

The formation of price and quantity indexes is not a trivial task. Building aggregates implies the restriction of own- and cross-price elasticities of the goods summarized in an aggregate in relation to other aggregates. DIEWERT and NAKAMURA (1993) define the index number problem as how to "aggregate or summarize individual microeconomic data on prices into a single aggregate price level and individual data on quantities into a single aggregate quantity

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37 Giving a value to family labour implies that the gross margin (GM) calculated in the financial analyses of coffee production in the first place indicates return to capital, land and management (which is qualified labour). The reward for the field work which may also directly benefit the farm household, has already been considered in the cost calculations.

38 Economic theory also suggests the consideration of input and output prices for cropping systems that could be grown instead of coffee. Those could be used to "deflate" prices for inputs used in coffee. These prices are neglected in the following analyses because they only would play a role in a long term perspective when a change in the production system can be envisaged.

level so that the product of the price level times the quantity level equals the sum of the individual prices times the quantities for the commodities to be aggregated". They further state that aggregation over goods encompasses two other aggregation problems, namely the aggregation over time problem and the aggregation over space problem. Both dimensions are relevant for this research which includes cross-sectional and time-series data.

Aggregation embraces two decisions: firstly, the decision on which components to summarize in an aggregate; and secondly, the decision on how to aggregate, i.e. which index to use for aggregation. The first decision can be based on theoretical findings or on plausibility criteria. But what does the index number theory suggest?

6.2.2.1 How to Aggregate?

Two important justifications for aggregation in empirical analysis are briefly discussed in this paragraph: Hicks' theorem for aggregation and Leontief's theorem for aggregation. According to Hicks' theorem an optimization on the basis of aggregates is identical to an optimization on the basis of individual components (goods, inputs), if prices within an aggregate vary proportionally (DIEWERT, 1978). Leontief states that an optimization on the basis of aggregates is identical to an optimization on the basis of individual components (goods, inputs) if the quantities within aggregates change proportionally (DIEWERT and NAKAMURA, 1993). Hence an aggregate is justified, if the goods considered represent a Leontief technology. This theorem suggests inclusion of complementary goods in an aggregate. The question on which theorem is appropriate for a particular aggregation problem may be tested by measuring the proportionality of prices or quantities over time (see DIEWERT and NAKAMURA, 1993).

However, in this research neither the direction of price movements nor the direction of quantity movements can be taken as a reference, because variation over time is not meaningful for panel data with only three time series and many more cross-sectional units. Therefore, inputs have been aggregated following plausibility considerations. First, aggregates were formed for inputs that can be used as substitutes such as herbicides, fungicides, nematicides, foliar nutrients/micro-elements and mineral fertilizers (see Table A 6-1 in Appendix 6). This step of the aggregation which led to indexes for the herbicides, fungicides, etc., i.e. for products that to a considerable extent may be used as substitutes, is in line with Hicks' aggregation theorem. However, some of these chemicals encompass elements of substitutability and complementarity. Several fertilizers, for example, to a large extent may be used as substitutes, in spite of the fact that they are most effective when used as complements.

Foliar nutrients and micro-elements play a particular role because in most cases they are applied in mixture with copper-based fungicides[39]. In fact, there is no empirical information on application without mixtures and therefore these product groups can hardly be separated in the quantitative analysis. Therefore it seems reasonable to form one aggregate of fungicides and foliar nutrients/micro-elements instead of analysing them seperately.

In a second step, an index of all pesticides (including foliar nutrients/micro-elements) was computed. Labour, fertilizer and pesticides are the most important variable inputs in coffee production[40].

6.2.2.2 Which Index is Appropriate?

Among the many index numbers that have been suggested in the index number theory, three standard index numbers have been taken into consideration for the present research, namely the Laspeyres, the Paasche and the Ideal Fisher indexes. The formula used for the computation of the respective price and quantity indexes are shown below. The variables p^1 and q^1 refer to prices and quantities in the base unit, p^t and q^t to prices and quantities in the unit that is compared to the base unit:

Laspeyres price index P_L and Laspeyres quantity index Q_L:

$$P_L = \frac{\sum p^t q^1}{\sum p^1 q^1} \quad \text{and} \quad Q_L = \frac{\sum p^1 q^t}{\sum p^1 q^1} \quad \text{with } t = 1, ..., T$$

Paasche price index P_P and Paasche quantity index Q_P:

$$P_P = \frac{\sum p^t q^t}{\sum p^1 q^t} \quad \text{and} \quad Q_P = \frac{\sum p^t q^t}{\sum p^t q^1} \quad \text{with } t = 1, ..., T$$

39 Atemi (cyproconazole) is the only fungicide that is supposed to be (and in most cases is) applied individually, i.e. not in mixture with foliar nutrients or micro nutrients.

40 In the Central Valley a few cases were identified (n=3), where coffee was irrigated. Because of the insignificance with regard to the whole sample, the water supplies were neglected as variable inputs. In any case, since water is free of charge, only the gazoline for running the pumps would have to be accounted for.

Ideal Fisher price index P_F and Ideal Fisher quantity index Q_F:

$$P_F = \sqrt{P_L * P_P} \qquad \text{and} \qquad Q_F = \sqrt{Q_L * Q_P}$$

The following discussions refer to price indexes but can equally be applied to quantity indexes. Various tests have been developed to assess the consistency of index numbers. DIEWERT (1993b) gives an overview of the test approach to bilateral index numbers[41]. Index number tests analyse, for instance, if the price index is unity when prices and quantities are all equal in the two periods or for the two regions under consideration (*identity test*). The *proportionality test* is another example, that examines whether, when all period t prices are multiplied by α, then the new price index equals α times the old price index. Other tests examine similar plausible assumptions. Most of the nine tests treated by DIEWERT are passed by the Laspeyres, the Paasche and the Fisher indexes. However, all three indexes fail the *transitivity test* which examines if (in case data for three time periods are available), the product of the price index going from period 1 to period 2 times the price index going from period 2 to 3 equals the price index going from period 1 to 3 directly.

Furthermore, the Laspeyres and the Paasche indexes fail in a *test of symmetric treatment of cross-sections or time*. This test examines if a price index equals the reciprocal of the original index when the role of periods 1 and 2 in the price index are interchanged. The Fisher index satisfies this desirable property and therefore in the following analyses is preferred to the Laspeyres and the Paasche indexes[42].

6.2.2.3 Which is the Correct Reference Period?

Having decided which index to use, the next important question arises: which is the suitable reference unit for the computation of the index. In principle, there are two options, namely to use a fixed reference or to formulate indexes according to the chain principle. The latter implies that the basis of an index changes in each period, i.e. in period t, prices and quantities of period t-1 are used as a reference. A chain index takes the form (FEGER, 1995):

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41 If only two units are to be compared, we speak of bilateral indexes, if more than two units are considered, we speak of multilateral indexes. For reasons of simplification, index number tests have been made for bilateral indexes but they can also be applied to multilateral indexes which, in fact, are more relevant in empirical research.

42 For further discussion of the test approach see DIEWERT (1993b).

$P(w^1, w^1, x^1, x^1)$,$P(w^1, w^2, x^1, x^2)$, $P(w^2, w^3, x^2, x^3)$, ..., $P(w^{T-1}, w^T, x^{T-1}, x^T)$ ..
This method is advantageous whenever the basket of goods changes frequently. However, it may lead to large distortions when analysing cross-sectional data, because the value of an index depends greatly on which units are neighbouring. An arbitrary selection of various cross-sectional units may lead to varying results when indexes are computed.

This is an important point because the data set to be analysed in this study originates from a panel of 325 cross-sectional units and three time periods. Biases by forming indexes across cross-sectional units may be significant, whereas it is less probable that the input basket changes considerably over the three periods. Hence, the major advantage of the chain principle, i.e. adjustment of the index to changing baskets, is not relevant for the present study.

Consequently, an index that is less susceptible to arbitrary selection of neighbouring units seems to be more suitable for this analysis. By using an appropriate reference unit the problem of arbitrary selection of neighbouring units may be lessened. A sequence of bilateral indexes referring to a fixed base unit takes the form:

$$P(w^1, w^1, x^1, x^1), P(w^1, w^2, x^1, x^2) , P(w^1, w^3, x^1, x^3), ..., P(w^1, w^T, x^1, x^T) ..$$

Obviously, misspecifications may still occur by arbitrarily selecting a base year and a base region. This can be avoided by using the average of a complete cross-section as the basis for the computations of the index. In this study, the average of 1995 - the most recent year that was documented - has been taken as a reference for the index computations[43].

Price indexes were computed for six sub-regions for each of the three years. These indexes reflect the regional price differences. Quantity indexes were computed for every single farm and each period with an average of the whole 1995 cross-section as a basis. The implications and possibilities for analysing pooled time series and cross-sectional data are discussed in the following section.

43 Therefore, the index $P(w^1, w^1, x^1, x^1)$ which equals 1 actually did not appear in the sample, because all the indexes were related to the sample average and not to a specific observation.

6.2.3 Aggregation and Explanatory Power

To what extent does aggregation modify the original substance of the data? As the previous sections show, this fundamental question in index number theory has been treated by various econometricians. One of the pioneers in this subject is THEIL (1957), who demonstrated various errors that result from aggregation under the assumption that micro equations are perfectly specified. Hence, a major concern in econometrics has been the loss of information when building aggregates.

On the other hand, aggregates frequently yield better results in econometric modelling than micro-data analyses, which at first glance is surprising. GRUNFELD and GRILICHES (1960), for example, argue that in applied econometrics aggregated data can provide more consistent results than disaggregated data. They challenge the hypothesis that micro equations can be perfectly specified and state that in practice researchers do not know enough about micro behaviour to be able to specify micro equations perfectly. GRUNFELD and GRILICHES (1960) conclude, that aggregation does not only produce an aggregation error, but may also produce an aggregation gain, which in fact frequently reduces specification errors. They show for regressions on investment in several industries and for the estimation of regional fertilizer demand in the USA, that aggregation increases the explanatory power of their econometric models.

"The fact that the aggregate R^2 is usually higher than the micro R^2 is due mainly to what may be best called a 'grouping' or 'synchronization' effect. It is the result of the empirical fact that most of the groupings that are likely to be used are such that aggregation will increase the variance of the denominator of R^2 relative to its numerator. The synchronization effect can be expressed as follows: the higher the correlation between the independent variables of different individuals or behavioural units, ceteris paribus, the higher the R^2 of the aggregate equation relative to the R^2s of the micro equations" (GRUNFELD and GRILICHES, 1960). GRUNFELD and GRILICHES (1960) further suggest that measurement errors in the independent variables and "in particular, the poor quality of micro data may be another source of aggregation gain".

In conclusion, it can be summarized that there is no doubt that micro equations are to be preferred whenever perfectly specified. However, it is not possible to capture all aspects of individual behaviour in micro equations, i.e., perfectly specified micro equations do not exist. Under these circumstances aggregation may lead to better results than estimation with micro data. GRUNFELD and GRILICHES (1960) further consider that "most of our economic theory, though couched in micro language, has really been derived with aggregates in mind. It is a theory that explains 'average' behaviour, never claiming to be able to explain the behaviour of a particular individual."

In their case studies, GRUNFELD and GRILICHES (1960) refer to aggregation over observations. In order to take full advantage of the micro data collected, no aggregates over observations will be built. However, the question if aggregation over variables may also lead to more conclusive results of the regression estimates will be relevant.

6.3 An Overview of the Sample

The following sections give a statistical overview of the sample and at the same time lay the ground for the econometric analyses and simulations conducted in Chapters 7 and 8.

6.3.1 Area, Yield and Location of the Coffee Farms

Table 6-3 gives an overview of the distribution of the area planted with coffee in 1995, the 1995 yields and the average prices paid for the 1995/96 harvest. Several descriptive statistics are used to characterize the complete sample and each regional subsample. The mode and median values show that more small farms have been interviewed than large farms. The mean value is misleading in this presentation. It is relatively high because a few huge coffee haciendas have been included in the sample, one of which grows more than 500 ha of coffee. Therefore the average farm size of farms interviewed in the Turrialba region is higher than the average farm size of the sample in the Central Valley, although in Turrialba the proportion of small farms included in the sample exceeds the proportion of small farms in the Central Valley. Table 6-3 includes only a subsample of 320 observations from the total of 325 farms investigated as at five farms no information on yields could be obtained.

Table 6-3: Overview of coffee area, coffee yields and coffee prices in the 1995/96 cropping season

Variable	N	Mode	Median	Mean	Standard Deviation	Minimum	Maximum
Sample							
Area planted with coffee (ha)	320	1.4	3.5	14.41	53.90	0.35	749.00
Yield (fan*/ha)	320	35.71	34.75	36.23	15.08	6.43	85.71
Coffee price for the 1995/96 harvest (CRC/DHL)	320	14392	17251	16303.91	1719.98	14107.30	18368.50
Turrialba							
Area planted with coffee	124	1.4	2.72	19.80	81.59	0.50	749.00
Yield (fan*/ha)	124	28.57	32.14	33.47	12.77	8.33	68.10
Coffee price for the 1995/96 harvest	124	14392	14392	14376.52	138.99	14107.30	14600.80
Central Valley							
Area planted with coffee	196	2.1	3.94	11.00	22.87	0.35	217.00
Yield (fan*/ha)	196	35.71	35.71	37.98	16.16	6.43	85.71
Coffee price for the 1995/96 harvest	196	17719	17718	17523.29	985.16	15350.66	18368.50

* fan = fanega (=400 litres), DHL = double hectolitres (200 litres)

Source: author's field survey

The statistics displayed in Table 6-3 show a wide range of different farm sizes and yield levels across the regions sampled. The large standard deviation for coffee yields can partly be explained by the biannual coffee production cycle with one year of high production followed by a year with low production. But there are other important reasons for the yield differences between the farms.

First, climate conditions are different; above all according to the altitude of farms. The farms in the Turrialba region are situated between 600 m and 1200 m above sea level, while the farms in the Central Valley are located between 1000 m and 1450 m above sea level. The altitude has a great impact on the yields but also on the quality of the coffee. Furthermore, the soils are different in the various locations. ROJAS (1987) has classified locations according to their suitability for coffee production according to an index which includes temperature, precipitation and soil parameters. Although this information is not detailed enough to be used in the econometric analyses, it illustrates differences in the agroclimatic conditions for coffee production which vary not only between the two regions included in this sample, but also within each region.

Second, the production technology differs between farms. This applies to fixed as well as to variable inputs as will be shown in the following sections.

6.3.2 Fixed Factors in Coffee Production

In addition to the environmental conditions for farming, the production system and the technology used highly influence the productivity of a farm. Production systems are mainly characterized by the planting density of coffee which is closely related to the question of whether coffee is grown under shade or not. The most significant fixed cost in coffee production is crop establishment. Planting coffee requires both labour and machinery, first to clear the field and prepare the soil and then to plant the coffee seedlings.

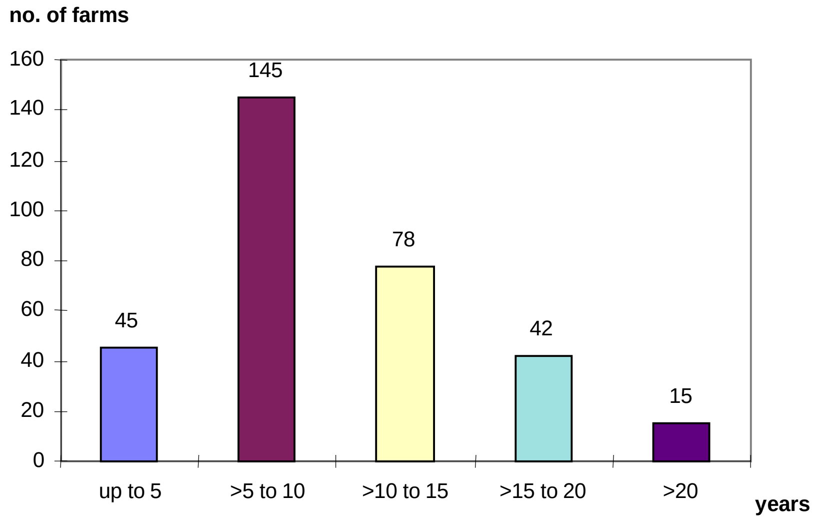
The choice of a cultivar and the number of bushes planted per hectare are major determinants of the productivity of a coffee field. Seedlings in most cases are purchased. After planting coffee, it takes about three years until the plantation has reached its full production potential.

Age of the Plantations and Varieties Used

Figure 6-1 shows that the average age of the coffee plantations varies greatly over the sample. This factor has an impact on both the use of variable inputs and on the productivity of farms.

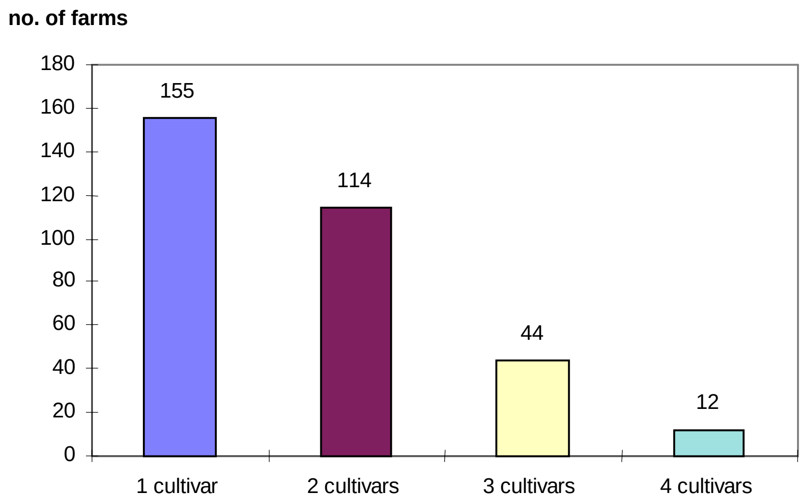
The heterogeneity of coffee plantations with regard to the varieties grown is often an indicator of the intensity of coffee production. Figure 6-2 displays a frequency distribution for the number of cultivars per farm. All the farms visited grow modern varieties, at least on a part of their coffee plantation. Farms that have one or two cultivars in general have more modern production systems, while farms with 3 or 4 cultivars usually do not renew their coffee plantations on a continuous basis, but retain their old cultivars.

Figure 6-1: Average age of the coffee plantations sampled in 1995



Source: author's field survey

Figure 6-2: Number of coffee cultivars per farm in 1995



Source: author's field survey

Coffee under Shade versus Coffee without Shade

Coffee under shade can be found in about 72% of the coffee area included in this survey. However, since the soil coverage due to shade was not specified, it is difficult to quantify the effect of shade on coffee production. Therefore, the inclusion of a shade dummy to the estimation of pesticide demand did not lead to any significant results.

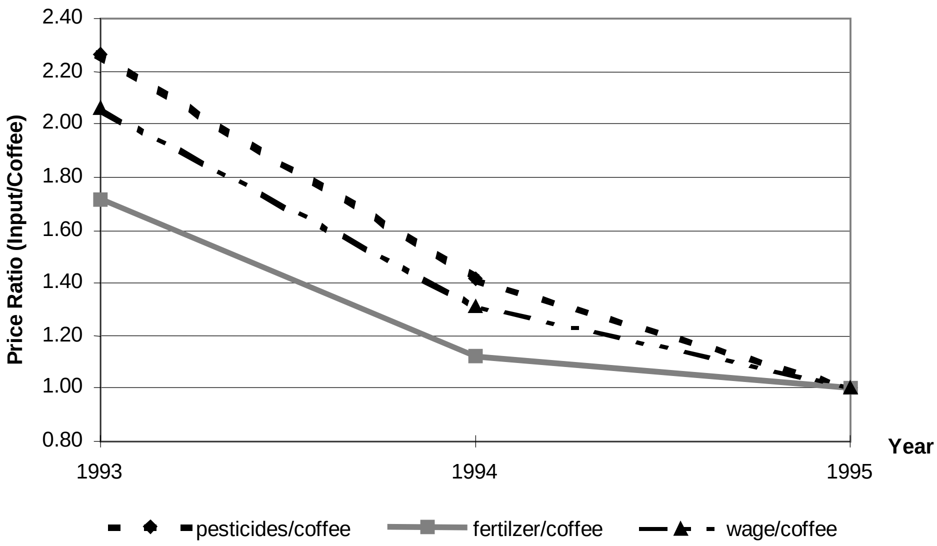
Pruning Technique

Pruning of the coffee bushes in principle may be considered as a variable input. However, the decision on what pruning system to use is a decision affecting several years and may not be changed in the short term. All the pruning techniques described in Section 5.3.1 are represented in the sample.

6.3.3 Variable Inputs in Coffee Production

The use of variable inputs is influenced by the product price and by input prices. Figure 6-3 shows that the price ratio between major inputs and coffee has continuously decreased between 1993 and 1995.

Figure 6-3: Ratio between aggregated input prices and the coffee price (1995 = 1)

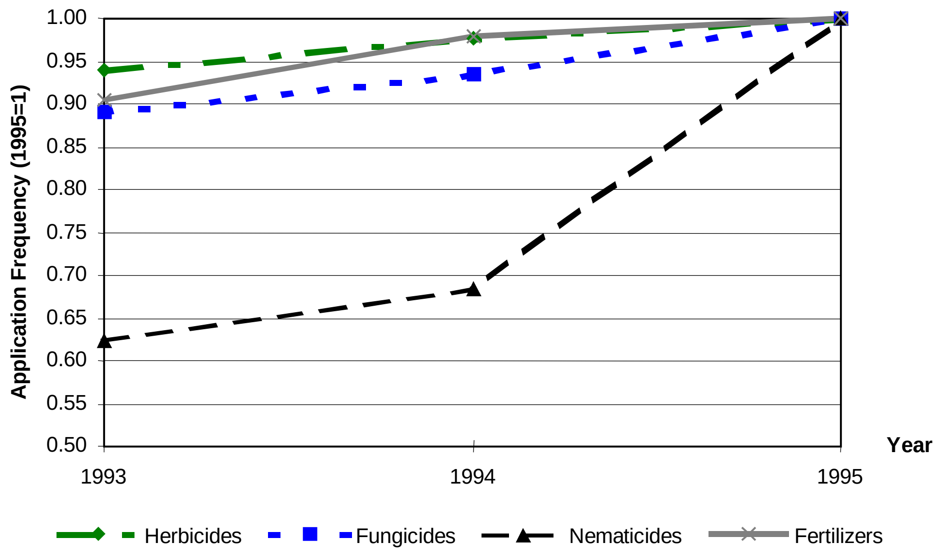


Source: ICAFE, personal communication, and author's survey on input prices

6.3.3.1 Agrochemical Use

The data collected in the Turrialba region and in the Central Valley show a continuous increase in the frequency of agrochemical applications in the study period (Figure 6-4).

Figure 6-4: Application frequency for agrochemical inputs (1995=1)



Source: author's field survey

The application frequency is a very rough measure for the intensity of pesticide use[44]. More meaningful analyses may be conducted by comparing aggregate quantity indexes for agrochemicals as done in Figure 6-5. The quantities refer to formulated pesticides, not to active ingredients. For all the product groups, the increase in amounts applied from 1993 to 1995 is more pronounced than the increase in the application frequency which implies that the dosage per application has also increased between 1993 and 1995.

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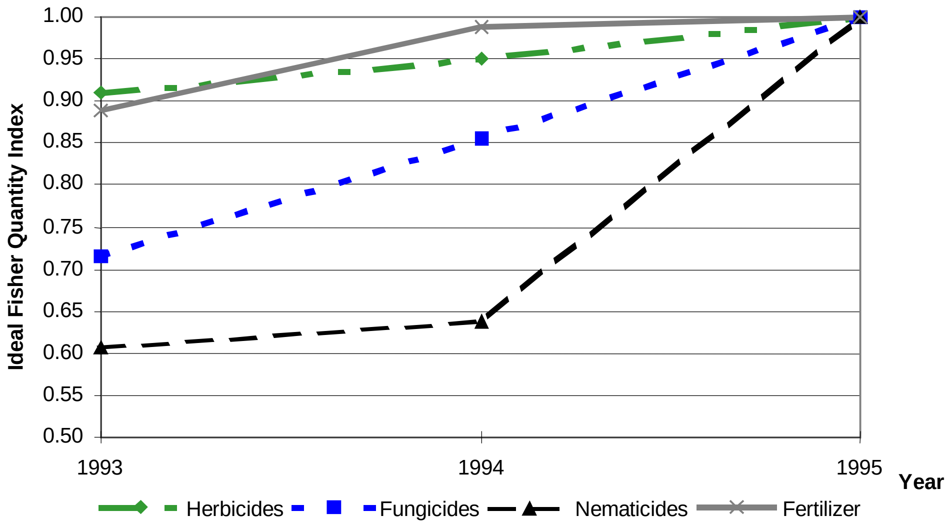
44 The empirical studies on input use in Costa Rican coffee production conducted so far have only recorded the application frequency of agrochemical inputs. Although more detailed information has been collected in this survey, the application frequency is displayed in order to make the data on input use comparable to existing information.

Figure 6-5: Application quantity of agrochemical inputs (1995 = 1)



Source: author's field survey

Pesticide use varies strongly between the farms. Table 6-4 shows descriptive statistics on the use of the most frequently used pesticides in Costa Rica's coffee production. The following statistics represent the average amount of formulated product in kilograms and/or litres per hectare and year. The data do not refer to single plots but are farm averages of the area under adult coffee. The data presented were extracted from the panel data set with 325 cross sections over three years, i.e. from 975 observations.

Nematicides and the WHO II herbicides (paraquat and 2,4 D) figure among the most toxic substances presently used in coffee production in Costa Rica. Nematicides used in coffee are classified as extremely hazardous or highly hazardous by the World Health Organization (WHO), while paraquat and 2,4 D are classified as moderately hazardous. Nematicides, which are usually applied once a year, were used in about 18% of all observations. The recommended dosage is 10 g per plant which is equivalent to approximately 50 kg to 80 kg per hectare, depending on the planting density (ICAFE, 1989). Farmers generally follow this recommendation, however, there are cases of strong overuse with applications of more than 200 kg of nematicides per hectare.

Table 6-4: Average annual application of selected pesticides from 1993-1995 ([kg or l]/ha/year)

Pesticide Name	Type*	No. of observations (total=975)	Mean	Std. Dev.	Minimum	Maximum
Atemi	F	421	1.20	1.35	0.03	10.71
Bayleton	F	32	1.28	1.27	0.26	4.58
Benlate	F	29	1.22	1.61	0.21	5.71
Cobre Sandoz	F	219	3.21	2.88	0.12	21.42
Coopecide	F	8	6.16	3.66	2.14	11.42
Cupravit	F	25	4.11	3.59	1.07	12.86
Kocide	F	209	3.17	2.08	0.17	12.87
2,4 D	H	198	1.99	1.80	0.07	8.58
Diuron	H	12	5.83	5.58	0.71	14.28
Evigras	H	30	3.32	2.37	0.36	8.80
Gardoprim	H	309	3.05	2.44	0.08	12.87
Gesaprim	H	4	3.93	0.71	2.86	4.28
Goal	H	278	1.35	1.21	0.02	8.56
Paraquat	H	780	3.57	2.72	0.12	16.23
Round up	H	487	2.58	3.11	0.07	25.71
Sagecoop	H	43	3.34	3.37	0.26	14.28
Tebutilazina	H	12	9.75	11.41	1.43	28.58
WHO II**	H	798	3.98	3.17	0.12	17.16
Nematicides	N	173	31.87	33.35	0.15	214.29

* F = fungicide, H = herbicide, N = nematicide

** WHO II refers to paraquat and 2,4 D which are the WHO II pesticides used in Costa Rican coffee production.

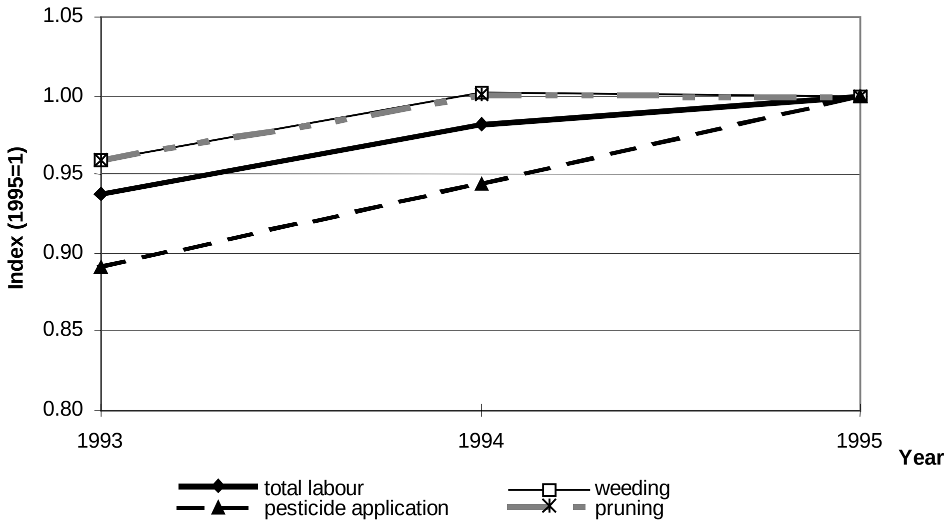
Source: author's field survey

Paraquat, which is known for its negative environmental and health impact, is a herbicide commonly used in coffee production. It has been used in 80% of all cases investigated in this survey. ICAFE (1989) recommends a dosage of 2 litres/hectare per application which in most cases is followed. Taking the average application frequency for herbicides as a reference which is about two (see Figure A 6-1 in Appendix 6), this would imply about 4 litres of paraquat per hectare and year. The mode of paraquat use in coffee production is 2.6 litres and the median is 2.5 litres per hectare and year. These two figures show that in most cases, the coffee farmers apply less than the recommended dosage. However, the mean of paraquat use is close to 4 litres per hectare and year and there are extreme cases with applications of up to more than 16 litres per hectare and year.

6.3.3.2 Labour Use

This section gives an overview of the labour intensity in Costa Rica's coffee production between 1993 and 1995. Labour is used for pruning and other cultural techniques, for pest management, fertilizer application and for harvesting. To some extent labour is also used for replanting, an activity which is not considered to be part of the variable production technology and therefore has been neglected in this study.

Figure 6-6: Labour use in coffee production from 1993 to 1995 (1995=1)



Source: author's field survey

Figure 6-6 shows that labour use has increased considerably between 1993 and 1995. Labour use in manual weeding and pruning increased in 1994 and remained at this level until 1995. Labour used for pesticide applications rose continuously from 1993 to 1995, which is in accordance with the development of the pesticide application frequency (see Figure 6-4).

6.4 Cost Structure and Gross Margin in Costa Rica's Coffee Production

The quantitative information collected in Costa Rica constitutes a panel of 325 cross-sections over three consecutive years. Extensive information on input use in coffee production is available that may be used for various types of statistical analyses. This section focuses on the cost structure of coffee production which represents the production technology. Cost structures may vary between years, between regions or depending on the size of a farm. For this research all three aspects are important.

6.4.1 Testing for the Normal Distribution

Many standard statistical procedures presuppose that the variables under consideration are normally distributed. Therefore, before applying these procedures, the normality assumption should be tested. The data collected in Costa Rica was first analysed with a SHAPIRO-WILK test for normal distribution (SHAPIRO and WILK, 1965) to find out whether the normality assumption holds. The SHAPIRO-WILK test starts from the null hypothesis that the variable of interest is normally distributed. The test statistic W[45] must be greater than zero and less than or equal to one, with small values of W leading to rejection of the null hypothesis. (SAS INSTITUTE, 1988a).

Table 6-5 contains the test statistics for the distribution of key variables over the panel sampled:

Table 6-5: SHAPIRO-WILK test for normal distribution

Variables tested	**W-value***	Prob<W
Yield	0.961	0.0001
Variable cost	0.969	0.0001
Expenditure for pre-harvest inputs**	0.868	0.0001
Expenditure for pesticides	0.782	0.0001
Expenditure for manual weed control	0.765	0.0001
Expenditure for fertilzer	0.578	0.0001
Expenditure for manual labour (excluding the costs of pesticide application and harvest)	0.912	0.0001

* W-value calculated with the Shapiro-Wilk statistics

** "Pre-harvest inputs" include expenditures for pesticides, foliar nutrients, fertilizers and manual labour for the application of agrochemicals, weeding, pruning and tree cutting, i.e. all the variable costs with the exception of harvesting and interest. Expenditure for harvesting is excluded because it depends strongly on the biannual production cycle and therefore would distort the information on production technology.

All the W-values are greater than 0.5, with most of them being even greater than 0.75. In conclusion, the null hypothesis that the variable is normally distributed cannot be rejected, and so the standard statistical procedures that presuppose a normal distribution of the variables concerned may be applied to these data.

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45 W is the ratio of the best estimator of the variance (based on the square linear combination of the order statistics) to the usual corrected sum of squares estimator of the variance.

6.4.2 Are there Differences in the Cost Structures Between Years, Regions and Farm Sizes?

This question is important for the subsequent steps of the analysis, in particular for the cost structure to be used in the partial budget computations. If the variation in cost structures between the years represented in the sample is not significant, it will suffice to take one cross-section as a reference for the partial budget analyses. Otherwise, it would be preferable to use an average over the three years represented in the panel. Similar considerations apply to differences according to region or to area planted with coffee. Significant regional differences or significant differences according to area under coffee would require differentiated analyses of partial budgets and of income effects of a pesticide tax.

In this context, three *t*-tests were carried out. Initially a test was made as to whether there were significant differences in the cost structure between 1993 and 1995, when the ratio of input prices and the coffee price differed most (see Figure 6-3). One would expect a significant increase in input use from 1993 to 1995 because the ratio of input prices to the coffee prices decreased considerably in this period. Table 6-6 shows that the variable costs and the pre-harvest inputs differed significantly between 1993 and 1995. Analysing the different types of variable inputs, it is shown that the differences in expenditure for pesticides were most pronounced, while the variation with respect to other inputs was not significant.

Table 6-6: *t*-test for variation in yields and inputs between 1993 and 1995

Variables tested	**H_0: 1993 = 1995**	
	t statistic	Prob>|T|
Yield	-1.401	0.1617
Variable cost	-8.070	0.0000
Expenditure for pre-harvest inputs*	-2.557	0.0079
Expenditure for pesticides	-5.323	0.0001
Expenditure for manual weed control	-0.430	0.6674
Expenditure for fertilzer	-1.063	0.2885
Expenditure for manual labour (excluding the costs of pesticide application and harvest)	-0.750	0.4534

* see definition in Table 6-5

The second *t*-test examined whether the cost structure differed significantly between the Turrialba region and the Central Valley (Table 6-7).

Table 6-7: *t*-test for variation in yields and inputs between the two regions

Variables tested	H_0: Turrialba = Central Valley	
	t statistic	Prob>|T|
Yield	-5.267	0.0001
Variable cost	-1.778	0.0757
Expenditure for pre-harvest inputs*	-2.480	0.0134
Expenditure for pesticides	-11.245	0.0001
Expenditure for manual weed control	2.257	0.0244
Expenditure for fertilzer	0.398	0.6912
Expenditure for manual labour (excluding the costs of pesticide application and harvest)	6.679	0.0001

* see definition in Table 6-5

The results of this t-test support the hypothesis that there are differences in the production technology between the two regions, with the exception of fertilizer use. Based on the secondary information gathered about coffee farming in these two regions, this result is not surprising.

Thirdly, tests were carried out to assess whether there were any significant differences in the cost structure between farms with up to 5 ha and those with more than 5 ha under coffee. This subdivision of coffee farms was adopted from ICAFE which analyses the productivity of coffee farms accordingly (see Figure 5-4)[46]. This distinction produced the most significant test results (Table 6-8).

Table 6-8: *t*-test for variation in yields and inputs according to the coffee area per farm

Variables tested	H_0: coffee area ≤ 5 ha = coffee area > 5 ha	
	t statistic	Prob>|T|
Yield	-2.907	0.0037
Variable cost	-3.150	0.0017
Expenditure for pre-harvest inputs**	-4.421	0.0000
Expenditure for pesticides	-8.239	0.0001
Expenditure for manual weed control	4.169	0.0001
Expenditure for fertilzer	-2.571	0.0103
Expenditure for manual labour (excluding the costs of pesticide application and harvest)	2.817	0.0050

* see definition in Table 6-5

[46] This stratification is supported by the results of *t*-tests for differences between the two lowest strata (i.e. up to 2 ha and from 2 to 5 ha), which were not significant.

The null hypothesis of no differences in production technology between the two types of farms mentioned is rejected.

All three *t*-tests produced results that suggest significant variations in production technology not only between years, but also between regions and for different farm classes. The results of the *t*-test that compares the 1993 with the 1995 production technology suggest that there may be an influence of prices on input use. The test statistic for pesticide expenditure was one of the most significant results.

A comparison of the three *t*-tests conducted shows that the size of the area cultivated with coffee leads to the most significant test results. This indicates that special attention has to be paid to farm size in any the subsequent analyses of production costs.

In conclusion, cost and partial budget analyses are best conducted using an average taken from the whole panel (3 cross sections of 325 observations each). At a later stage of the analyses, the average partial budgets will be used to assess the impact of pesticide taxes on farm income. In addition to the analysis of the overall impact of pesticide taxation on the coffee sector, it will be necessary to examine the impact of taxes in detail for the different farm sizes.

6.4.3 Variable Production Costs in Coffee Production

This section examines the structure of variable production costs in coffee focusing on expenditures for agrochemicals and labour except labour for harvesting. All of the values presented refer to per hectare averages and are expressed in CRC of 1995. Interest on working capital will not be included in this part of the analysis. This section gives a general picture of expenditures for major inputs by comparing sample average cost structures to cost structures for each region and according to farm size.

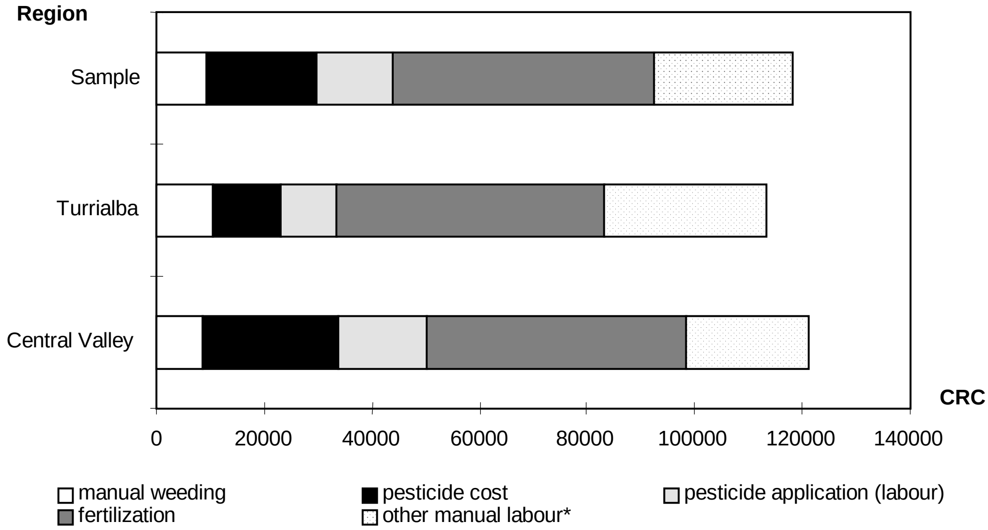
Costs of Pre-harvest Variable Inputs

Expenditures for variable inputs (except harvesting) represent the variable technology used in coffee production. On average, fertilizer application accounts for approximately 43%, pesticides for about 15% and the cost of pesticide application for about 13% of the pre-harvest inputs[47]. Fertilization

[47] The "pre-harvest inputs" include expenditure for pesticides, foliar nutrients, fertilizers and manual labour for the application of agrochemicals, weeding, pruning and tree cutting, i.e. all the variable costs with the exception of harvesting and interest. Harvest expenditures are excluded because

includes expenditure for mineral fertilizer and its application as well as the cost of foliar nutrients. Manual weed control represents about 8%, and manual labour related to pruning about 21% of the expenditure for the average pre-harvest inputs in coffee production.

Figure 6-7: Pre-harvest variable production costs in the regions included in the sample (in 1995 CRC/ha)



* other manual labour = all labour related to the pruning of the coffee bushes and of the shade trees

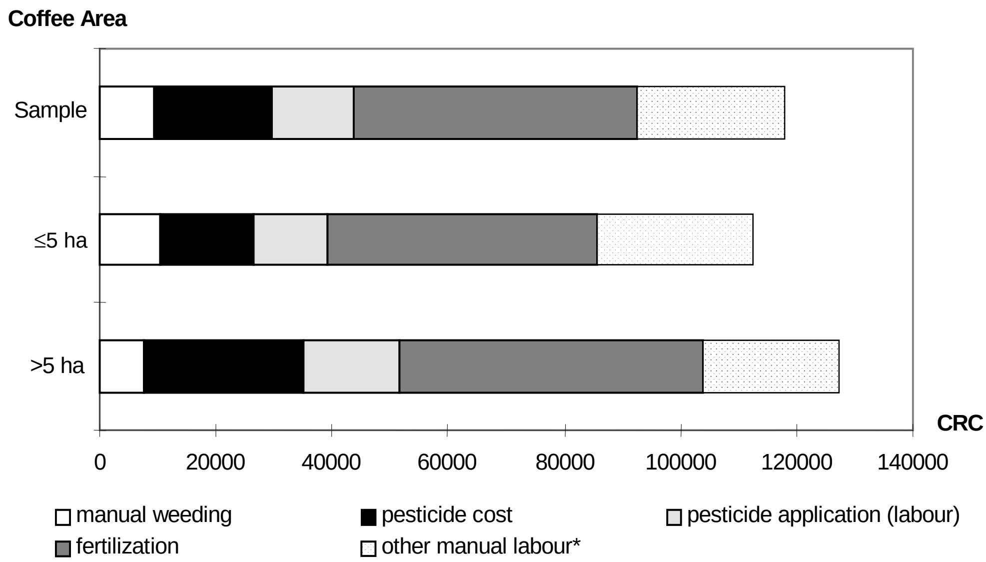
Source: author's field survey

Figure 6-7 shows that expenditures for pesticides are almost twice as high in the Central Valley than in the Turrialba region. This is due to the more frequent application of fungicides and nematicides. Herbicide use and the cost of manual weed control are higher in the Turrialba region than in the Central Valley, mainly because of the humid climate in Turrialba which favours the growth of weeds. Average expenditures for the pre-harvest variable inputs in the Central Valley exceed those in the Turrialba region by 9%.

The difference in expenditure for variable inputs is even more pronounced when comparing coffee plantations of up to 5 ha (small plantations) with coffee plantation greater than 5 ha (big plantations). Big plantations spend about 14% more for pre-harvest inputs than small plantations (see Table A 6-2 in Appendix 6). Figure 6-8 shows that small farms use more manual labour in pest management than big farms.

they depend on the biannual production cycle and would therefore distort the information on production technology.

Figure 6-8: Pre-harvest variable production costs according to the coffee area (in 1995 CRC/ha)



* other manual labour = all labour related to the pruning of the coffee bushes and of the shade trees

Source: author's field survey

6.4.4 A Detailed Partial Budget for Costa Rica's Coffee Production

The computation of partial budgets for coffee production in Costa Rica is not a simple task because various time lags have to be taken into account. First, there is a time lag between the decision on input use and the harvest. As mentioned in Chapter 5, one cropping season is about 12 months. Second, there is a time lag between delivering the harvest to the coffee mills and payment to the farmer. Coffee is paid for in three to four shares over a period of 12 months. Both time lags need to be considered in the partial budget analysis.

Interest for working capital was computed following the methodology used by ICAFE (1995e): working capital is defined as pre-harvest variable production costs which on average are fixed for half a year. Following ICAFE, an interest rate of 32% was applied to working capital over a period of six months.

Payments for the harvest which are made in several shares over a year have been discounted over six months at the average interest rate for 6-month government bonds. As in the cost analysis, the factor 0.5 takes account of the fact that only a part of the payments is fixed over the whole year, while the other parts are paid immediately after the harvest or after a few months.

Before computing the average for the whole sample, all costs and revenues for the 1993 and 1994 observations were expressed in 1995 prices. Expenditures for inputs were transformed with the aid of the respective Ideal Fisher Price Indexes; coffee revenues were transformed using the appropriate consumer price indexes (CPI). Table 6-9 presents a detailed overview of the 1993-1995 average of variable production costs for coffee disaggregated by pesticide use, fertilizer and labour.

The pre-harvest inputs referred to in the previous section account for less than 50% of variable production costs, because harvesting is by far the most expensive activity. Expenditures for herbicides and fungicides are equally important, while the cost of nematicides is less significant.

Herbicides are subdivided into hazardous herbicides and other herbicides. This distinction refers to the damage reported by coffee farmers and is in line with the toxicity classification proposed by the World Health Organization (WHO)[48]. Herbicides that were found to be problematic in coffee production belonged to the WHO class II and the other herbicides belonged to WHO classes III and IV. A study of health registers at the Turrialba hospital revealed that most occupational poisonings in coffee production requiring hospitalization occurred when nematicides were applied. The nematicides used in coffee production belong to the WHO class Ia or Ib pesticides, i.e. they are classified as extremely hazardous or highly hazardous, respectively. Both, nematicides and WHO class II herbicides represent a minor share of the variable production costs in coffee.

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48 The WHO classification presupposes judicious use of pesticides. When used appropriately the WHO-classification stands for: WHO Ia = extremely hazardous, WHO Ib = highly hazardous, WHO II = moderately hazardous, WHO III = slightly hazardous, WHO IV = not hazardous

Table 6-9: Sample average of variable production costs for coffee (in 1995 CRC/ha)

	CRC	in % of variable costs
pesticides	**18488.95**	**6.76%**
WHO II herbicides	2633.60	0.96%
other herbicides	6148.40	2.25%
fungicides	7302.19	2.67%
nematicides	2404.76	0.88%
pesticide application	**16289.03**	**5.96%**
herbicide application	8444.06	3.09%
fungicide and foliar nutrient application	7417.77	2.71%
nematicide application	427.20	0.16%
fertilization	**52374.72**	**19.15%**
foliar nutrients	3644.94	1.33%
fertilizer	43125.17	15.77%
fertilizer application	5604.61	2.05%
manual labour	**34888.40**	**12.76%**
manual weeding	9334.74	3.41%
pruning etc.	25553.66	9.34%
interest	**19475.33**	**7.12%**
harvesting	**131989.85**	**48.26%**
variable costs	**273506.28**	**100.00%**

Source: computations based on the author's field survey

This cost computation does not include costs for transportation of coffee and inputs or the cost of social security payments, because these were not recorded in the survey[49]. Furthermore, it should be kept in mind that coffee is a perennial crop and therefore requires major investment in the initial period. According to ICAFE's model calculations, the variable production costs represent approximately two-thirds of total production costs (ICAFE, 1995e).

The average revenues per hectare between 1993 and 1995 were CRC 566,663 (at 1995 prices) or approximately two times variable costs.

49 According to model cost calculations by ICAFE (1995e), transportation costs and social security payments in 1995 represented about 7.4% and 7.5% of variable costs of coffee farming, respectively. Hence, the actual variable costs of production are likely to be about 15% higher than the totals computed in Table 6-9.

Table 6-10: Revenue, variable costs and gross margin (in 1995 CRC/ha)

	CRC	in % of revenue
revenue	566663.52	100.00%
variable costs	273506.28	48.27%
gross margin	293157.24	51.73%

Source: author's computations based on the field survey

Tables A 6-2 and A 6-3 in Appendix 6 show the partial budgets for both the farms that grow up to 5 ha of coffee and the farms that grow more than that. Variable per hectare production costs on the big farms are about CRC 26,000 higher than those on the small farms. However, this cost difference is more than offset by the higher yields and higher revenues obtained on the big farms. The average per hectare revenues on the big farms are about CRC 73,500 higher than those on the small farms. Hence, the difference in the gross margin is about CRC 47,500/ha.

6.5 Conclusions

The statistical analyses conducted in Chapter 6 have shown that the use of agrochemicals and of labour has risen significantly from 1993 to 1995, which is related to the increase in world market coffee prices during this period. Furthermore, it is evident that yields and the use of variable inputs also differed significantly between the two regions included in the sample and between different farm sizes. The most significant differences were found when comparing input use according to farm size.

Expenditures for pesticides on average total about 7% of variable production costs. Hence, an increase in pesticide prices is not likely to affect significantly the costs of coffee production. The partial budget analysis revealed that between 1993 and 1995 the variable costs of production on average were equivalent to about 50% of the revenue obtained with coffee. In a situation where a pesticide tax is introduced, the percentage increase in variable production costs reflects approximately the percentage decrease in the gross margin. At this point, it is interesting to note that expenditures for pesticides take up a higher share of variable production costs on big farms than on small farms (see Table A 6-2 in Appendix 6).

7 The Econometric Estimation of Pesticide Demand

The analysis of pesticide demand is a precondition for the appropriate design of policies that affect pesticide prices. Econometric estimates conducted by OSKAM ET AL. (1992) and by AALTINK (1992) suggest that pesticide demand is rather inelastic, implying that taxes on pesticides would have little impact on pesticide use unless they were set prohibitively high. Low price-elasticities of pesticides also imply that there are few options for the substitution of pesticides in agricultural production resulting in high costs to the agricultural sector in case pesticide prices rise[50].

This chapter deals with the estimation of pesticide demand in Costa Rica's coffee production. It first concentrates on the methodological questions such as the identification of a suitable panel model and of the appropriate functional form, and then discusses the results obtained in the econometric estimates.

7.1 The Analysis of Panel Data

Pooling cross-sectional and time series data has become common in empirical studies, which is reflected in a growing literature on the analysis of panel data. The following sections address the most important features of panel data analysis which relate to this empirical study. It compares panel data analysis to an ordinary least squares (OLS) regression on pooled data, and briefly discusses panel models that are relevant to this study.

Panel data offer researchers many more possibilities than purely cross-sectional or time series data. Panel data sets usually include a large number of data points, which increase the degrees of freedom, reduce the collinearity among explanatory variables, and hence, improve the efficiency of econometric estimates (HSIAO, 1986). Furthermore, panel data provide possibilities for lowering the estimation bias by reducing or eliminating the omitted variable bias[51] through a number of data transformations. This is

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50 SAHA, SHUMWAY and HAVENNER (1997) found that a misspecification of the production function can result in "gross underestimation of the demand responsiveness of an increase in pesticide prices". They further concluded that "such an underestimation could result in severe hardship to the agricultural community and a welfare reduction to society in general when a policy intended to restrict pesticide usage to critical applications results de facto in an outright ban."

51 "A standard assumption in statistical specification is that the random-error term representing the effect of omitted variables is orthogonal to the included explanatory variables. Otherwise, the estimates are subject to omitted variable bias when these correlations are not explicitly allowed for." (HSIAO, 1995:362)

possible when the correlations between included explanatory variables and the random-error terms follow specific patterns (HISAO, 1995).

With reference to this research, it is particularly important that panel data allow the specification of more complicated behavioural hypotheses by "blending the characteristics of inter-individual differences across cross-sectional units and the intra-individual dynamics over time" (HISAO, 1995). This is how panel data allow the more accurate prediction of individual outcomes. In contrast to the argument on the advantages of aggregated data raised by GRUNFELD and GRILICHES (1960), panel data analysis aims at making available and taking into account as much of the micro information as possible.

7.1.1 Advantages of a Panel Data Analysis in Comparison to a Classical Regression on Pooled Data

A comparison of a panel data analysis to a classical linear regression on pooled data best elucidates the advantages of the panel approach. Let

(7-1) $$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{u}$$

where **y** is a (NT) x 1 vector of observations on the regressands, **X** is composed of a (NT) x k matrix of observations on k regressors, and **u** is the (NT) x 1 vector of disturbances. This statement of model assumes that the response vector, $\boldsymbol{\beta}$, is identical within each unit, and is identical across all units. In other words, the classical regression model presupposes that all cross-sectional units have the same behavioural pattern, which, of course, is a testable assumption (DARNELL, 1994).

For further discussion, let us simplify the above model by isolating a single observation of the endogenous variable *y* and a single set of regressands $\mathbf{x_{it}}$ from it:

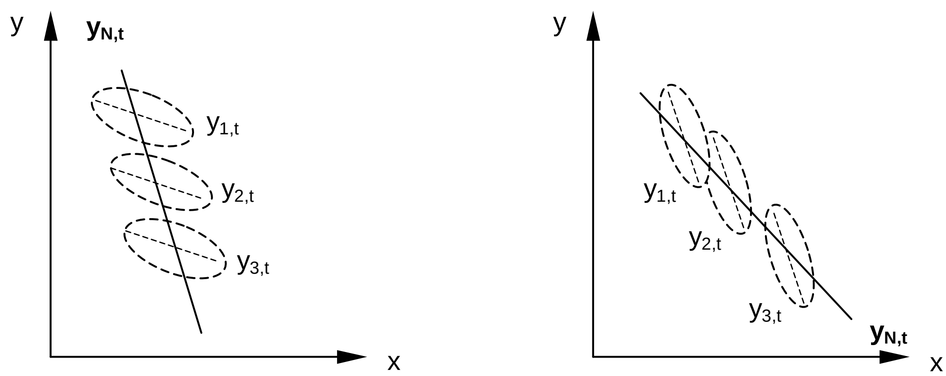
(7-2) $$y_{it} = \alpha_i + \beta_i \mathbf{x_{it}} + u_{it} \ , \qquad i = 1, \ldots, N \ , \qquad t = 1, \ldots, T.$$

where u_{it} is the error term with mean zero and constant variance σ^2_u. The parameters α_i and β_i may be different for each observation within a cross-section, although constant for each sampling unit over time. Following this assumption, a variety of sampling distributions may occur. Such sampling distributions can seriously mislead the least-squares regression of y_{it} on $\mathbf{x_{it}}$, particularly when all NT observations are used to estimate the model (HSIAO, 1986). A standard regression model applied to a set of pooled cross-sectional and time-series data take the form of NT equations with a single α and a single β across all observations which may be written as:

(7-3) $$y_{it} = \alpha + \beta x_{it} + u_{it} \ , \qquad i = 1, \ldots, N , \qquad t = 1, \ldots, T.$$

Several forms of misspecification may occur when regressing on pooled data, depending on which parameter is not constant over the cross-sections. First, consider a case with heterogenous intercepts ($\alpha_i \neq \alpha_j$) and homogeneous slope ($\beta_i = \beta_j$). If this is true for the case of pesticide demand in Costa Rica's coffee production, an ordinary regression on pooled data could lead to a biased estimator β, which might overstate (see Figure 7-1, left) or understate (see Figure 7-1, right) the slope of the demand curve. In Figure 7-1 the broken line circles represent the point scatter for an individual over time, and the broken straight lines represent the individual regressions. The solid lines result from a least-squares regression using all NT observations.

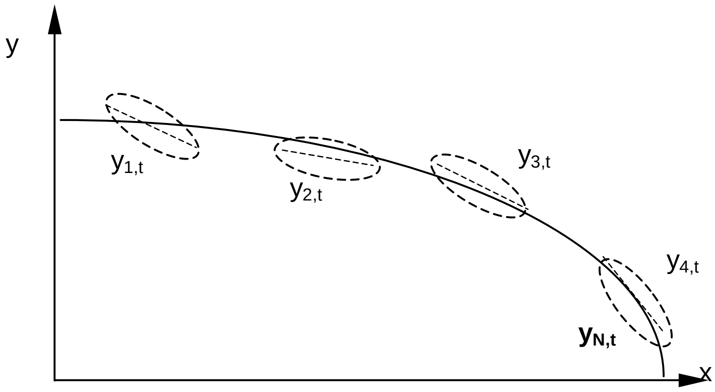
Figure 7-1: Comparison of a heterogenous intercept estimator with an OLS regression on pooled data



Source: after HSIAO, 1986

Another case arises when intercepts and slopes are heterogenous across individuals ($\alpha_i \neq \alpha_j$ and $\beta_i \neq \beta_j$). Figure 7-2 illustrates that case for a demand function.

Figure 7-2: Heterogenous intercepts and heterogenous slopes across individuals



Source: after HSIAO, 1986

Again, the broken line circles represent the point scatter for an individual over time, and the broken straight lines represent the individual regressions with heterogenous intercepts and slopes. A straightforward regression on all NT observations would lead to the solid line shown in Figure 7.2 and to the false inference that the pooled relation is curvilinear ($\mathbf{y_{N,t}}$). In all three cases illustrated here, the classical paradigm of the "representative agent" does not hold.

In addition to individual specific effects, there may be period-specific effects that cause similar patterns of bias even when intercepts and slopes are identical for all individuals for a given time period (HSIAO, 1986). This somewhat confusing variety of possibilities and models in panel data analysis shall be examined in an economic context, in order to identify the relevant issues and the appropriate model for the analysis of data on pesticide use in Costa Rican coffee production.

7.1.2 Individual-specific and Time-specific Effects in Panel Models

At this stage, it is important to state, once again, the objective of the research, which is to estimate a pesticide demand function for Costa Rica's coffee sector, that may be used to simulate the effects of a pesticide tax on pesticide demand. This objective implies the estimation of a model with fixed coefficients across the whole sample that can be interpreted as an average for Costa Rica's coffee sector. However, models with heterogenous slope coefficients across individuals as illustrated in Figure 7-2 do not provide such an average, and consequently, are not further treated here.

The discussion below concentrates on variable intercept models. The initial part of the analysis refers to Equation 7-2, which introduces a new parameter α_i into the regression that captures individual-specific effects. Equation 7-2 may be generalized for the case of individual-specific and time-specific effects, as follows:

(7-4) $$y_{it} = \alpha_i + \gamma_t + \beta x_{it} + u_{it} \;, \qquad i = 1, \ldots, N \;, \qquad t = 1, \ldots, T.$$

where α_i stands for individual-specific effects and γ_t for time- or period-specific effects. The basic assumption of such models is, that (conditional on the observed explanatory variables) the effects of all omitted (or excluded) variables are driven by three types of variables: individual time-invariant (= individual-specific), period individual-invariant (= period-specific), and individual time-varying (= individual- and period-specific) variables. Let us examine the characteristics of those variables, which represent the different types of effects, and discover if these are relevant for the empirical study on coffee production in Costa Rica[52].

Individual-specific variables, i.e. variables which are the same for a given cross-sectional unit through time but that vary across cross-sectional units are definitely relevant for this study. Examples of these variables are not only the attributes of individual-firm management or socio-economic background variables (HSIAO, 1995), but also specific features of a farm such as soil quality and the microclimate. These variables are not part of the demand function and, therefore, must be considered in the data analysis.

Period-specific variables are the same for all cross-sectional units at a given point in time but vary through time. Examples of these variables are prices or the specific climatic conditions in agricultural production for a given year. In this study, period-specific variables are neglected because prices, which obviously are important for the analysis of pesticide demand, are explanatory variables in the demand function. The specific climatic conditions for a given

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52 At this point it should be recalled, that "the variable-intercept models assume that conditional on the observed explanatory variables, the effects of all omitted (or excluded) variables are also driven by these three types of variables in which the effects of the numerous omitted individual time-varying variables are each individually unimportant but are collectively significant and possess the property of a random variable that is uncorrelated with (or independent of) all other included variables. On the other hand, because the effects of all omitted individual time-invariant or period individual-invariant variables either stay constant through time for a given cross-sectional unit or are the same for all cross-sectional units at a given point in time, or a combination of both, they can be absorbed into the intercept term of a regression model as temporal cross-sectional data (e.g. Kuh, 1963; Mundlak, 1978)" (HSIAO, 1995).

year are not part of the model, and are neglected because the climate variations between the regions and locations are more important than the variations at a given location, between years. Consequently, climate in the first place has to be treated as an individual-specific variable and not as a time-specific variable.

Variables such as firm profits, sales and capital stock vary across cross-sectional units at a given point in time and also exhibit variations through time (*individual- and period-specific variables*) (HSIAO, 1995). This type of variable, which is individual and period-specific, does not play a predominant role in the analysis and therefore may also be omitted from the estimation procedure[53]. It can be concluded, that the analysis of the panel data collected in Costa Rica has to focus on individual-specific variables.

7.1.3 How to Take Account of Individual-specific Effects

When the overall homogeneity hypothesis is rejected by the panel data, a simple way to take account of the heterogeneity across individuals, and/or through time, is to use the variable-intercept models. In these models, the slope coefficients are constant and the intercept either varies over individuals or, over time; or, over both individuals and time. As outlined in the previous section, this research concentrates on the models with variable intercepts over individuals.

7.1.3.1 The Fixed-effects Model

The fixed-effects model introduces individual-specific intercepts which account for the effects of those omitted variables that are specific to individual cross-sectional units, but which stay constant over time as shown in Equation 7-2. The error term, u_{it}, represents the effects of the omitted variables that are peculiar to both the individual units and time periods. In this sense, the error term u_{it} may be seen as capturing the general ignorance of the process, while α_i captures the ignorance specific to the behaviour of agent i. (DARNELL, 1994). We assume that u_{it} can be characterized by an independently identically distributed random variable with mean zero and variance σ^2.

[53] In coffee production profits depend on prices and on the production technology. Prices are included in the model and the production technology can be taken account of in the first group of variables which is individual-specific.

The covariance estimator is unbiased. It is also consistent when either N or T or both tend to infinity. However, the estimator for the intercept, $\hat{\alpha}_i$, though unbiased, is consistent only when T $\rightarrow \infty$.

7.1.3.2 The Random-effects Model

The random-effects or error-components model treats the individual-specific effects as random variables (like u_{it}). The error term is subdivided in three parts, namely in a cross-section specific component, a time specific component, and the residual error. For the purpose of this study time-specific effects are not treated and hence, the residual, v_{it}, is assumed to consist of two components whose variances are not known:

(7-7) $$v_{it} = \alpha_i + u_{it}$$

(7-8) $$\sigma_y^2 = \sigma_\alpha^2 + \sigma_u^2$$

The difference between the random-effects model and the fixed-effects model is the assumption about the error terms. The former presumes that the variance of the error term is not known, the latter assumes u_{it} as an independently indentically distributed random variable with mean zero and variance σ_u^2. Therefore different estimators need to be used.

7.1.3.3 Which Model to Choose?

In deciding which model to choose, the discussion shall not be limited to the above variable-intercept models but will also mention the OLS regression. This is because the first question to be addressed is whether or not there are individual-specific effects. If individual-specific effects are present, then it must determined how they can be best taken into account, i.e., whether a fixed-effects or a random-effects model is more appropriate.

The question as to whether omitted variables are important or not for the estimation of pesticide demand in Costa Rica's coffee production has in principle been answered, from an economic point of view, when discussing the various types of variables in Section 7.1.2. Indeed, important individual-specific variables such as the natural conditions for coffee production or managerial ability of the farmer are not included in the model and therefore have to be taken account of in the data analysis.

The hypothesis as to whether there are individual-specific effects may be tested statistically by BREUSCH and PAGAN's (1979) specification of the Lagrange multiplier test for heteroskedastic disturbances in a linear regression model. The test is performed by estimating the regression model subject to constraints which are introduced as a set of Lagrange multipliers, one for each constraint. "If the constraints are satisfied exactly in the sample, then the resulting Lagrange multipliers will be exactly zero. [...] [The] multipliers are shadow prices of the constraints, and the smaller is the multiplier, the less binding is the associated restriction and vice versa. This approach to testing restrictions is, therefore, to test that the Lagrange multipliers are zero" (DARNELL, 1994). If the null-hypothesis can be rejected, then it is likely that there are fixed effects.

For finite samples, the Lagrange multiplier statistic is F-distributed (DARNELL, 1994). The tests conducted with the aggregate pesticide demand functions yielded an F-statistic of at least 14.83 which is well above the 0.01 level of significance. Hence, the null-hypothesis that the Lagrange multipliers are zero, i.e., that there are no-fixed effects, can be rejected. It seems that the effects of the omitted variables are correlated with the included explanatory variables, and that these correlations need to be explicitly allowed for by variable intercept models. These findings support the above arguments on individual-specific effects, and at the same time, they raise the question as to the character of these effects.

For time-invariant variables the omitted-variable bias can be eliminated by using dummy variables to capture the unobserved effects (fixed-effects model) or, instead, by postulating a conditional distribution of unobserved effects, given observed exogenous variables (error-components model). Thus, the next stage of this analysis is to decide whether to use a fixed- or random-effects variable intercept model. HSIAO (1986) explains the difference between these two models as follows:

"The fixed-effects model is viewed as one in which investigators make inferences conditional on the effects that are in the sample. The random-effects model is viewed as one in which investigators make unconditional or marginal inferences with respect to the population of all effects. There is really no distinction in the 'nature (of the effect)'. It is up to the investigator to decide whether to make inference with respect to the population characteristics or only with respect to the effects that are in the sample. [...] When inferences are going to be confined to the effects in the model, the effects are more appropriately considered fixed. When inferences will be made about a population of effects from which those in the data are considered to be a random sample, then the effects should be considered random."

On the other hand, MUNDLAK (1978) states that the "whole approach which calls for a decision on the nature of the effect, whether it is random or fixed, is both arbitrary and unnecessary. Without a loss in generality, it can be assumed from the outset that the effects are random and view the FE [fixed-effects] inference as a conditional inference, that is conditional on the effects that are in the sample."

The random sample for coffee production in Costa Rica is supposed to be the basis for conclusions with regard to the population of coffee producers and therefore it would be desirable to use a random coefficient model. However, efficient and unbiased estimates of random coefficient models may only be obtained when the random effects and the regressors are uncorrelated. It is possible to test for orthogonality of the random effects and the regressors by means of a specification test formulated by HAUSMAN (1978). The Hausman test is based on the idea that under the hypothesis of no correlation, both the fixed- and the random-effects models are consistent, but that the fixed-effects model is inefficient; while under the alternative, the fixed-effects model is consistent, but the random-effects model is not. Therefore, under the null hypothesis, the two estimates should not differ systematically, and a test can be based on the difference. HAUSMAN's fundamental result is that the covariance of an efficient estimator with its difference from an inefficient estimator, is zero (GREENE, 1993).

The Hausman statistic (*m*-value) has an asymptotic $\chi^2_{(K)}$-distribution (JUDGE ET AL., 1985). The *m*-value computed for the aggregate pesticide demand models is at least 22.83 with 4 degrees of freedom. The critical value of the $\chi^2_{(K)}$-distribution at a 0.005 level of confidence and 4 degrees of freedom is 14.86, so that the null hypothesis can be rejected. Consequently, the estimation of a random effects model is biased and the fixed-effects estimator is, thus, preferred.

7.2 The Estimation of Factor Demand Functions

Over the last two decades, the dual approach to the analysis of production has gained importance, mainly because it deals with prices, costs and profits - data that are often easier to acquire than data on input use and their technical relationship to production. This analysis is confined to the effect of price changes on pesticide use and therefore would obviously benefit from the dual approach.

Section 4.1.1 has introduced the concept of duality and has exemplified, with the Cobb-Douglas production function, how primal production functions and dual profit functions are linked. Initially, this section explains how the exogenous variables included in the analysis of pesticide demand were selected, and then it discusses the functional forms which were used to estimate pesticide demand in Costa Rica's coffee production. In the first place, single equation models were estimated and then, a complete system of output supply and demand equations for variable factors in coffee production was estimated.

7.2.1 Choice of Exogenous Variables

7.2.1.1 Which Variables and Which Reference Unit to Choose?

Pesticide demand depends on prices, but also on various other variables. Chapter 4 has discussed risk perception, path dependence and asymmetric information, which influence the farmers' decision making on pesticide use. In addition, pesticide use is determined by environmental conditions and fixed factors that characterize the production system. Some of these farm-specific characteristics have been mentioned in Chapters 5 and 6.

Little quantitative farm-specific information on the non-price determinants of pesticide use was available. The fact that a number of important variables are not explicitly reckoned in the econometric model to some extent may be compensated by using panel models for the estimation of pesticide demand, which may take account of unknown individual specific effects.

Whenever panel models cannot be applied for the estimation, some individual specific characteristics may be captured by dummy variables. In order to model the demand of an input with cross-sectional farm data, it is important to know whether a farmer generally uses an input or not. On fully grown coffee plantations, for example, nematicides are used by a small proportion of the farmers only. Therefore, the information whether or not a farmer has used nematicides in the observed period is crucial for the estimation of nematicide demand and can easily be modelled with an integer variable.

The reference unit for all estimations is the per hectare average of input use per farm. The average intensity was computed taking into account the amount of an input used per land unit and also the proportion between the area treated and the area that was not treated. For example, if a given per hectare dose x

of a fungicide was applied to 50% of the coffee plantation, the average per hectare intensity considered in the econometric model was the dose *x* times 0.5.

Since this research is based on data from three time periods, only short-term input demand could be estimated. Therefore, the impact of changes in the area planted with coffee on pesticide demand has not been considered.

7.2.1.2 Aggregation of Input Prices

The model of pesticide demand in coffee production mainly relies on prices as exogenous variables. As discussed in Section 6.2.2, it is necessary to form price aggregates in order to reduce the number of exogenous variables. The important question that has not been addressed yet, is: to what extent should prices be aggregated?

The degree of detail which is necessary depends on the scope of the analysis. If an econometric model is to be used to analyse how pesticide demand would be affected by a uniform tax on all pesticides, then an aggregation of all pesticide prices to a single price index is a possible solution. If the impact of differentiated taxes for different types of pesticides is to be analysed, then price indexes for the different types of pesticides have to be computed.

From a policy perspective, a high degree of disaggregation is desirable, because the more detailed the econometric model, the more specific policy scenarios may be analysed. However, from an econometric point of view there is likely to be a trade-off between the level of detail of an estimation and the precision of the estimates. Increasing the number of exogenous variables often implies increasing estimation problems such as collinearity. Preliminary correlation analyses of the price variables have shown a high degree of correlation between these, so that serious collinearity problems may be expected. Therefore both, highly aggregated models and disaggregated models have been estimated and compared in this research.

The aggregated model distinguishes three exogenous variables, namely the price indexes for pesticides, mineral fertilizers and labour. The more differentiated model distinguishes price indexes and quantity indexes for four types of pesticides, mineral fertilizers and labour. Demand equations for all these variable inputs have been estimated in a simultaneous equations model. In the more detailed model the aggregate "pesticides" has been subdivided into:

- WHO class II herbicides,

- other herbicides (WHO class III and IV),
- fungicides + foliar nutrients[54], and
- nematicides.

This subdivision is based on the WHO classification of pesticides. As mentioned in Chapter 6, the WHO classification coincides with the information obtained at the farms visited in this study and from the medical services, which state that human intoxication from pesticide use in coffee production is mainly caused by nematicides, paraquat and 2,4 D. Nematicides are classified as extremely, or as highly hazardous by the World Health Organization (WHO class Ia and Ib pesticides), while paraquat and 2,4 D are classified as moderately hazardous (WHO class II pesticides). Most of the other herbicides used in coffee production are classified as WHO class III (slightly hazardous), and most fungicides and foliar nutrients appertain to WHO classes III, and IV (not hazardous [if used correctly]).

7.2.1.3 Price Expectation of Coffee Farmers

Decisions on input use in coffee production are made before farmers know the prices they will receive for their produce. A cropping season lasts about one year and the marketing of coffee is done in shares over the subsequent year (see Section 5.1.2). Hence, there is a time lag of one to two years between expenditures on inputs and the receipt of payments for coffee. The situation is further complicated by the fact that coffee prices tend to vary often and widely. However, HAZELL (1994) found that Costa Rican farmers are well informed about the international coffee market and are able to forecast prices up to 16-17 months ahead with a degree of accuracy that is comparable to the New York futures market.

Management options over one cropping season are limited because an increase in inputs is only partly reflected in current productivity and partly accrues in the following years. TÖLKE (1998), for example, assumes a 5-year time lag when estimating Costa Rica's long-term export supply function for coffee.

It is assumed that coffee farmers are aware of price fluctuations on the coffee market and of the impact of input use on immediate and mid-term productivity. On this basis, it is hypothesized that coffee farmers make two types of input decisions.

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54 The aggregate "foliar nutrients" includes foliar fertilizers, micro-nutrients, and adjuvants. Since these inputs are usually applied in mixture with fungicides a single aggregate has been formed.

First, farmers decide on a minimal technology package to be used over several years which is oriented to their average price expectations over several years. A model for these expectations which defines the expected price as a weighted sum of all past prices with a geometrically declining set of weights is represented by the Nerlovian supply response model (SADOULET and DE JANVRY, 1995):

$$p_t^e = \gamma \sum_{i=1}^{\infty} (1-\gamma)^{i-1} p_{t-i} \ ,$$

where p_t^e is the expected coffee price at the time when the output is marketed, p_{t-1} is the price that prevails when decision-making for production in period t occurs, γ is the adaptive-expectations coefficient[55]. Such a model may be useful for a study on the long-term effects of price expectations on input use and productivity in coffee.

Second, and in addition to the long-term strategy on input use, it is hypothesized that coffee farmers adjust the intensity of coffee production within a cropping season according to the coffee prices at the time they make their input decision. They are aware of these prices through the media but also through the quarterly payments they receive for the previous harvest. Farmers expect that the actual prices are an indicator for the price levels they may receive for their harvest and adjust their short-term input use accordingly.

This hypothesis is supported by the fact that the liquidity of coffee farmers is closely related to coffee prices. For example, high prices imply high quarterly payments for the commercialization of the previous harvest, and, consequently, high liquidity. Particularly for resource-poor farmers liquidity is an important factor in the decision on input use.

This research deals with the short-term adjustment of input use and therefore may only consider how the short-term price expectations of coffee farmers influence input use. For this purpose, data on the production technology has been obtained for individual farms, and input prices and average coffee prices for each coffee location have been collected for 1993, 1994 and 1995. For the demand analysis conducted in this study, the actual coffee price paid in each location has been considered as the most relevant factor for the farmers' short-term decision on input use.

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[55] This approach has been critisized because price weights are ad hoc and because price predictions underuse information available to the decision maker (SADOULET and DE JANVRY, 1995)

7.2.2 Functional Forms Considered in the Analysis

In the literature on the dual analysis of production, a number of functional forms have been proposed which are not as restrictive as the traditional Leontief, Cobb-Douglas, and CES technologies. Basic characteristics of these "flexible functional forms" are discussed in Section 7.2.2.1. The factor demand functions were derived from standard profit functions by applying Hotelling's lemma (see Section 4.1.1.3).

The Translog profit function initially had been included in the analysis. However, since the model was not significant as indicated by the *F*-test and the parameter estimates were also not significant and inconclusive, it was not considered further. This outcome is probably related to the fact that input demand equations that have profits (or profit shares in the multi-output case) as dependent variables are likely to be biased, whenever the profits are not directly related to input use. This is the case in coffee production, where the gross margins in coffee depend mainly on the world market coffee prices and on the physical coffee production cycle which is biannual.

Based on the assumption that the demand for variable inputs and fixed factors are separable in coffee, the following analyses concentrate on the variable production technology. However, as far as possible, the individual-specific characteristics, that were treated as "fixed factors" have been taken into account.

7.2.2.1 Flexible Functional Forms in the Dual Analysis of Production

Flexible functional forms place fewer restrictions prior to estimation than the more traditional forms. "In most instances, they let measures like the elasticity of size and elasticities of substitution depend on the data. Hence, they can vary across the sample and need not be parametric as they are for most of the more traditional forms" (CHAMBERS, 1988). In the context of this research, flexibility is required because of the importance of the substitutive relationships which would be forced to unity or a constant by the non-flexible functional forms mentioned above.

Such flexible functional forms have generally been interpreted as approximations of unknown arbitrary technologies. However, as stated in CHAMBERS (1988), "even if flexible forms are not restrictive, their ability to approximate arbitrary technologies is limited. The notions of approximation relied upon are local in nature: either a point approximation to the function gradient, and Hessian or a second-order Taylor series expansion. Neither are truly global, and approximations based on them cannot be very exact for a wide range of observations."

Flexible functional forms have been used in a number of studies on input use and output supply in agricultural production. SIDHU and BAANANTE (1981), for example, have estimated farm-level input demand and wheat supply in the Indian Punjab using a Translog profit function, and BAPNA, BINSWANGER and QUIZON (1984) have estimated systems of output supply and input demand which were derived from the Normalized Quadratic and the Generalized Leontief profit functions for six regions in India. All these functional forms fulfil the major theoretical requirements of production economics. Therefore, they were all considered in the initial phase of the data analysis. In addition, factor demand functions derived from the Quadratic profit function were estimated. The Quadratic profit function shares most properties of the Normalized Quadratic with one exception: it is not homogeneous of degree zero.

The following sections give an overview of the functional forms that were used in this study. Although the empirical analysis is confined to variable inputs, the following discussion also includes fixed factors. Fixed factors are interpreted in a broad sense including investments but also climate conditions or farmer-specific characteristics[56]. Output and input prices (p_i), and output and input quantities (q_i) have the same notation and inputs are defined as negative outputs. This procedure is consistent with Hotelling's lemma presented in Section 4.1.1.3. Since this research deals with a single output, profit shares which in the multi-output case have to be considered in the computation of elasticities, are set at 1.

7.2.2.2 The Quadratic Profit Function and its Derivatives

The Quadratic profit function has the major properties of a profit function as outlined in Section 4.1.2, but it is not homogeneous of degree one, i.e. confusing changes in money values with changes in real values cannot be ruled out. It is written as:

$$\Pi = a_o + \sum_i a_i p_i + \frac{1}{2}\sum_{i,j} b_{ij} p_i p_j + \sum_m b_{im} p_i z_m, \quad i,j = 1, ..., n \text{ with } b_{ij}=b_{ji}. \tag{7-9}$$

[56] For example, at a later stage, the fact whether or not a farmer uses an input will be modeled as a fixed factor dummy variable.

where p_i stands for the input prices and the output price and z_m are the fixed factors

Deriving the Quadratic profit function leads to a set of linear output supply and factor demand functions:

(7-10) $$q_i = a_i + \sum_j b_{ij} p_j + \sum_m b_{im} z_m$$

where q_i is the output or input quantity, a_i is the intercept, p_j are output and input prices. For the analysis of coffee production in Costa Rica, there is only one output price and various input prices.

Price elasticities can be computed at any particular value of prices and quantities as:

$$e_{ij} = b_{ij} \frac{p_j}{q_i}$$

7.2.2.3 The Normalized Quadratic Profit Function and its Derivatives

The Normalized Quadratic profit function is a transformation of the Quadratic profit function. If there is a single output (as in Costa Rican coffee production), the normalized profit function, Π^* is defined as the ratio of the profit function to the price of the output. It is a function of the relative prices of the inputs, $\mathbf{p}^* = \mathbf{p}/p_n$, that is, $\Pi^* = \Pi^*(\mathbf{p}^*)$. The Normalized Quadratic profit function uses the price of the n^{th} output as a numéraire to normalize profit and prices. This procedure implements homogeneity of degree one in prices[57] (SADOULET and DE JANVRY, 1995).

(7-11) $$\Pi^* = \Pi / p_n = a_o + \sum_i a_i p_i^* + \frac{1}{2} \sum_{i,j} b_{ij} p_i^* p_j^* + \sum_m b_{im} p_i^* z_m$$

$i,j = 1, ..., n-1$, with $b_{ij}=b_{ji}$.

where $p_i^* = p_i / p_n$ are the normalized input prices and z_m are the fixed factors. The derived system of output supply and factor demand is:

(7-12) $$q_i = a_i + \sum_j b_{ij} p_j^* + \sum_m b_{im} z_m$$

Supply for the n-th commodity, whose price served as a numéraire, is:

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[57] However, homogeneity may not be implemented for the fixed factors.

(7-13) $$q_n = \Pi^* - \sum_i p_i^* q_i = a_0 - \frac{1}{2}\sum_{i,j} b_{ij}\, p_i^*\, p_j^*$$

The derived price elasticities are not constant, but they can be computed at any given value of prices and quantities with the following expressions (SADOULET and DE JANVRY, 1995):

$$e_{ij}^* = b_{ij}\,\frac{p_j^*}{q_i}, \quad i,j \neq n,$$

$$e_{nj}^* = \sum_i e_{ij} \qquad \text{and} \qquad e_{nn}^* = -\sum_i e_{ni}\ .$$

Among the flexible profit functions discussed here, the Normalized Quadratic is one that fulfils most of the fundamental assumptions of demand theory. In contrast, the Generalized Leontief and the Translog profit functions are not globally concave which implies gross substitutability (CHAMBERS, 1988). However, they are still frequently used in applied research and are therefore also considered here.

7.2.2.4 The Generalized Leontief Profit Function and its Derivatives

The Generalized Leontief profit function is defined as (SADOULET and DE JANVRY, 1995):

(7-14) $$\Pi = \sum_{i,j} b_{ij}\sqrt{p_i\, p_j} + \sum_{i,m} b_{im}\, p_i\, z_m \qquad \text{with } b_{ij} = b_{ji}$$

The Generalized Leontief profit function is homogeneous of degree one in all prices[58]. The equations for the factor demands and output supplies are:

(7-15) $$q_i = b_{ii} + \sum_{j \neq i} b_{ij}\sqrt{\frac{p_j}{p_i}} + \sum_m b_{im}\, z_m$$

The derived price elasticities can be computed at any particular value of prices and quantities as:

$$e_{ij} = \frac{b_{ij}}{2q_i}\sqrt{\frac{p_j}{p_i}}, \qquad \text{for } i \neq j, \qquad \text{and} \qquad e_{ii} = -\sum_{j \neq i} e_{ij}$$

58 This does not apply to the fixed factors.

From the Generalized Leontief profit function own-price elasticities are computed residually from all price coefficients in an equation. This makes sure that the adding-up property is fulfilled. However, this method may lead to inaccurate results: first a left-out bias may arise for the included price coefficients and second, the possible non-zero coefficient of a missing price may lead to biased own-price elasticities (BAPNA, BINSWANGER and QUIZON, 1984).

7.2.3 The Appropriate Estimation Approach

This section discusses two options for the estimation of pesticide demand that have been used in this study. Both methods are compared and conclusions are drawn with regard to their potential for the analysis of pesticide demand.

7.2.3.1 A Single Equation Model Versus a System of Factor Demand Functions

Economic analyses often focus on a single equation model such as an aggregate consumption function, a demand function for a commodity or for an input. "However, economic theory teaches that such equations are embedded in a system or subset of related equations. Thus one must examine whether the presence of these related equations has any implications for the estimation of the focus equation. More importantly, the estimation of a complete system of equations is often an important practical problem, whether the objective is to test economic theories about the nature of the system or to use the complete system to make joint predictions of a set of related variables" (JOHNSTON, 1991).

A single equation model is more flexible and may better fit empirical data than a complete system of equations because it is estimated under fewer restrictions. This is a strength, and at the same time, a weakness of the multiple regression approach, because fewer restrictions also imply that some of the properties a demand function is supposed to fulfil cannot be imposed. Furthermore, it is not possible to depict the effect of price changes on different factors simultaneously, which is a great disadvantage when the effect of changes in various exogenous variables (prices) on a number of endogenous variables (factor demand and output supply) are to be analysed at the same time.

When it comes to the use of panel models, a single equation estimation is advantageous because most econometric software packages for the analysis of panel data are designed for single equation models. The combination of panel models and simultaneous equations systems raises a number of theoretical issues and also requires considerable econometric programming. The latter goes beyond the scope of this research and therefore, panel models were only used for the estimation of single equation demand functions[59]. A different approach was chosen for the estimation of a system of factor demand functions which is outlined in the following section.

7.2.3.2 Seemingly Unrelated Regression

In order to assess the cross-price relationships simultaneously for variable inputs in coffee production a simultaneous equations system was estimated. Each equation is, by itself, a classical regression and is linked to the other equations only by its disturbance. Applying ZELLNER's seemingly unrelated regressions method is at least asymptotically more efficient than those obtained by an equation-by-equation application. "This gain in efficiency can be quite large if 'independent' variables in different equations are not highly correlated and if disturbance terms in different equations are highly correlated" ZELLNER (1962).

The seemingly unrelated regression is a full information estimation technique, i.e. all model parameters are estimated in one go. Even if the regressions appear unrelated to one another, there is cross-correlation between the different error terms. The seemingly unrelated regression approach takes account of such cross-correlation by combining the equations of a system into a single equation for estimation purposes, and by applying generalized least squares to this equation (MUKHERJEE, WHITE and WUYTS, 1998).

7.2.3.3 Objective of the Analysis and Model Specification

The decision on the specification of the econometric model has to be guided by the requirements of the policy analyses that are envisaged. If the effect of a uniform pesticide tax on pesticide demand is to be assessed, a multiple regression model may provide useful insights. It may be used to estimate the effect of a uniform tax on overall pesticide use and also to assess the impact of such a tax on the demand for various types of pesticides. This can be done by regressing consecutively the demand for the various types of pesticides on

59 Standard econometric software allows to estimate simultaneous equations models with fixed-effects by two-stage least squares (GREENE, 1995). However, the software available to the author did not permit the implementation of symmetry restrictions on the parameters when using two-stage least squares in combination with panel models. Therefore, this approach could not be used.

aggregated price indexes for pesticides, fertilizer, labour and coffee, as suggested in Section 7.2.1.2.

If more differentiated tax regimes are to be analysed, it is advisable to estimate a system of factor demand functions that is able to depict these effects simultaneously. This has been done for the demand of variable inputs in Costa Rica's coffee production. Section 7.3 will present the results obtained in estimating single equation panel models and in estimating a system of simultaneous input demand equations.

7.3 Results of the Econometric Analysis

This section initially compares the results in the panel estimation of aggregated pesticide demand with four flexible demand functions. The functional form that provided the most significant results was chosen to estimate demand functions for the different types of pesticides. Then, the results obtained with a system of output supply and input demand equations are discussed. The last subsection draws conclusions from the results of the econometric analysis and discusses them in the context of the results obtained in other econometric studies on pesticide demand.

7.3.1 Fixed-effects Panel Models

In Section 7.2.2.1, it was pointed out that various functional forms may be used to estimate pesticide demand. From a theoretical point of view, the Quadratic, the Normalized Quadratic, the Generalized Leontief, and the Translog profit functions are all suitable for the analysis of input demand in coffee and therefore have been considered in this econometric analysis. First, aggregated pesticide demand has been estimated as a function of four exogenous variables, namely the price index for pesticides, the price index for mineral fertilizer, the wage index and the price index for coffee.

In addition to these explicit variables, the fixed-effects model estimates individual intercepts for each cross-sectional unit in order to capture individual-specific effects. With regard to pesticide use in coffee, these effects include factors such as the managerial ability of the farmer, the degree of risk aversion, path dependence, and also environment and technology specific conditions of each farm. Estimating the individual intercepts considerably raises the explanatory power of the model, indicating that there are important individual specific variables that influence pesticide use which go beyond the set of explanatory variables included in the regression model. However, R^2 should not be overinterpreted, because it cannot be assessed as to what extent the cross-section specific intercepts account for factors related to pesticide use.

The estimates of the four demand functions were compared in order to identify the model which gives the best fit. There are different ways of evaluating the fit of functional forms. R^2, the F-value and the significance of the parameter estimates are statistical criteria for the evaluation of the estimates. Furthermore, there are economic criteria which in the first place concern the signs of the parameter estimates. For example, it can be expected that the own-price effect for a good is negative. Pesticides and fertilizers are usually considered as complementary inputs and therefore a negative sign can be anticipated for this cross-price effect. Pesticides and labour to some extent are complements as labour is required for pesticide application. However, and more importantly, manual labour may substitute pesticides in crop protection, and therefore labour and pesticides are more likely to be substitutes for which a positive cross-price effect can be expected. Production economics further suggests that the intensity of production rises when the output price increases. Hence, a positive relationship is expected between pesticide demand and the coffee price. Table 7-1 summarizes the results of the parameter estimates:

Table 7-1: Parameter estimates for various fixed-effects pesticide demand models

	Intercept	Pesticide Price	Fertilizer Price	Wage	Coffee Price
Quadratic					
Parameter Estimate	1.9294	-1.7720	-0.0473	1.3418	0.2946
Standard Error	0.5149	0.6048	0.2554	0.7691	0.2195
Prob > |T|	0.0002	0.0035	0.8532	0.0815	0.1801
R2	0.9181				
F value	52.3181				
Normalized Quadratic					
Parameter Estimate	2.1577	-0.1419	0.4543	-0.3166	
Standard Error	0.2044	0.1663	0.1044	0.2043	
Prob > |T|	0.0001	0.3936	0.0001	0.1218	
R2	0.9174				
F value	122.1245				
Generalized Leontief⁺					
Parameter Estimate		-0.6500	0.2810	1.9820	0.1957
Standard Error		1.4440	0.4788	1.6991	0.1515
Prob > |T|		0.6528	0.5575	0.2438	0.1968
R2	0.9176				

F value	47.9672

+ For the demand function derived from the Generalized Leontief profit function, the intercept estimate is equal to the own-price effect.

Source: author's estimations

Table 7-1 shows that the demand function derived from the Quadratic profit function generates parameter estimates which all make sense from an economic point of view. The own-price effect is negative, and the cross-price effect with fertilizer is positive proposing that fertilizer and pesticides are complementary inputs. This cross-price effect, however, is not significantly different from zero. The positive coefficient related to the wage indicates that pesticides and labour are substitutes and a positive parameter estimate for coffee suggests that the intensity of pesticide use increases when coffee prices raise. These interpretations are in accordance with the economics of agricultural production. Three of the parameter estimates obtained with the Quadratic model are significant.

Although not significant, three of the four parameters obtained with the Generalized Leontief function also make sense from an economic point of view. The demand functions derived from the Normalized Quadratic profit function has not proven useful because some of the signs are equivocal and most of the parameter estimates are not significant.

A number of factors may cause insignificant and misleading parameter estimates, among which multicollinearity of the price variables, missing variables, inadequacy of the econometric model, and data problems can be important. Collinearity is most likely one of the most important issues in this research because the correlation between the price variables is usually high. Prices are correlated in time series due to inflation, and in cross-sections because regional price differences are mainly caused by transport costs which affect all input prices accordingly.

The correlation between the exogenous variables differs in the various models. It is highest in the demand function derived from the Normalized Quadratic profit function, followed by the Quadratic, and the Generalized Leontief functions. Consequently, multicollinearity to some extent may explain the inconclusive parameter estimates obtained with the Normalized Quadratic model. The most appropriate approach to address the collinearity problem is to include further variables in the analysis. Since besides prices and quantities of variable inputs in coffee production, little additional information on the physical determinants of pesticide use in coffee is available, this was not possible.

The above parameter estimates were used to compute price elasticities at mean prices and quantities (Table 7-2). Out of these elasticities only those derived from the Quadratic function are compatible with the assumptions of economic theory. The Quadratic model suggests that the own-price elasticity of overall pesticide demand in coffee is -0.99, a result that is higher than average price elasticities estimated in other studies but plausible, because coffee in fact offers possibilities for the substitution of various types of pesticides, mainly through labour (see Section 5.3.). This substitutive relationship between pesticide use and labour is clearly shown by a positive cross-price elasticity between pesticide use and wage (+0.71). The price elasticities displayed for the Normalized Quadratic function refer to normalized prices.

Table 7-2: Price elasticities for aggregated pesticide demand (mean based)*

	Pesticide Price	Fertilizer Price	Wage	Coffee Price
Quadratic	-0.99 (0.34)	-0.02 (0.12)	0.71 (0.41)	0.12 (0.09)
Normalized Quadratic	-0.11 (0.13)	0.30 (0.07)	-0.23 (0.15)	0.04+
Generalized Leontief[60]	-0.69+	0.08 (0.13)	0.57 (0.49)	0.05 (0.04)

* Numbers in parentheses are standard errors.

\+ These elasticities were not estimated but computed as residuals.

Source: author's computations

7.3.2 Estimation of a System of Input Demand Equations for Coffee Production

A uniform tax on all pesticides may have undesired effects on pesticide demand. Where different types of products are available for pest control, more expensive products, which tend to be less hazardous, are likely to be substituted by cheap, more hazardous products. This negative effect can be addressed by differentiated taxes set according to the hazardousness of a pesticide. The impact of such tax schemes can only be analysed with

60 Own elasticities for the Generalized Leontief form are computed residually from all price coefficients in an equation. This may cause a problem, because even if no left out variable bias arises for the included price coefficients, the residual computation omits the possible non-zero coefficients of a missing price and this can lead to biased own elasticities (BAPNA, BINSWANGER and QUIZON, 1984).

econometric models that take account of cross-substitution effects, namely with a simultaneous equations model as introduced in Section 7.2.3.2.

Coffee supply and the profit function have not been included in the system of equations, because it is very difficult to correctly specify coffee supply. Coffee has a biannual production cycle and therefore yield variation is extremely high between years. As a consequence, the use of variable inputs is only one, and most likely not the most important, determinant of short-term productivity. It was not possible to model the relation between input use and yield appropriately with only three time series. Therefore, the coffee supply function and the profit function were excluded from this analysis. Coffee supply is better estimated using aggregated data and long time series as done by TÖLKE (1998).

Systems of factor demand equations derived from the Quadratic and the Normalized Quadratic profit function were estimated with ZELLNER's seemingly unrelated regression method. The symmetry of cross-price effects was imposed as a restriction.

The variable inputs were subdivided into the following groups:

- WHO class II herbicides,
- other herbicides,
- fungicides and foliar nutrients[61],
- nematicides,
- mineral fertilizers, and
- labour.

Fungicides and foliar nutrients were summarized in a single subgroup which, to some extent, reduces the multicollinearity problem. This aggregation is in full accordance with the fungicide and foliar nutrient application practice in Costa Rica's coffee fields because both types of inputs are usually applied in a mixture. From a tax policy perspective, it is also appropriate to aggregate these components because they both do not belong to the group of the highly toxic substances which are the prime candidates for taxation.

Although panel models could not be applied to this estimation of a system of demand functions, some individual specific characteristics were modelled in the following way: for each type of agrochemical input a dummy was introduced that specified whether or not, a farmer had used the respective

61 The term "foliar nutrients" refers to foliar fertilizers, micro-nutrients and adjuvants.

input over the period observed. Technically, these dummies were treated as "fixed factors" (see Section 7.2.2.3).

Since the quality of the parameter estimates from both systems was similar, the subsequent analyses have been conducted with the results obtained with a system derived from a Normalized Quadratic profit function because it guaranteed homogeneity of degree zero. Table 7-3 shows the summary statistics obtained in the estimation of the six input demand functions.

Table 7-3: Summary statistics for the input demand equations

Equation	R^2	adjusted R^2
WHOII herbicides	0.1545	0.1470
other herbicides	0.1242	0.1165
fungicides +foliar nutrients	0.2177	0.2108
nematicides	0.2435	0.2368
fertilizer	0.2149	0.2080
labour	0.0519	0.0436

Source: author's estimations

At a first glance, the explanatory power of the demand equations seems quite low, with the adjusted R^2 ranging from 0.12 to 0.24 for the agrochemical inputs and being 0.04 for labour. However, it is well known that R^2 is likely to decrease when the number of observations increases, especially with cross-sectional data. GOLLNICK (1968) shows that the significance of $R^2 = 0.63$ in a sample with three exogenous variables and 15 observations corresponds to $R^2 = 0.074$ in a sample with the same number of exogenous variables and 150 observations[62]. In view of the large size of this sample on coffee production in Costa Rica (n=975), the explanatory power (adjusted R^2) of the demand equations is not unacceptable from a statistical point of view. Furthermore, for the purpose of this study, it is more important whether the parameter estimates are satisfactory or not. A low R^2 is mainly due to the fact that besides prices there are a number of other determinants of pesticide use which are not captured in the model.

In Table 7-4, it can be seen that many of the signs of the parameter estimates make sense from an economic point of view. The own-price effects are all

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62 $R^2 = 0.63$ ($R^2 = 0.074$) with $n = 15$ ($n = 150$) observations and $m = 3$ exogenous variables corresponds to $F = 6.22$ ($F = 3.91$), which is significant at $\alpha = 0.01$ (probability of error). R^2 may easily be computed by applying $R^2 = \frac{mF}{mF + n - m - 1}$ (GOLLNICK, 1968)

negative, and most of the cross-price effects are also conclusive. For example, the cross-price elasticity for the two types of herbicides used in coffee is positive, suggesting that these inputs are substitutes. Following a common practice in applied econometrics, regression coefficients are considered as useful as long as the absolute value of the regression coefficient is at least as high as the standard error (SCHMIDT, 1984)[63].

Table 7-4: Price elasticities for variable inputs in coffee (mean based)

	P* (WHOII herbicides)	P* (other herbicides)	P* (fungicides + foliar nutrients)	P* (nematicides)	P* (fertilizer)	P* (wage)
Q (WHOII herbicides)	-0.68 (0.61)	0.36 (0.27)	-0.80 (0.46)	1.09 (0.62)	0.01 (0.11)	0.03 (0.10)
Q (other herbicides)	0.35 (0.27)	-0.34 (0.23)	0.34 (0.25)	-0.40 (0.35)	-0.05 (0.08)	0.10 (0.08)
Q (fungicides +foliar nutrients)	-0.58 (0.33)	0.25 (0.18)	-0.84 (0.50)	1.30 (0.52)	-0.21 (0.09)	0. 02 (0.08)
Q (nematicides)	0.46 (0.26)	-0.17 (0.15)	0.75 (0.30)	-1.18 (0.41)	0.13 (0.07)	-0.03 (0.06)
Q (fertilizer)	-0.01 (0.13)	-0.06 (0.10)	-0.33 (0.15)	0.37 (0.19)	-0.15 (0.07)	0.12 (0.05)
Q (labour)	0.04 (0.11)	0.12 (0.09)	0.03 (0.13)	-0.09 (0.18)	0.12 (0.05)	-0.23 (0.07)

P = price (exogenous variable), Q = quantity (endogenous variable)
Numbers in parentheses are approximated standard errors.
* prices normalized by the coffee price
Source: author's computations

Following this criteria, all of the own-price effects are acceptable. These results suggest that the demand for nematicides with an own-price elasticity of -1.18 is quite elastic which is probably due to the fact that fully grown coffee plantations in most locations can actually be run without nematicides. Even if a coffee plantation is infested with nematodes, nematicide use is avoidable, because adult coffee to a large extent is nematode tolerant. The demand for fungicides and foliar nutrients is also quite elastic, probably because these inputs in many cases are also not indispensable. The own-price elasticity of herbicides varies between -0.68 and -0.34, depending on the type of herbicide.

63 According to GOLLNICK and THIEL (1980), a regression coefficient that satisfies $t \geq 1$, decreases the estimate of the residual variance. Hence, the "t-criteria" is related to the maximization of R^2. SCHMIDT (1984) points out that relaxing the criteria for standard statistical hypothesis testing is particularly appropriate whenever the exogenous variables can be expected to be collinear, because then the standard errors are likely to be overestimated.

This can be explained by the possibility of substituting herbicides by manual labour.

In the panel model it was pointed out that labour input to some extent is a substitute for pesticides. The cross-price effects between the different types of pesticides and labour obtained in this system of demand equations are not significantly different from zero, and therefore can hardly be interpreted. However, the positive signs of most of these cross-price effects suggest a substitutive relationship between labour and pesticides (with the exemption of nematicides which, in fact, cannot be substituted by manual labour). Note that in coffee production, labour demand seems to be much more inelastic than pesticide demand.

Some of the parameter estimates are not significant and some of the cross-relationships are not conclusive and therefore have to be interpreted with care. For example, the substitutive relationship between fungicides and nematicides as suggested by a positive cross-price elasticity is difficult to explain.

7.3.3 Discussion of the Results Obtained in the Econometric Analyses

Implications of the Estimates

The econometric analyses suggest that pesticide demand in coffee is rather elastic. The single equation panel model explained a great part of the variation of pesticide demand and most of its parameter estimates were significant. The own-price elasticity for pesticides at means was estimated at -0.99, the cross-price elasticity with reference to the wage at 0.71.

The results obtained with a system of simultaneous demand equations for coffee were more difficult to interpret, mostly because some cross-price effects did not make sense. The own-price effects were conclusive and supported the findings obtained in the single equation model. The high standard errors in the system of demand equations can partly be explained by the size of the panel data set with 325 cross-sectional units over three years (n = 975 observations). Furthermore, multicollinearity between the price variables may have played an important role.

The explanatory power of the model would most likely have been increased by including additional variables in the estimation. Climatic conditions and other farm-specific characteristics are important determinants of pesticide use. The inclusion of such additional explanatory variables would possibly have raised the explanatory power of the model and lessened the multicollinearity problem.

This implies a certain misspecification of the model, that could not be avoided and that may be another important reason for the relatively weak results obtained in the differentiated system of demand equations utilized in this work (BELSLEY and KUH, 1986; BELSLEY, 1988).

Furthermore, data problems to some extent may have caused these weak results. The consequences of errors in the data are particularly severe when micro demand functions are estimated. Therefore, as stated by GRUNFELD and GRILICHES (1960), the poor quality of micro data may be a source of aggregation gain.

Nevertheless, there are strong reasons to assume that pesticide demand in Costa Rica's coffee production is relatively price elastic, even in the short run.

Comparison with other Studies on the Elasticity of Pesticide Demand

Most studies that have estimated the demand elasticity for pesticides have used aggregated time series data. Even though, as discussed in Section 6.2.3, aggregation may considerably improve estimates, many of these studies had to face similar problems to those discussed above, in particular high standard errors. Table 7-5 gives an overview of the own-price elasticities of pesticides analysed in various parts of the world. The upper section shows own-price elasticities derived from econometric estimates. The range of the estimates goes from -0.22 in The Netherlands to -1.9 in Rhineland Palatinate. The lower section of Table 7-5 presents the own-price elasticities derived from simulation runs obtained with linear programming models for a 100% increase in pesticide prices in Germany, and for an average pesticide price increase of 120% for Denmark.

It has to be stressed, that the estimates in Table 7-5 are based on data obtained from a wide range of crops and from different regions, and are therefore not fully comparable. However, the distribution of the estimates suggests that pesticides are rather price elastic.

OSKAM ET AL. (1992) estimated the own-price elasticity of pesticide demand for the Dutch horticultural sector between 1970 and 1988 at -0.25 in the short run and -0.29 in the long run. Using a similar econometric approach AALTINK (1992, cited in OSKAM ET AL., 1992) estimated the own-price elasticity of pesticide demand for the arable sector in the Netherlands at -0.21 in the short run and -0.22 in the long run. These estimates on the Dutch arable and horticultural sectors have to be interpreted with care because of their high standard errors.

In their analysis of the effects of a reform of the Common Agricultural Policy (CAP) on the demand for pesticides in the United Kingdom, RUSSEL, SMITH and GOODWIN (1997) estimated the own-price elasticity of pesticides based on 1989-1993 panel data. They formulated two models which differ only by the inclusion in one of them of a dummy on participation in set-aside programmes in 1993. In Model I the set-aside dummy is one for those farms which did set aside agricultural land in 1993. In Model II the set-aside dummy is one for all farms included in the sample. The own-price elasticity is slightly higher with Model I (-1.12) than with Model II (-1.09).

The demand for herbicides, fungicides and insecticides was assessed by DUBGAARD (1991) using 1971-1985 longitudinal data from Denmark. He estimated the own-price elasticity of herbicides at -0.69 and the aggregated own-price elasticity of fungicides and insecticides at -0.81, respectively. GREN (1994) has estimated the demand for herbicides, fungicides and insecticides in Sweden for the 1948-1989 period. She found that herbicide demand in Sweden was more elastic than fungicide and insecticide demand. The own-price elasticity of herbicides, fungicides and insecticides was -0.93, -0.52 and -0.39, respectively. All estimates were significant.

RENDLEMAN (1993) estimated the aggregate US demands for fertilizer, pesticides and other inputs with time series data covering 1948 to 1989 based on a Translog cost function. He found aggregate US pesticide demand to be price elastic with an own-price elasticity of -1.74.

Table 7-5: The own-price elasticity of pesticides

Author	Type of pesticide and location	Time horizon	Own-price elasticity
Econometric models			
DUBGAARD (1991)	herbicides (Denmark)	long-run	-0.69
	fungicides and insecticides (Denmark)	long-run	-0.81
AALTINK (1992)	all pesticides (Dutch horticulture)	short-run	-0.21
		long-run	-0.22
OSKAM et al. (1992)	all pesticides (Dutch agriculture)	short-run	-0.25
		long-run	-0.29
DUBBERKE and SCHMITZ (1993)	all pesticides (Germany)	long-run	-0.78
	all pesticides (Schleswig-Holstein)	long-run	-1.78
	all pesticides (Lower Saxony)	long-run	-0.50
	all pesticides (North Rhine-Westphalia)	long-run	-1.60
	all pesticides (Hesse)	long-run	-1.38
	all pesticides (Rhineland-Palatinate)	long-run	-1.90
	all pesticides (Baden-Württemberg)	long-run	-1.42
	all pesticides (Bavaria)	long-run	-1.53
	all pesticides (Saarland)	long-run	-1.37
RANDLEMAN (1993)	all pesticides (USA)	long-run	-1.74
GREN (1994)	herbicides (Sweden)	long-run	-0.93
	fungicides (Sweden)	long-run	-0.52
	insecticides (Sweden)	long-run	-0.39
RUSSEL, SMITH and GOODWIN (1997)	all pesticides (UK, Model I)	medium-run	-1.12
	all pesticides (UK, Model II)	medium-run	-1.09
Linear programming models			
SCHULTE (1984:252) (elasticities derived with a 100% tax on pesticides)	fungicides (Germany)	long-run	-0.45
	fungicides (Rhineland)	long-run	-0.67
	fungicides (Schleswig Holstein)	long-run	-0.80
	fungicides (Hesse)	long-run	-1.00
OHLHOFF (1987) (elasticities derived with a 100% tax on pesticides)	location without nematodes (Germany)		
	herbicides	long-run	-0.84
	fungicides	long-run	-0.51
	growth regulators	long-run	-0.08
	insecticides	long-run	-0.00
	all pesticides	long-run	-0.62
	location with nematodes (Germany)		
	herbicides	long-run	-0.84
	fungicides	long-run	-0.51
	growth regulators	long-run	0.15
	insecticides	long-run	-0.43
	nematicides	long-run	-1.00
	all pesticides	long-run	-0.75
DUBGAARD (1991) (elasticities derived with a price increase of 200 DKr per labelled dosage = increasing the average pesticide price by 120%)	all pesticides (Denmark)	long-run	-0.30

Source: author's presentation

In addition to the aforementioned econometric studies, price elasticities for pesticides have been derived from various linear programming models. SCHULTE (1984) used a linear programming model to investigate the effect of four different fungicide tax levels (100%, 200%, 300%, 400%) for five different regions in Germany. Depending on the scenario and the region, the implicit price elasticity for pesticides varied between -0.19 and -1. Table 7-5 displays the results of the 100% tax scenario for Germany as a whole and for three individual federal states.

OHLHOFF (1987) analysed the impact of six pesticide tax scenarios (50%, 100%, 150%, 200%, 250%, 300%) on pesticide use in a cropping system. He assessed the impact of the pesticide tax on the cropping pattern, the expenditure for pesticides for each crop and then computed a cropping system average. All the scenarios were run for locations without nematode infestation and for locations which are infested with nematodes. The derived elasticities in Table 7-5 refer to the cropping system average obtained under the scenario with a 100% pesticide tax. In his simulations using a linear programming based threshold model, DUBGAARD (1991) derived a price elasticity for pesticide demand of about -0.3.

Many of the above studies have estimated elasticities which are similar to those obtained for Costa Rica's coffee production in this publication.

8 The Impact of Pesticide Taxation on Coffee Farming and Policy Implications

This chapter assesses the impact of different pesticide taxation schemes on the income from coffee production and on pesticide demand. It then discusses the question if a pesticide tax is an appropriate policy option for Costa Rica and points out the issues that have to be taken into consideration for the design of such a tax.

Among Costa Rican crop protection experts there is a consensus that pesticides are overused in the country's agriculture. This is reflected in a commitment of crop protection policy to reduce pesticide use by promoting IPM. The first formal debate on a pesticide tax took place at a national workshop on crop protection policy in Costa Rica, which was organized by the Interamerican Institute of Co-operation for Agriculture (IICA) in December 1995. More than 20 experts from ministries, national and international government organizations, research institutions and from the private sector expressed their opinion on a pesticide tax and other issues related to pesticide policies. Sections 8.2 to 8.3 discuss pesticide taxation with reference to the information obtained in the above discussions.

8.1 The Impact of Pesticide Taxation on the Coffee Sector

The impact of various pesticide taxation schemes on coffee production can be assessed by using the results obtained in Chapters 6 and 7. Three tax scenarios will be analysed with respect to their income effects and to their impact on pesticide use in coffee.

8.1.1 Income Effects

The partial budget model presented in Section 6.4 is used to assess the income effect of pesticide taxes in coffee. Partial budget models tend to overestimate negative income effects from a pesticide tax because they assume a fixed technology package and do not take into account any options for pesticide substitution. This is not realistic as the econometric analyses of pesticide demand in Chapter 7 have shown. Pesticide demand in coffee is relatively price elastic which implies that pesticides to some extent may be substituted by other inputs. In spite of its shortcomings, the partial budget model can still be used to predict short-term income effects of pesticide taxation. The following three tax scenarios were used as a basis for the simulations:

- a 10% uniform ad valorem tax on all pesticides,
- a 50% ad valorem tax on nematicides (WHO I) and WHO II herbicides, as well as
- a 20% ad valorem tax on nematicides (WHO I) and WHO II herbicides and a 5% ad valorem tax on all other pesticides.

All three scenarios were computed for the sample average and for two groups of coffee farms, namely for farms with up to 5 ha planted with coffee and for farms bigger than that. This distinction has been made based on the results of the statistical analyses presented in Chapter 6 which indicated, that the difference in technology use is highly significant between these two groups of coffee farmers.

It has also been shown in Chapter 6 that on average both the gross margin and the variable production costs represent about 50% of the revenue from coffee production. Hence, the percentage decrease of the gross margin caused by the various tax schemes will approximately correspond to the percentage increase in the variable costs of production.

The three tax schemes proposed above have a similar impact on income from coffee production: on average, a 10% tax on pesticides would decrease the gross margin by about 0.63% and a 50% tax on WHO I and WHO II pesticides by 0.85%. A combined tax of 20% on WHO I and II pesticides and of 5% on all other pesticides would result in a 0.57% decrease in the gross margin. As pointed out above, these are short-term effects assuming a zero elasticity of substitution between all the variable inputs[64].

The percentage decrease in the gross margin in all cases is more pronounced for coffee plantations greater that 5 ha than for those with up to 5 ha under coffee because the former apply more pesticides than the latter. Consequently, big farmers would be slightly more affected by a pesticide tax than small farmers. However, with or without a tax the gross margin per hectare at big farms is about 17% higher than that obtained at small farms. Table 8-1 gives an overview of the results obtained in the simulations:

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[64] In the partial budget calculations, the tax rate only refers to pesticides, i.e. the expenditure for foliar nutrients remains unchanged.

Table 8-1: The impact of three tax scenarios on the gross margin in coffee

	Scenario 1: **10% tax on all pesticides**	Scenario 2: **50% tax on WHO I+II pesticides**	Scenario 3: **20% tax on WHO I+II, 5% tax on other pesticides**
sample average	-0.63%	-0.86%	-0.57%
coffee area ≤ 5 ha	-0.53%	-0.76%	-0.50%
coffee area > 5 ha	-0.77%	-1.00%	-0.68%

Source: author's computations

The differences of the impact of pesticide taxes on the gross margin between the two regions included in the sample are similar to those between the different farm sizes as presented in Table 8-1. The Central Valley which has a more intensive coffee production would be slightly more affected by a pesticide tax than the Turrialba region.

These results suggest that the competitiveness of coffee production in Costa Rica would not be substantially hindered by a pesticide tax. Interestingly, these results are similar to what OSKAM et al. (1992) and AALTINK (1992) obtained in their econometric analyses of income effects due to pesticide taxes for the Dutch agricultural and horticultural sectors, which are known to be highly pesticide intensive. OSKAM ET AL. (1992) estimated that a 1% increase in the pesticide prices on average leads to a 0.06% decrease in farm income in the arable sector, and AALTINK (1992, cited in OSKAM ET AL., 1992) found that a 1% increase in the pesticide prices on average reduces the income in the horticulture sector by 0.04%.

8.1.2 Impact on Pesticide Use

Two approaches have been used to estimate the pesticide demand in Costa Rica's coffee production: a panel model, and a system of demand functions for variable inputs in coffee. Both models estimate linear demand functions which have different price elasticities at each point. Downward sloping linear demand functions are more elastic for high prices than for low prices (SADOULET and DE JANVRY, 1995). Hence, the impact of a price increase on demand is rather underestimated when extrapolating from mean values over a large space.

8.1.2.1 Projections on the Basis of the Panel Model

The panel model has explained much of the variation in pesticide use ($R^2 = 0.92$) and has generated significant parameter estimates. It suggests that pesticide use in coffee is quite price elastic with an own-price elasticity of aggregated pesticide use of -0.99 at mean values. This figure implies that a 1% increase in pesticide prices would lead to a 0.99% decrease in pesticide demand.

Using the elasticity of pesticide demand at mean prices and quantities for the projection of a 10% price increase for pesticides would lead to an approximately 10% decrease in pesticide use. This prediction is made under the assumption that the pesticide aggregate will remain unchanged, i.e. no substitution between different types of pesticides takes place.

8.1.2.2 Projections on the Basis of the System of Demand Equations

The simultaneous equations system for input demand in coffee provides more detailed information on pesticide demand by differentiating four types of pesticides as outlined in Section 7.3.2. The demands for nematicides and WHO II herbicides have been modelled in individual equations because these pesticides are the prime candidates for taxation. Although some of the parameter estimates obtained with the system of demand equations are inconclusive, it has been used to simulate the above policy scenarios on pesticide use. The results of the simulations are summarized in Table 8-2:

Table 8-2: Simulation of the impact of pesticide taxation on input demand in coffee (% change over base value)

	Scenario 1: **10% tax on all pesticides**	Scenario 2: **50% tax on WHO I+II pesticides**	Scenario 3: **20% tax on WHO I+II, 5% tax on other pesticides**
WHOII herbicides	-0.24%	20.15%	5.92%
other herbicides	-0.48%	-1.99%	-0.84%
fungicides +foliar nutrients	1.30%	36.00%	11.45%
nematicides	-1.44%	-36.36%	-11.63%
fertilizer	-0.22%	18.76%	5.52%
labour	0.95%	-2.82%	-0.37%

Source: author's computations

A number of positive cross-price effects between different types of pesticides, which are not plausible, cause the surprising results presented in Table 8-2. According to the results obtained with the system of demand equations, a 10% increase of pesticide prices would lead to change in pesticide use ranging from +1.30% for fungicides to —1.44% for nematicides (scenario I). In scenario II, a 50% increase in prices for WHO II herbicides and for nematicides leads to an increase in the demand for WHO II herbicides. This implausible result is mainly due to the positive cross-price coefficients between nematicides and WHO II herbicides. In conclusion, the results obtained in these simulations must be rejected and cannot be used for policy analysis.

8.1.2.3 Conclusions with Regard to Pesticide Demand in Coffee

The results of the quantitative analyses show that pesticide demand in coffee is rather elastic. The panel estimate for the elasticity of aggregated pesticide demand is -0.99 at mean prices and quantities. Furthermore, the panel model suggests that there is an important substitutional relationship between labour and pesticides which is reflected by a cross-price elasticity of 0.71 for pesticides with regard to wages.

The panel model may be used to simulate the effect of an ad valorem pesticide tax on aggregated pesticide demand. Tax schemes that differentiate between different types of pesticides in principle may be analysed using a system of demand equations. Unfortunately, some of the parameter estimates obtained in the system are not conclusive and therefore the simulations conducted with this model lead to contradictory results. However, taking into account the limitations of the estimated system of simultaneous demand equations, the results suggest that the own-price elasticities derived at means for all pesticides used in coffee are relatively price elastic, with nematicides being the most price elastic (Table 8-3).

Table 8-3: Own-price elasticities derived at means

Input	Own-price elasticity
WHO II herbicides	-0.68
other herbicides	-0.34
fungicides and foliar nutrients	-0.84
nematicides	-1.18
fertilizer	-0.15
labour	-0.23

Source: author's computations

Nematicides are the most hazardous pesticides used in coffee production and therefore most likely to be taxed. An own-price elasticity of -1.18 suggests that a tax would have a considerable impact on nematicide use. Furthermore, WHO II herbicides (classified by WHO as moderately hazardous), seem to be more price elastic than the "other herbicides" (classified by WHO as slightly hazardous) used in coffee production.

The conclusion that a pesticide tax would seem to have a significant impact on pesticide use in coffee production is in accordance with options for pesticide substitution in the field: herbicides may be substituted by manual labour, nematicides are not essential in fully grown coffee plantations, and fungicides and foliar nutrients, though increasing the productivity, in many places are not indispensable either.

8.2 Implications of the Introduction of a Pesticide Tax in Costa Rica

The present agricultural policy in Costa Rica has the objective of promoting sustainable agricultural practices and, in this context, to reduce pesticide use. Therefore, a pesticide tax in Costa Rica could be used as an instrument for this objective by increasing pesticide prices in order to reduce demand. However, the effects of a pesticide tax are very complex and may result in a number of desired and undesired impacts some of which are analysed in this section.

8.2.1 Efficiency and Effectiveness of a Pesticide Tax

"Efficiency in a fiscal sense is when a tax raises revenues with as little impact as possible on production or consumption patterns. Efficiency in environmental terms refers to a policy that induces agents to change their behaviour with the least economic costs, in order to meet environmental goals. [...] Environmental taxes help change relative prices and provide incentives to use more environment-friendly products and methods of production. By pricing the environment and thereby reducing market distortions, environmental taxes not only reduce externalities, but they also improve economic efficiency" (OECD, 1996c).

According to PIGOU (1924), to fully internalize social costs, the appropriate tax rate should be set where the marginal cost of reducing emissions equals marginal social damage[65]. This, however, requires a large set of information which is often not available, and difficult (if not impossible) to acquire in time. In many cases the adverse environmental effects of pesticides, which are non-point pollutants, cannot be directly assigned to a specific source of pollution nor to an active ingredient of a formulated product. Furthermore, many of the damage effects, in particular the chronic health impacts, occur through small doses over a long period of time. Therefore, it is often impossible to quantify these effects directly, especially given that the chemicals involved change with time (PEARCE and TINCH, 1998).

The problem of tax specification is further aggravated by the fact that in order to be efficient, tax rates for pesticides would have to be differentiated according to regions and even to the application technology used at each farm as stated by ZILBERMAN and MILLOCK (1997). They conclude that a special tax rate may be needed for every applicator, and that, in such cases, the use of taxation does not have the advantage of ease of implementation. In fact, under such conditions, the cost of pesticide taxation would be prohibitively high.

This brief introduction to the theoretical requirements of an efficient environmental tax on pesticides has made it clear that in practice there is not likely to be a solution that satisfies all the theoretical criteria. Since it is difficult to assess the marginal costs of each pesticide, a more practical method is to quantify the total external costs of pesticide use as it has been done in the USA and in Germany (see Appendix 3). On this basis, the average external costs can be computed and used as a basis for the determination of the tax rate. Nonetheless, it still remains difficult to attribute costs to specific types of pesticides. In Costa Rica more research is needed for the assessment of the external costs of pesticide use. However, given the evidence for external effects presented in Section 2.3.2, it can be expected that a pesticide tax, if designed appropriately, would move pesticide use towards the social optimum (as illustrated in Figure 3-1)[66].

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65 The Pigouvian principle refers to a first-best setting where no other taxes are present. Nonetheless, SANDMO's (1975) analysis revealed that, if other taxes are present, environmental and ordinary taxes need to be examined together. The impact of incremental or marginal reforms cannot be effectively evaluated without paying attention to the magnitudes and types of existing, distortionary taxes (GOULDER, 1997). However, the consideration of all taxes present in an economy raises additional methodological and data problems and is therefore often is not feasible.

66 The impact of pesticide use in coffee production on human health has been reported by QUIRÓS, SALAS and LEVERIDGE (1994). Based on the analysis of pesticide intoxications registered at Costa Rica's National Centre for Poisoning Monitoring, they found that between 1986 and 1992 coffee was one of the crops in which most occupational intoxications occurred. Furthermore, the survey on input use in coffee production conducted in this study provides evidence for excessive pesticide use on some coffee farms (see Section 6.3.3.1).

If no (or insufficient) information is available to approximate the external costs of pesticide use, a second-best approach to the determination of the tax rate consists in setting the tax rate according to a predetermined environmental target and the anticipated response to various changes in price signals (OECD, 1996c). In view of the government's objective of reducing pesticide use, such a pragmatic approach could be a suitable solution for Costa Rica. Setting an environmental target is a political decision in which all of the stakeholders concerned should be involved. The results obtained in this research could be used as a reference to help specify the tax rate required to reach the respective pesticide use reduction targets.

Taxation, Innovation and Adoption of Non-chemical Technologies

HAYAMI and RUTTAN (1985) have shown that factor prices not only have an impact on the optimal factor allocation at a given point of time, but also induce technological change. Hence, a price increase for inputs that cause external effects through environmental taxes would provide a permanent incentive to reduce pollution and to innovate in order to reduce tax payments. This is known as "dynamic efficiency" (OECD, 1993).

A reduction in pollution can happen through the development of new technologies or through the adoption of technologies which are already available. Evaluating the impact of policy instruments on technological change for various non-agricultural industries[67], KEMP (1997) found that in most circumstances a tax regime provides less inducement to innovation in pollution control technology than direct control through regulations. The reason why the innovation effects of a pollution tax are relatively small is that the tax rate in general is set at a rather low level in order not to impose high environmental costs on the industry concerned. More importantly, KEMP (1997) also found that environmental taxes have an important role in stimulating the use of technology that is already in existence. KEMP concluded that a tax would be most effective when it is combined with other complementary measures.

In Costa Rica, therefore, these findings indicate that a pesticide tax would possibly improve the adoption of non-chemical techniques in crop protection in

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67 Kemp's study includes empirical analyses of the impact of policy instruments on the technological diffusion of biological waste-water treatment plants and thermal home insulation in the Netherlands. Furthermore, it contains a literature review of empirical studies on the effects of past environmental policies on the development and adoption of cleaner technologies and presents the findings of three case studies, namely for Chlorofluorocarbon (CFC) substitutes, low-solvent paints and membrane filtration.

general, while its impact on the development of non-chemical crop protection measures would be limited. Research by OSKAM, VIJFTIGSCHILD and GRAVELAND (1998) suggests that the effectiveness of a pesticide tax regarding the reduction of pesticide use could be increased through complementary measures such as extension programmes.

8.2.2 Societal Acceptability and Equity Aspects of a Pesticide Tax

A pesticide tax, like any other tax, implies a redistribution of income. Depending on the type of tax and on the destination of the tax revenue the distributional effects can be between sectors or within the agricultural sector. Societal consensus and in particular, the agreement of the farmers concerned, may most likely be reached when redistributional effects are low. Societal acceptance of a pesticide tax also has to do with a number of concerns that are often raised with regard to the impact of a pesticide tax on the environment, on the competitiveness of the agricultural sector, or on consumer prices for agricultural products when the increase of production costs is passed on to the consumer. The following paragraphs will focus on the equity and profitability aspects of a pesticide tax. The problem of potential undesired environmental impacts of a pesticide tax will be addressed in Section 8.3.

The empirical part of this study has shown that a tax on pesticides would not significantly affect the profitability of coffee production in Costa Rica, but that it would have a substantial impact on pesticide use in this crop. Therefore, the competitiveness of coffee production would not be threatened by a tax on pesticides. Highly pesticide intensive coffee farms would be affected more than average by a pesticide tax which is in accordance with the main objective of reducing pesticide use.

In Costa Rica a wide variety of crops are grown, some of which are more pesticide intensive than coffee. In the short run, these other crops are likely to be more affected by a tax than the coffee producers. From a social point of view this would be justified, since pesticide-intensive crops in general cause more external costs than pesticide-extensive crops. Despite this, the agricultural sector as a whole would most likely not have its competitive position substantially weakened[68]. Nor would consumer prices be affected

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[68] Sectoral analyses in the Netherlands, which are well known for their pesticide-intensive agriculture, have shown that the impact of a pesticide tax on farm income would be similar to that calculated in this research for Costa Rica's coffee production (OSKAM, 1992; AALTINK, 1992).

significantly, because on average pesticides represent only a small proportion of the total production costs in agriculture[69].

The Destination of the Tax Proceeds

Societal acceptance and equity are closely related to the destination of the tax revenue. Tax proceeds can be used for at least three main purposes: to reduce budget deficits, to increase government expenditure on particular public programmes, and to reduce other taxes (OECD, 1996c). The question of whether a pesticide tax should contribute to the general government budget or be reinvested in agriculture cannot be answered on the basis of the empirical part of this thesis[70]. However, the destination of the tax revenue is an essential question and therefore deserves some consideration.

If the pesticide tax in the first place is meant to compensate society for the externalities caused by pesticides, it would be adequate to contribute the tax proceeds to the government budget and decide on the basis of priority development objectives on the utilization of these resources. In this case, as mentioned earlier, detailed research on the environmental cost of each pesticide would be needed to facilitate any decision making on the respective tax rates.

But if a pesticide tax is to be introduced as an instrument for the reduction of pesticide use down to a previously defined pesticide use reduction target (for which no exact statement needs to be made regarding the external costs provoked by each pesticide), an investment of the tax proceeds in complementary measures that support the pesticide use reduction objective could be envisaged. The reinvestment of such a tax in the agricultural sector could help the achievement of a societal consensus on pesticide taxation in Costa Rica and most likely would increase the effectiveness of its impact on pesticide use reduction.

If it is decided by the society, the agricultural producers could be compensated for the increase in their production costs in a way that maintains the tax incentives. For example, the tax proceeds could be used to lower other taxes as proposed by SMITH (1996). In Costa Rica, for example, one such option

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69 Appendix 8 discusses the example of the short-term impact of a 10% ad valorem pesticide tax on Chrysanthemum production. It shows for a pesticide intensive crop that, even if the increase in production costs is passed on to the consumers, the consumer price would not significantly change. Chrysanthemum is one of the most pesticide intensive crops produced in Costa Rica.

70 MANIG (1981) has analysed in detail the various options of taxation in the context of rural development.

could be to restitute a proportion of the pesticide tax revenue by lowering the recently introduced land tax. Nonetheless, such options would need a thorough analysis with regard to the administrative costs and other transaction costs of the restitution and its implications for factor allocation.

8.3 The Appropriate Design of a Pesticide Tax in Costa Rica

The fundamental considerations related to a pesticide tax raised in the previous section lead to more practical questions on the options for the design of a pesticide tax. A pesticide tax should ideally be predictable and relatively stable to allow farmers to adjust to the new prices. Simplicity and low costs of administration, monitoring and compliance are also desirable (OECD, 1996c). Among the many possiblities for the design of a pesticide tax there is an obvious trade-off between administrative simplicity on the one hand and economic efficiency and environmental effectiveness on the other hand. It is clear that a suitable policy should take into account all three aspects.

The design of a pesticide tax in Costa Rica shall now be discussed in the light of an effective pesticide use reduction. In this context the tax base, the tax collection, the time frame for the introduction of a tax and monitoring requirements need to be discussed.

8.3.1 Tax Base

The selection of the appropriate tax base is probably the most difficult task in designing a pesticide tax. There are a number of options that could be applied to pesticides such as sales value, per hectare dosage, the weight of active ingredient, or the environmental impact of a product.

From an administrative point of view, a uniform ad valorem tax on all pesticides would be the preferred solution, because it is easy to understand and to administer. However, an ad valorem tax would mostly affect the price of expensive pesticides, whereas the prices of cheap pesticides would increase less. As pointed out earlier, the price of a pesticide is not linked to its environmental hazardousness and therefore an ad valorem tax might lead to an inefficient outcome, where the use of cheap pesticides, which are often classified as highly hazardous, is increased at the expense of more expensive, but often less toxic pesticides. Therefore, from an environmental and economic point of view, a differentiated tax that takes account of the environmental hazard of a pesticide would be the preferred solution.

A pesticide tax as it is proposed here, would in the first place be a measure that helps to reduce pesticide use. Therefore, the focus of the tax design should be on the impact of the tax on pesticide demand; one of the main focuses of this research. The question whether the tax rate equals the marginal external costs of a pesticide or not would then be secondary. In order to avoid any adverse environmental effects, highly hazardous pesticides should receive special consideration when fixing the tax rates. A pesticide tax that consists of two components (as displayed in Table 8-4) could be used to discourage the purchase of the most problematic pesticides (i.e. those pesticides which are known for causing significant environmental damage):

Table 8-4: Possible components of a tax on pesticides

Tax component	Which pesticides?	Impact on pesticide use
general ad valorem tax	all	low
additional environmental tax (differentiated according to the environmental hazardousness)	environmentally hazardous	intermediate

Source: author's presentation

These two components would ensure that environmentally highly hazardous pesticides would be more affected by the tax than any of the other pesticides. The elasticities estimated for pesticide demand in coffee production could serve as an orientation for the definition of both the general and the environmental tax rates. However, more technical input on the likely elasticity of pesticide demand in other crops would be required from all stakeholders in crop protection.

The environmental component of the tax could be assessed according to the evidence for the actual or potential hazardousness of a pesticide available at the time when the tax policy is initiated. Since the data base for this initial classification is likely to be rather weak, experts from the areas of crop protection, environment and health could help to classify pesticides based on their experience and knowledge. Classifications from other countries could also be used as a reference (e.g. the "environmental yardstick" developed by REUS, 1998)[71].

Monitoring and Point of Tax Collection

However, the outcome of the tax policy should be reviewed at regular intervals because the response may end up being different from what was first expected and thus the rate schedule may have to be adjusted. Monitoring of pesticide use and its environmental impact would improve the basis for levying taxes, but also for evaluating the environmental and economic impacts of the taxes (OECD, 1996c). The adjustment of both the general and the environmental components of the tax could be envisaged in previously specified intervals, e.g., at each re-registration.

With the view of keeping the administrative costs as low as possible, the number of tax collection points should be minimized. If imposed early in the distribution chain, the number of transactions is limited and the size of the tax base is maximized. Furthermore, it would be advantageous to incorporate the tax in the existing systems of administration and control (OECD, 1996c). Therefore, in Costa Rica, the most appropriate points of imposition for pesticide taxes would be the points of entry for imports and the Costa Rican pesticide manufacturers.

8.3.2 Time Frame for the Introduction of a Tax

When choosing a tax rate, care should be taken to distinguish between short-term and long-term objectives. If the environmental objectives are long term, the tax rate may be set initially at a much lower rate than if one seeks to achieve major results in a short period. Long-term objectives allow for a more gradual approach" (OECD, 1996c).

In order to allow a smooth transition for the agricultural sector to the new prices, it may be advantageous to introduce a tax in several steps that should be defined by the societal groups concerned. This would give farmers time to adopt and further develop non-chemical crop protection measures. The initial price incentive could be relatively low, but it should be made clear to all the parties concerned that within a given period, the level of taxation will increase in a stepwise fashion. The two components of the tax that have been proposed

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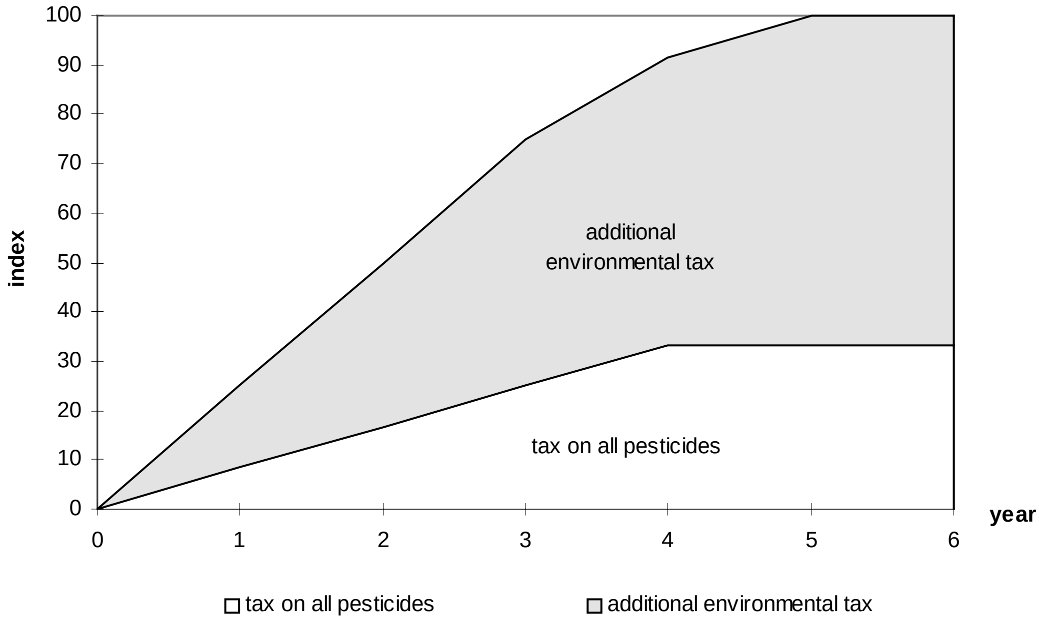
71 At present a 0.5% fee on the cif-value is charged on agrochemcial imports to Costa Rica. The resources obtained with this charge are foreseen as being used for the government's activities in crop protection. Until a differentiated tax system is established, this charge could be kept in place at the current level, and become part of the general ad-valorem tax at a later stage.

could be increased in parallel in order to prevent any negative environmental effects being elicited due to the taxation. Figure 8-1 illustrates how such a tax could be introduced over a given period.

Figure 8-1: Example of a stepwise introduction of a pesticide tax in Costa Rica



Source: author's presentation

The determination of the tax rates and the time frame for the introduction of a potential pesticide tax are subject to the outcome of consultations with the various stakeholders in the crop protection sector. In Figure 8-1 a gradual increase in the tax rates over five years is proposed for illustration purposes. The tax rates are not specified but indicated with an index which reaches its maximum after five years. As discussed earlier, the environmental component of the tax is to be specified for each pesticide based on the available evidence of its detrimental environmental effects and should be subject to monitoring and review at regular intervals.

8.3.3 Conclusions

One major conclusion of the previous discussion is that the decisions on tax rates and on the destination of the tax proceeds are political. Once these decisions have been made, it can be ensured that the tax revenue is allocated accordingly. In Costa Rica, the tax base, tax rates and the destination of the tax proceeds could be specified in a single law[72].

A pesticide tax would offer an opportunity to policy makers for the preparation of a set of accompanying policies that could make the tax not only more efficient but also more acceptable, especially if they can capitalize on the increasing support for environmental goals. WAIBEL (1998), for example, proposes a set of measures that could be implemented in promoting integrated pest management. A comprehensive policy package should include measures that reduce non-price barriers to effective pesticide use reduction, such as lack of information. This would increase the elasticities of pesticide demand and lead to a shorter and less costly period of adjustment. Appendix 9 contains the results of an expert survey on the determinants of pesticide use in Costa Rica. The findings of this survey could be used as a basis for the discussion on complementary measures for pesticide use reduction.

[72] According to the Ministry of Finance, the appropriate legal instrument would be a law on a "selective sales tax on pesticides" *(impuesto selectivo para el consumo)*.
Source: José Luis León, Departamento de Política Fiscal, Ministerio de Hacienda de Costa Rica, personal communication (1995)

9 Conclusions

Based upon a number of external effects related to pesticide use in Costa Rica and the Costa Rican government's objectives of promoting integrated pest management and reducing pesticide use, this thesis has analysed pesticide taxation as one option for dealing with these issues. On theoretical grounds it has been shown that a pesticide tax can be a means of internalizing the external costs of pesticide use and that such a tax, if implemented appropriately, can be an effective complement to regulatory and moral suasion instruments in crop protection policy.

Although pesticides are not ordinary inputs, neoclassical models are appropriate for the assessment of the impact of pesticide taxation on pesticide use and on income in coffee production. Two approaches were chosen for the estimation of pesticide demand: a single equation fixed effects panel model and a system of simultaneous factor demand equations. The panel model, which was used to estimate aggregated pesticide demand, generated significant results: it explained about 92% of the variation in pesticide demand and most of the parameter estimates were significant. The own-price elasticity of pesticides computed at means was -0.99, suggesting that pesticide demand in coffee is rather elastic. Furthermore, the estimates show that in coffee, pesticides and labour are important substitutes with a cross-price elasticity of 0.79. As the panel model, however, does not allow to draw any conclusions about the impact of a tax on the demand of the different types of pesticides, a system of factor demand equations with four types of pesticides, fertilizer and labour was also estimated. Not all the results of this system of demand equations were conclusive and therefore had to be rejected. However, it should be noted that the own-price effects that were estimated are in accordance with what had already been found in the aggregated single equation panel model. They suggest that the own-price elasticities at means for the different types of pesticides used in coffee production vary between -0.34 and -1.18, with nematicides being the most price elastic. This finding is important because nematicides are the most toxic substances used in coffee production and are therefore prime candidates for taxation.

The conclusions that can be drawn from these results with respect to the appropriate methods for the analysis of pesticide demand using farm data are as follows:

The aggregated panel model is more robust than the differentiated system of demand equations and therefore yields more significant results. However, even in the aggregated model collinearity problems may arise and therefore the selection of the appropriate exogenous variables and functional form is important.

A system of differentiated simultaneous demand equations is more susceptible to misspecifications and errors in the data. It is more than likely, that the problems encountered when estimating a simultaneous system are particularly pronounced when farm data are used. However, it would be worth trying to estimate a similar system of demand equations with a panel consisting of less cross-sections and a longer time series. In addition to the price variables, data on non-price variables such as climate conditions in the various locations should then be collected and included in the model.

The income effects of a pesticide tax on coffee production were analysed with a partial budget model. Even though partial budgets overestimate the negative income effects from pesticide taxation because they presuppose a fixed technology package and do not take into account any of the options for factor substitution, this model for a pesticide tax did not result in a substantial income reduction for coffee farmers. In conclusion, both hypotheses of this research were confirmed: pesticide use in coffee is rather price elastic and income effects resulting from a pesticide tax are not substantial.

These results suggest that a tax on pesticides would be an effective policy instrument for the reduction of pesticide use. Both, the methodological and the data problems that arise when determining a tax rate that internalizes external costs have been considered in this analysis. These problems are particularly significant especially as there is little data available about the external costs of pesticide use in Costa Rica. A second-best approach to the determination of a tax rate for pesticides would consist of setting the tax rate according to a predetermined environmental target and the anticipated response to various changes in price signals. The environmental target would then be defined by the various societal groups involved in crop protection.

The experiences of some European countries suggest that the effectiveness of a tax in reducing pesticide use would most likely be enhanced by complementary measures that aim at pesticide use reduction. Information and "awareness" instruction for all groups in society affected by pesticide use, effective training programmes for farmers, as well as the development of additional non-chemical crop protection methods are issues that should all be considered when designing such complementary measures.

When designing a tax, both administrative simplicity and environmental effectiveness have to be taken into account. In order to avoid detrimental environmental effects when introducing a tax, it would be advantageous to differentiate the tax rates according to the environmental impact of a pesticide. For Costa Rica, a tax that consists of two components has been proposed: a general component which applies to all pesticides and an additional environmental component set according to the hazardousness of a pesticide. The environmental component could be applied to all products that are known to be environmentally hazardous. The environmental impact of the pesticides should be further monitored in order to collect data for a sound environmental evaluation of each pesticide. The results of this monitoring could then be used to adjust the pesticide specific environmental component of the pesticide tax at defined intervals.

To keep the impact of a tax on farm income low, it would be best to introduce the tax in several steps. This would then give the farmers enough time to adjust their production to the new price signals. Nonetheless, it should be made clear from the onset of taxation to all the parties concerned at which intervals the tax rates will be increased.

The decision on the destination of the tax proceeds is a political decision. If it is decided that the farmers should be compensated for the introduction of a pesticide tax, this should only be done in a way that maintains the tax incentives on pesticide use reduction. For example, a defined proportion of the tax revenue could be restituted to the farmers by lowering other taxes such as the recently introduced land tax. Nonetheless, such measures would require thorough studies on the administrative feasibility and on the transaction costs involved.

10 Summary

Over the past few decades, a number of developing countries have set up programmes to regulate pesticide use and, more recently, to reduce pesticide use by promoting integrated pest management (IPM). Costa Rica is one of the most advanced countries in this field in Central America. However, as elucidated in Chapter 2, in spite of Costa Rica's sophisticated legislation, there is current evidence of excessive pesticide use and of various external effects caused by the use of pesticides. Therefore, there is scope for the application of additional instruments in Costa Rica's crop protection policy. The overall objective of this research is to discuss pesticide taxation as an additional instrument in pesticide policies and to assess the impact of such a tax on pesticide use and income in Costa Rica's coffee production.

The two chapters concerned with basic theory elaborate on the economics of pesticide taxation and pesticide use. Chapter 3 hypothesizes that the private and the social optima of pesticide use diverge and evidence is presented on the amount of external costs arising due to pesticide use from different countries. Then different approaches to deal with the externality problem are discussed with a focus on economic instruments. It is concluded that, in view of the large number of individuals who are directly or indirectly concerned with pesticide use, the negotiation approach as proposed by COASE (1960) would not be a feasible solution. In contrast, pesticide taxation, if implemented appropriately, seems to be a more promising approach to internalize the external costs of pesticide use and would act as an effective adjunct to regulatory and moral suasion instruments in crop protection policy. Chapter 3 also presents various experiences with economic instruments in pesticide policies in both developing and developed countries. It is reported that in the past massive direct price subsidies for pesticides considerably stimulated pesticide use in developing countries. On the other hand, a number of experiences with pesticide taxation (which are more recent) have been documented.

Chapter 4 looks at pesticide use from a farm perspective. The standard neoclassical optimization model is briefly introduced emphasizing the concept of factor substitutability and the dual approach to production analysis. Then, the special nature of crop protection inputs is discussed and models that to some extent take account of that specificity are presented. Nonetheless, a literature review on the econometric estimation of pesticide productivity shows, that for many years the productivity of pesticides has been overestimated because of the use of standard production functions in analysing pesticide use. More recent approaches have introduced a damage function into the production function and, depending on the form chosen for the damage function, have yielded more plausible results. However, pesticide productivity remains a difficult topic. Pesticide use levels above the optimum may partly be explained by uncertainty in pest management, risk aversion, path dependence and asymmetric information.

Based on the aforementioned theory chapters, two hypotheses have been derived that challenge common beliefs regarding pesticide taxation: firstly, it is hypothesized that pesticide demand in coffee is rather elastic and secondly, it is hypothesized that a pesticide tax would not substantially affect income from coffee production.

Chapter 5 presents the main characteristics of Costa Rica's coffee economy. The organization of the coffee sector is elucidated with a focus on the marketing and pricing system for coffee. Costa Rican coffee farmers are price takers and directly exposed to price fluctuations on the world market for coffee. Due to the commercialization system in Costa Rica, the coffee farmer receives his payments in shares over a period of one year. Therefore, farmers are aware of the coffee prices at each time of the year and are able to adjust their variable input use, if considered necessary.

The average productivity of coffee in Costa Rica is the highest in the world. Data published by ICAFE suggest that productivity on average is higher on farms with more than 5 ha planted with coffee than on farms with less than 5 ha under coffee. Conventional coffee production is predominant in Costa Rica while organic production plays a growing but still very small part. Detailed empirical data on pesticide use and other variable inputs in coffee production are not available and therefore it was necessary to conduct a survey for the purpose of this study. The production system of coffee is relatively simple and therefore could easily be recorded in a survey.

Chapter 6 presents the data collection, data processing and aggregation, and the statistical analyses. It first introduces the design of the survey, the data collection method, the structure of the questionnaire and the initial data processing. In order to estimate demand functions for pesticides, it was necessary to aggregate the inputs. Aggregation and the selection of the appropriate index are not simple tasks, because both have a number of implications for the subsequent analyses. These are discussed and it is explained how the aggregates were formed by computing Ideal Fisher price and quantity indexes. Aggregation imposes a number of restrictions on the micro data but, at the same time, may increase the explanatory power of data. This is due to a reduction of the multicollinearity problem by forming aggregates over price variables and to the fact that aggregates, in general, are less susceptible to specification errors than disaggregated data.

Various *t*-tests showed that the use of agrochemicals and of labour in coffee production have increased significantly from 1993 to 1995, which is most likely related to the increase in world market coffee prices during this period. Further *t*-tests revealed that the yields and the use of variable inputs also differed significantly between the two regions included in the sample and between the different farm sizes. The most significant differences were found when comparing input use according to the area cultivated with coffee.

Average production costs and revenues were computed for the whole panel. In order to make the expenditures and revenues of the various years comparable, all the items were transformed to 1995 prices. A detailed costs analysis displayed that the expenditure for pesticides on average totaled about 7% of the variable production costs. Herbicides had the highest share of the variable production costs with about 3.2%, followed by fungicides (2.7%) and by nematicides (0.9%). The cost of pesticide application on average was almost as high as the expenditure for these products. The partial budget analysis conducted with the panel data set, furthermore, established that the variable costs of production from 1993 to 1995 on average were equivalent to about 50% of the revenue obtained with coffee. Hence, if a pesticide tax were to be introduced, the percentage increase in variable production costs would reflect approximately the percentage decrease in the gross margin.

Chapter 7 focuses on the estimation of pesticide demand. The introduction to panel data analysis makes explicit that panel models are to be preferred to the classical OLS regression models for the analysis of pooled time series and cross-sectional data. Among the various panel models that take into account unknown individual-specific and/or time-specific effects, the fixed-effects model has been identified as being the most appropriate for this research.

Three flexible forms were used to estimate the aggregated pesticide demand in a fixed-effects panel model, namely demand functions derived from the Quadratic, the Normalized Quadratic and the Generalized Leontief profit functions. These dual forms are not as restrictive as the standard Cobb-Douglas or CES types, and therefore were preferred for the analysis of pesticide demand in coffee. The demand function derived from the Quadratic model provided both significant and plausible results. The own-price elasticity at means of aggregated pesticide demand was estimated at -0.99, and the cross-price elasticity between pesticide demand and the wage at 0.79, suggesting that labour is an important substitute for pesticides in coffee. The demand functions derived from the Normalized Quadratic and the Generalized Leontief profit functions did not generate meaningful results.

A more differentiated analysis of the different types of pesticides that takes into account the cross-price relationships cannot be conducted appropriately in a single equation model. Therefore, a system of simultaneous demand equations was estimated using Zellner's seemingly unrelated regression method. Own-price elasticities at means obtained in the system of demand equations varied between -0.34 and -1.18, which is in accordance with the own-price elasticity estimated in the aggregated single equation panel model. However, since some cross-price effects estimated with the system of demand equations are inconclusive, these results have to be interpreted with reservation.

Based on the results obtained in Chapters 6 and 7, the impact of three pesticide tax scenarios on income from coffee production and pesticide demand was assessed. The first scenario was a 10% ad valorem tax on all pesticides, the second, a 50% ad valorem tax on the most hazardous pesticides used in coffee production and the third scenario was a 20% tax on the most hazardous pesticides and a 5% tax on all other pesticides. All three scenarios led to a reduction in the gross margin of about 0.7%. Hence, the impact of pesticide taxes on income from coffee production is not substantial.

Then the possible changes in pesticide demand were examined under the above scenarios. First, the impact of a uniform ad valorem tax was simulated with the aid of the single equation panel model which suggested a significant decrease in pesticide demand: using the own-price elasticity computed at means, a 10% ad valorem tax on all pesticides would result in a decrease of 9.9% in pesticide use. The impact of the two more differentiated tax scenarios was assessed with estimates obtained in the seemingly unrelated regression estimation. However, since some of the parameters estimated are not plausible, the simulation runs based on this system of demand equations had to be rejected.

The results obtained in the policy simulations led to the conclusion that a pesticide tax would not substantially affect income from coffee production but would substantially reduce the pesticide use in this crop. The hypotheses of this research are therefore both confirmed: pesticide demand is not as inelastic as is frequently thought, and a pesticide tax would not considerably affect income from coffee production.

The last two sections of Chapter 8 elaborate on the implications of a pesticide tax with regard to economic efficiency, environmental effectiveness, acceptance in the society and equity. Given the evidence of the external effects of pesticide use in Costa Rica, it is likely that a pesticide tax would be efficient by moving pesticide use to the social optimum. However, no statement can be made on the tax rate that would be efficient because the marginal external costs of pesticide use in Costa Rica's agriculture are not known. Nevertheless, since pesticide demand in coffee is rather elastic, a pesticide tax seems to be an effective policy instrument that could contribute to the government's objective of reducing pesticide use.

Acceptance of a tax in the society and distributional aspects are closely related. Societal consensus and in particular, the agreement of the farmers concerned may most likely be reached when redistributional effects are low. Therefore, any additional measures that support the agricultural sector in adjusting to the new price signals or the restitution of a part of the tax revenue by lowering other taxes such as the recently introduced land tax could be envisaged. However, these alternatives would require a thorough analysis with regard to their transaction cost and their effectiveness. The more fundamental question of the efficient allocation of tax revenue goes beyond the scope of this research.

In order to avoid any detrimental environmental effects when introducing a pesticide tax, the tax should be differentiated according to the environmental risk related to a pesticide. As an example, a two component tax was discussed which consists of a general component applicable to all pesticides and of an environmental component to be differentiated according to the likely environmental impact of a pesticide. It has been pointed out, that a stepwise introduction of a pesticide tax would be advantageous, because it would give farmers the opportunity to adjust to the new price signals.

Based on the findings from other countries, the effectiveness of a tax in reducing pesticide use could possibly be enhanced by complementary measures such as information and awareness building for all groups in society affected by pesticide use, effective training programmes for farmers, and the development of additional non-chemical crop protection methods. However, the design of a comprehensive pesticide use reduction strategy for Costa Rica would require more research.

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Appendix 1: Map of Costa Rica

Figure A 1-1: Duration of the growing season in various locations in Costa Rica (days/year)

Source: ROJAS (1987)

Appendix 2: Pesticide Policy in Costa Rica

Table A 2-1: Determinants of pesticide use in Costa Rica

Institutional factors and information	Price factors and external costs
• special budget for emergency spraying operations • allocation of public resources in research for pesticide use • subsidies to agricultural products that require a high plant protection intensity • lack of transparency in the pesticide registration system • lack of information on non-chemical measures for plant protection at the political, administrative and the extension level • guidelines for plant protection given to farmers by extensionists • credit facilities that require the use of certain types of pesticides • relative importance of pesticide versus non-chemical pest management in the school and university curricula • lack of knowledge for the definition of damage and damage threshold levels • incomplete or misleading information by the chemical industry or traders on pesticide use, pesticide productivity and side-effects	• direct subsidies or taxes applied to pesticides • subsidies to complementary inputs (spraying equipment, gasoline for aeroplanes, etc.) • subsidies to local producers of pesticides • free distribution of pesticides by the government or by donor institutions • subsidized credits for pesticide purchase • preferential exchange-rates for pesticides • reduced import levies for pesticides • reduced sales taxes for pesticides • non-internalization of externalities caused by pesticides (government expenditure to reduce damage caused by pesticide use, e.g. for the national health system)

Source: after WAIBEL, 1993

Table A 2-2: Composition of Costa Rica's Pesticide Assessory Commission and of the Commission deciding on tax exemptions

Institution	**Number of representatives**	
	Pesticide Assessory Commission*	Commission deciding on tax exemptions**
Ministry of Agriculture and Livestock (MAG)	▮ + ■	▮ + ■
Ministry of Health (MH)	■	
Ministry of Labour (MTSS)	■	
Ministry of the Environment and Energy (MINAE)	■	
Ministry of Economy, Industry and Trade (MEIC)		■
Ministry of Finance (MF)		■
National Centre for Poisoning Monitoring	■	
Cámara de Insumos Agropecuarios***	■ + ■	■
Co-operatives (FEDECOOP)		■
Association of Agronomists****	■	
TOTAL	**9**	**6**

▮ = president of the commission, ■ = commission member

* Comisión Asesora Nacional de Plaguicidas

** Comisión Técnica de Exoneración de Insumos Agropecuarios

*** National Chamber of Producers, Importers and Distributors of Agricultural Inputs (Cámara de Fabricantes, Importadores y Distribuidores de Insumos Agropecuarios)

**** The Association of Agronomists is the professional association of all agronomists in Costa Rica.

Source: author’s presentation

Table A 2-3: Prohibited pesticides in Costa Rica

Active Ingredient	Biological Activity*	WHO Classification	Year of Prohibition
Mercury compounds	F	Ib	1960
2,4,5-T	H	III	1986
Aldrin	I	Ib	1988
Chlordecone	I, A	Ib	1988
Chlordimeform	I, A	II	1988
DDT	I	II	1988
Dibromochloro-propane (DBCP)	N	Ia	1988
Dieldrin	I	Ib	1988
Dinoseb	H	Ib	1988
Ethylene dibromide	I, N, T		1988
Nitrofen	H	IV	1988
Toxaphene			1988
Captafol	F	Ia	1988
Lead arsenite			1990
Endrin	I, R	Ib	1990
Pentaclorphenol (PCP)	I, F, H	Ib	1990
Cyhexatin	A	III	1990
Chlordane	I	II	1991
Heptachlor	I	II	1991

* A = acaricide, F = fungicide, H = herbicide, I = insecticide, N = nematicide, P = plant growth regulator, T = soil treatment

Source: Edgar Vega, MAG, Dirección General de Protección Agropecuaria, San José, Costa Rica

Table A 2-4: Restricted* pesticides in Costa Rica

Active Ingredient	Biological Activity**	WHO Classification	Year of Prohibition
M.A.F.A.***	F	n.a.	1982
Methyl bromide	T	n.a.	1987
Carbofuran 48%	I, A, N	Ib	1987
Ethyl + methyl parathion	I, A	Ia	1987
Parathion methyl 48%	I, A	Ia	1987
Phorate 48 and 80%	I, A, N	Ia	1987
Aluminium phosphide	I, T	n.c.	1987
Monocrotofos 60%	I, A	Ib	1987
Lindane	I	II	1988
Daminozide	P	IV	1992
Captan			1995

* Restriction means use and sales restriction. Restricted pesticides can only be purchased with a prescription written by an agronomist.

** A = acaricide, F = fungicide, H = herbicide, I = insecticide, N = nematicide, P = plant growth regulator, T = soil treatment

*** MAFA = *metano arsenato ferrico amonico* = ferric ammonium salt of methane arsenic acid. MAFA used to be imported from Japan mainly for use in coffee production. It has not been imported for many years now (Dr. Bernal Valverde, CATIE, personal communication).

Source: Edgar Vega, MAG, Dirección General de Protección Agropecuaria and Dr. Jaime García, Universitdad Nacional Estatal a Distancia, San José, Costa Rica

Table A 2-5: Status of PIC and PAN list pesticides in Costa Rica*

Active Ingredient	PIC-List*	PAN* "Dirty Dozen"	Status in Costa Rica
2,4,5 T		√	P
Aldrin	√	√	P
Aldicarb (Temik)		√	r
Camphechlor (Toxaphene)		√	P
Chlordane	√	√	P
Chlordimeform	√	√	P
Cyhexatin	√		P
DBCP		√	P
DDT	√	√	P
Dieldrin	√	√	P
Dinoseb	√		P
EDB (Ethylene Dibromide)	√	√	P
Endrin		√	P
Fluoroacetamide	√		A
HCH**	√	√	N
Heptachlor	√	√	P
Lindane		√	R
Mercury Compounds***	√		P
Paraquat		√	r
Parathion		√	A
Parathion- Methyl		√	R
Pentachlorophenol (PCP)		√	P

√ = included, P = prohibited, R = restricted sales and use (only available on prescription), r = restricted use , A = allowed, N = not registered

* PIC = FAO Prior Informed Consent, PAN = Pesticide Action Network

** HCH = Hexachlorocyclohexane

*** mercuric oxide, mercurous chloride, calomel, other inorganic mercury compounds, alkyl mercury compounds, alkoxyalkyl and aryl mercury compounds

Source: author’s presentation

Appendix 3: Studies on the Environmental and Social Costs of Pesticide Use

Table A 3-1: Total estimated environmental and social costs from pesticides in the United States of America (in million US$ per year)

Impact	Cost
Public health impacts	787
Domestic animal deaths and contamination	30
Loss of natural enemies	520
Cost of pesticide resistance	1400
Honeybee and pollination loss	320
Crop losses	942
Fishery losses	24
Bird losses	2100
Groundwater contamination	1800
Government regulations to prevent damage	200
Total	8123

Source: PIMENTEL et al., 1992 (In: BioScience:750-760)

Table A 3-2: Private and social cost of pesticide use in Germany in comparison to the returns from pesticide use (in million DM per year)

	Scenario 1	Scenario 2
Private cost		
pesticide cost	1100	1100
storage and application cost	589	589
SUBTOTAL	1689	1689
External costs		
contamination of drinking water resources	128	186
damage to honey bees	2	4
loss of biodiversity caused by herbicide use	10	10
monitoring of food residues	23	23
damage to human health	23	23
costs of government control activities	66	66
SUBTOTAL	252	312
TOTAL COST	**1941**	**2001**
Net private benefit	1150	1150
GROSS BENEFIT	**2839**	**2839**
SOCIAL BENEFIT/COST RATIO	**1.46**	**1.42**

Source: WAIBEL and FLEISCHER (1998)

Table A 3-3: Estimated external costs of chemical pesticide use in Thailand (in million Baht per year)

Type of cost	Derived from	Estimated cost (lower boundary)	Estimated cost (upper boundary)
Health	official statistics	1.00	
	estimates based on in-depth case studies		13.00
Residues in food	fruit and vegetable residue analysis		5017.00
Resistance and pest resurgence	costs related to a brown planthopper outbreak	57.40	57.40
Research budget for chemical pest control	government budget	25.29	25.29
Pesticide quality and residue monitoring	government budget	48.47	48.47
Pesticide regulation and market monitoring	government budget	46.00	46.00
Extension for pesticide use	government budget	286.64	284.64
TOTAL		**464.80**	**5491.80**

Source: JUNGBLUTH (1996)

Table A 3-4: Economic instruments in pesticide policies

Fees (e.g. for registration) can provide financial resources for the registration and regulatory authorities. Fees indirectly raise the price of pesticides, but only to a small extent.

Taxes (product charges) are suitably applicable to pesticides. When input use and emission are directly linked, product charges are effective in decreasing environmental contamination.

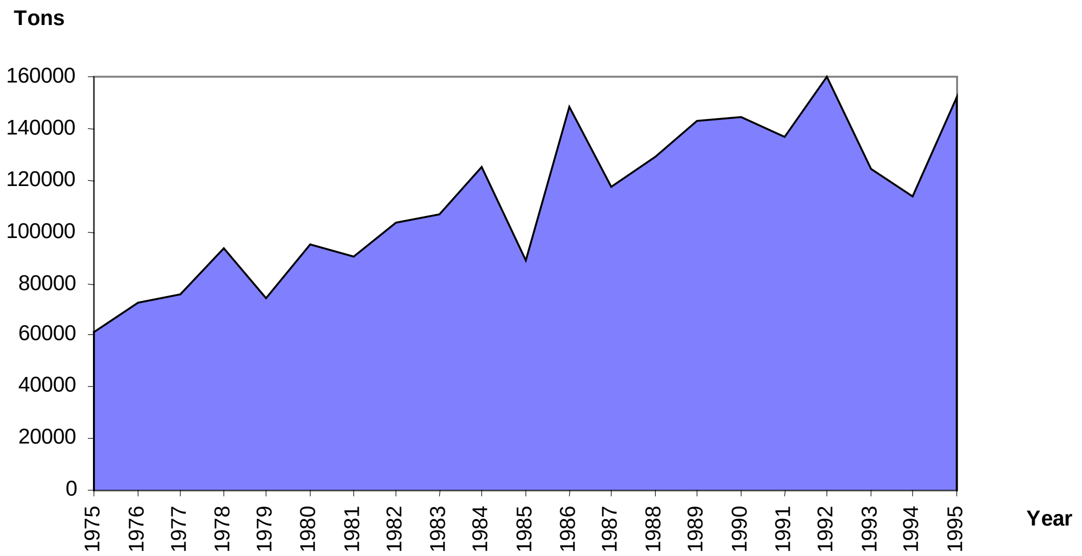
Subsidies (incentive payments) could be given to non-chemical crop protection measures. They accelerate the adoption of new technologies.

Tradable permits could be issued when maximum ceilings to total pollution are required. They offer advantages in situations where the marginal costs of adaptation of pesticide users differ substantially. Least-cost solutions can be achieved when farmers with low abatement costs sell their permits to those with few possibilities for substitution.

Deposit-refund systems may be considered for the problem of disposal of pesticide packaging material. Containers would be returned to the retailer level for destruction after use.

Appendix 4: The Coffee Sector in Costa Rica

Figure A 4-1: Costa Rican coffee exports from 1975/1976 to 1995/1996



Source: ICAFE, Informe Sobre la Actividad Cafetalera de Costa Rica, various issues.

Table A 4-1: Computation of the producer price for coffee in Costa Rica*

1. General information

Exchange rate CRC/US$ = 202.61

	US$/46kg	CRC/46kg
FOB price (applicable to 90% of total coffee production)	118.81	24072.16
National market price (applicable to 10% of total coffee production)	77.59	15720.50
Processing cost	9.88	2001.00

2. Computation of the loco coffee mill export price per 46 kg	**US$/46kg**	**CRC/46kg**
PRICE 1 (FOB price)	118.81	24072.16
- transport cost (fixed at 1.65 US$/46kg, incl. insurance)	-1.65	-334.31
- 1.5% contribution to ICAFE (research and promotion)	-1.78	-361.08
- 1.0% export tax (if PRICE 1 > 92 US$))	-0.01	-2.03
- 2.0% profit of the exporter	-2.38	-481.44
= PRICE 2 (export price loco coffee mill)	112.99	22893.30

3. Computation of the weighted average price loco coffee mill per 46 kg	**US$/46kg**	**CRC/46kg**
0.9 x PRICE 2 (export price loco coffee mill; for 90% of total sales)	112.99	22893.30
+ 0.1 x PRICE 3 (local price loco coffee mill; for 10% of total sales)	77.59	15720.50
= PRICE 4 (weighted average price loco coffee mill)	109.45	22176.02

4. Computation of the gross producer price per 46 kg	**US$/46kg**	**CRC/46kg**
PRICE 4 (weighted average price loco coffee mill)	109.45	
- processing cost**	-9.88	-2001.00
- profit of the coffee mill (9% of [PRICE 4 - processing cost])	-10.74	-2175.93
- Contribution to FONECAFE*** (if applicable)	-0.04	-8.10
= PRICE 5 (gross producer price)	88.80	17990.99

5. Computation of the farm profit subject to taxation and of the net producer price per 46 kg	**US$/46kg**	**CRC/46kg**
PRICE 5 (gross producer price)	88.80	17990.99
- agricultural production cost (per 46 kg)**	-81.93	-16599.84
= FARM PROFIT per 46 kg subject to taxation	6.87	1391.15
PRICE 5 (gross producer price)	88.80	17990.99
- income tax (20% if farm profit > 0)	-1.37	-278.23
= PRICE 6 (net producer price)	87.42	17712.76

* average prices and average exchange rate for the 1995/96 coffee year

** as assessed by ICAFE

*** contributions to FONECAFE depend on the price (US$/46kg) loco coffee mill *(precio rieles)*
if PRICE 4 <= 92 then contribution = 0%
if PRICE 4 > 92 and PRICE 4 <=100 then contribution = 3%
if PRICE 4 >100 and PRICE 4 <=125 then contribution = 4%)
if PRICE 4 >125 and PRICE 4 <=150 then contribution = 6%)
if PRICE 4 >150 then contribution = 10%)

* average prices and average exchange rate for the 1995/96 coffee year

Table A 4-2: Application frequency of different types of agrochemicals in Costa Rica's coffee farming from 1989 to 1995

TYPE OF AGRO-CHEMICAL	PERCENTAGE OF COFFEE FARMERS BY NUMBER OF APPLICATION			
Fungicides				
Year	No application	1 application	2 applications	3 or more applications
1989	13.8	19.2	33.9	33.1
1990	25.3	17.6	29.4	27.7
1991	21.6	16.4	35.1	26.9
1992	17.0	17.0	31.0	35.0
1993	17.6	22.2	36.1	24.1
1994	27.5	41.8	22.5	8.2
1995	28.2	9.7	33.0	29.1
Herbicides				
Year	No application	1 application	2 applications	3 or more applications
1989	5.4	32.3	40.8	21.5
1990	20.6	27.1	38.8	13.5
1991	20.9	29.1	32.1	17.9
1992	15.0	31.0	38.0	16.0
1993	13.9	22.2	45.4	18.5
1994	19.4	41.8	26.5	12.3
1995	15.5	34.0	28.2	22.3
Fertilizers				
Year	No application	1 application	2 applications	3 or more applications
1989	5.4	12.3	53.1	29.2
1990	6.5	23.5	50.6	19.4
1991	14.2	18.6	48.5	18.7
1992	9.0	20.0	54.0	17.0
1993	11.1	13.9	54.6	20.4
1994	7.1	14.3	43.9	34.7
1995	6.8	8.7	50.5	33.4

Source: ICAFE (1995d); ICAFE (1997c)

Appendix 5: Questionnaire on Coffee Production in Costa Rica

CUESTIONARIO PRODUCCIÓN CAFETALERA

Nombre del encuestador: ____

Fecha: ______________ *Distrito:* ______________________________

A. Información general

1. a) Nombre del caficultor: __________________________________ tel: ______________

   b) Nombre del encargado: __________________________________ tel: ______________

2. a) Dirección de la casa: ____

   ____

   b) Dirección de la finca: ____

   ____

3. Altura de la finca: ________________ msnm

4. Formación de la persona que maneja la finca?

   ____

   Quién la maneja? propietario ☐ administrador ☐ mandador ☐

5. A qué beneficios entrega su café? ____

6. Es socio de una cooperativa? si ☐ no ☐ De cuál? ____________________

7. Área total de la finca y siembra de diferentes cultivos (incl. pasto):

Área total de la finca	**Área sembrada con café**			
mz\ha	mz\ha	mz\ha	mz\ha	mz\ha

MEDIDA CON QUE CALCULA: *manzana (mz)* ☐ *o* *hectarea (ha)* ☐

8. Pendientes en los cafetales? fuertes ____ %, intermedios ____%, planos ______%

9. Hace siembra intercalada en los cafetales? si ☐ no ☐

   Con qué cultivos? ____

10. Cambios del área sembrada con café en los últimos 7 años?

En los últimos 7 años	**s/n**	**Cuánto?**	**Para sembrar qué?**
- vendió cafetales?		mz\ha	X
- compró cafetales?		mz\ha	X
- arranco cafetales?		mz\ha	

11. Tiene producción pecuaria? si ☐ no ☐ Cuál? ____________________________

12. La finca es de su propiedad? si ☐ no ☐ ________________________________

13. Número de familiares que viven de la finca: ___________________________

14. Trabaja usted o familiares suyos fuera de su finca? si ☐ no ☐

    Actividades? ____

15. Qué porcentaje de ingresos percibe fuera de agricultura y ganadería?
    _____ %

16. Qué porcentaje contribuye la caficultura a los ingresos de agricultura y ganadería?____ %

A llenar después de la entrevista: Las cantidades de insumos mencionadas en este cuestionario se refieren a

mz\ha ☐ el área de café en producción en la finca ☐ otra medida ☐. Cúal?________________

Información cuantitativa: confiable ☐ regular ☐ no confiable ☐.

B. Información global sobre la caficultura en el 1995/96

17. Área de café en producción en 1995/1996: __________ mz\ha

    Resembró? Cuántas mz\ha o cuántas plantas? _____ mz\ha o _____ plantas

18. Producción de café cosecha 1995/1996: __________ fanegas

19. Qué variedades de café tenia usted sembradas en el 1995/96?

Cultivar	Edad (en años)	Área (mz\ha)	Produce (si o no)	Densidad de siembra: distancia A x B en m\varas	Densidad de siembra: cafetos por ha\mz
1.					
2.					
3.					
4.					

20. Tenia usted café bajo sombra en el 1995/96? si ☐ no ☐

Variedades de árboles	Edad (en años)	Área (mz\ha)	Densidad de siembra: distancia A x B en m\varas	Densidad de siembra: árboles por ha\mz
1.				
2.				
3.				

21. Costos de mano de obra en el 1995/1996:

	Hombres		**Mujeres y niños**	
Tipo de trabajo	*Col./jornal*	*horas/día*	*Col./jornal*	*horas/día*
Labores livianas				
Labores pesadas				
Cosecha	Colones/cajuela			

22. Pagó seguro social en el 1995/1996? (garantías sociales como feriados, prestaciones, cargas sociales, riesgos profesionales)? si ☐ no ☐

    Para cuántas personas? ________________

    Qué porcentaje? ________________ %

C. Manejo de malezas y plagas en el 1995/1996 y aspectos generales de fitoprotección

23. Cómo controló malezas, enfermedades, nemátodos y plagas **en el 1995/1996**? Por favor especifique primero el control químico incluyendo aplicación de coadyuvantes y de abono foliar y después el control biológico y mecánico.

A llenar después: *El agricultor calcula en*

litros\kg ☐ *onzas* ☐ *otra medida* ☐ *por mz\ha* ☐ *por estañón* ☐ *por bomba* ☐

Manejo de malezas		Plaguicida o medida cultural	Para combatir qué?	Se aplicó a cuántas mz\ha?	Cantidad de plaguicida por estañón \ bomba	No. de estañones \ bombas por mz\ha	Jornales por mz\ha
No	Fecha (mes)				o kg\l por mz\ha		
Aplicaciones de herbicidas, chapias, lumbreas y paleas							
1ª							

Manejo de hongos y enfermedades		Plaguicida o medida cultural	Para combatir qué?	Se aplicó a cuántas mz\ha?	Cantidad de plaguicida por estañón \ bomba	No. de estañones \ bombas por mz\ha	Jornales por mz\ha
No	Fecha (mes)				o kg\l por mz\ha		
Atomizaciones							
1 [a]							

Manejo de plagas		Plaguicida o medida cultural	Para combatir qué?	Se aplicó a cuántas mz\ha?	Cantidad de plaguicida por estañón \ bomba	No. de estañones \ bombas por mz\ha	Jornales por mz\ha
No	Fecha (mes)				o kg\l por mz\ha		
Nematicidas e insecticidas							
1 a							
Otras medidas químicas o no químicas de fitoprotección que todavía no ha mencionado?							
1 a							

D. Fertilización y poda en el 1995/1996

24. Fertilización del cafetal **en el 1995/1996**

Aplicaciones	Fecha de la aplicación (mes)	Fórmula / Tipo	Cantidad (sacos de 46\50 kg) por mz\ha	Área fertilizada (mz\ha)	No. de jornales por mz\ha
Primera					
Segunda					
Tercera					
Cuarta					
Cal					
Abono orgánico					

25. Arreglo de sombra, poda, deshija y conservación de suelos **en el 1995/1996**

Medida (tipo de poda, tipo de conservación)	Fecha (mes)	No. de mz\ha?	No. de jornales por mz\ha
1. Tipo de arreglo de sombra			
2. Tipo de poda del cafeto			
3. Deshija del cafeto			
primera deshija			
segunda deshija			

4. Conservacion de suelos y otras medidas	**si/no**	**Cuánto?** *mz\ha*	**Mantenimiento?** *jornales por año por mz\ha*
- siembra del café en curvas a nivel			X

E. Diferencias de cosecha y de manejo en los últimos 3 años

26. Informaciones generales

	1995/1996	1994/1995	1993/1994
Precio del café	*regular*	*muy bueno*	*muy malo*
Producción total en fanegas?			
Área de café en producción (mz\ha)?			
Resiembra (mz\ha o no. de plantas)			
Cuáles son las razónes por las diferencias? (Clima? Caída? Manejo? Otras?)			

27. Manejo de malezas, hongos y plagas **<u>en el 1994/1995 y en el 1993/1994</u>**

precios muy buenos *precios muy malos*

1994/1995				1993/1994			
No	Plaguicida o medida	Se aplicó a cuántas mz\ha?	Cantidad de plaguicida por estañón \ bomba o kg\l por mz\ha o jornales por mz\ha	No	Herbicida o medida	Se aplicó a cuántas mz\ha?	Cantidad de plaguicida por estañón \ bomba o kg\l por mz\ha o jornales por mz\ha
Aplicaciones de herbicidas, chapias, lumbreas, raspas y paleas							
1ª				1ª			
Atomizaciones							
1ª				1ª			

1994/1995				1993/1994			
No	Plaguicida o medida	Se aplicó a cuántas mz\ha?	Cantidad de plaguicida por estañón \ bomba o kg\l por mz\ha	No	Plaguicida o medida	Se aplicó a cuántas mz\ha?	Cantidad de plaguicida por estañón \ bomba o kg\l por mz\ha
Atomizaciones (continuación página 8)							
Nematicidas insecticidas u otras medidas							
1ª				1ª			

28. Fertilización **en el 1994/1995 y en el 1993/1994**

precios muy buenos *precios muy malos*

	1994/1995			1993/1994		
No.	Fórmula / Tipo	Se aplicó a cuántas mz\ha?	Cantidad (sacos de 46 \50 kg por mz\ha)	Fórmula / Tipo	Se aplicó a cuántas mz\ha?	Cantidad (sacos de 46 \50 kg por mz\ha)
1ª						
2ª						
3ª						
4ª						
Cal						
A. orgán.						

29. Arreglo de sombra, poda, deshija y conservación de suelos **en el 94/95 y en el 93/94:**

precios muy buenos *precios muy malos*

1994/1995			1993/1994		
Tipo de arreglo	Área (mz\ha)?	No. de jornales por mz\ha	Tipo de arreglo	Área (mz\ha)?	No. de jornales por mz\ha
1. Arreglo de sombra					
2. Poda del cafeto					
3. Deshija del cafeto					
4. Conservación de suelos u otros					

30. Resumen de los cambios de manejo entre los últimos 3 años hecho por el encuestador. No es necesario poner todas las cifras otro vez. Solo marque las diferencias. Por favor considere comentarios del agricultor.

	1995/1996	*1994/1995*	*1993/1994*
Producción			
Manejo de malezas			
Atomizaciones			
Aplicación de nematicidas e insecticidas			
Fertilización			
Arreglo de sombra, poda, deshija			

F. Aspectos generales de fitoprotección en los últimos años

31.1 Cómo decide si hay que aplicar y en qué fecha hay que aplicar?

Tipo de Plaguicida	Aplicación según calendario (c)	Aplicación según incidencia (i)
Herbicidas		
Fungicidas (atomizaciones)		
Nematicidas e insecticidas		

31.2 Quién le proporciona información sobre medidas de fitoprotección?

(1) vendedores / casas comerciales ☐, (2) MAG / ICAFE / IDA ☐, (3) otros ☐

31.3 La información que recibe es suficiente? si ☐ no ☐

Qué tipo de información le hace falta? ______________________________

32. Ha tenido problemas como dolor de cabeza, mareos, intoxicaciones, etc. cuando ha aplicado plaguicidas? si ☐ no ☐

Con qué plaguicida?				
Qué síntomas?				

33. Ha observado resistencia contra los plaguicidas o sea ha observado que un plaguicida no funcionó después de una aplicación aunque el clima era favorable? si ☐ no ☐

Qué plaguicidas? ____________________

34. Recibe créditos para la producción? Ni siquiera de la Cooperativa? si ☐ no ☐

Qué institución le da crédito? ____________________

Para obtener el crédito hay requisitos que le obligan a aplicar plaguicidas? si ☐no ☐

Cuáles? ____________________

35. Alternativas al uso de plaguicidas

35.1 Para combatir malezas existe la posibilidad de utilizar coberturas naturales. Coberturas naturales se pueden sembrar (maní) o se pueden obtener por manejo selectivo de malezas. Manejo selectivo quiere decir que sólo se combaten malezas que compiten con el café como los zacates mientras que las malezas que no compiten (malezas nobles) se toleran. Con esta técnica se pueden bajar las aplicaciones de plaguicidas y se evita la erosión del suelo.

Ha pensado en utilizar coberturas? si ☐ no ☐

Le interesa obtener más información sobre coberturas? si ☐ no ☐

Qué problemas relacionados con coberturas naturales ve usted?

____

35.2 Para substituir herbicidas por mano de obra se necesitarían las medidas siguientes:

	Paleas	Raspas	Lumbreas	Chapias
Cuántas veces por año?				
Cuántos jornales por medida por mz\ha?				

35.3 Existen medidas para sustituir

a) fungicidas? si ☐ no ☐ Cuáles? ____________________

b) nematicidas/insecticidas? si ☐ no ☐ Cuáles? ____________________

35.4 A cuánto estima la pérdida de cosecha en promedio de los últimos 3 a 5 años si no hubiera aplicado

a) fungicidas? ____%

b) nematicidas/insecticidas? ____%

Appendix 6: Results of the Field Survey on Coffee Production in Costa Rica

Table A 6-1: Agrochemicals used in coffee production

Product name	Active ingredient(s)	Type*	Aggregate
2,4 D	2,4 D	H	WHO II herbicides
Gramoxone	Paraquat dichloride	H	WHO II herbicides
Radex	Paraquat dichloride	H	WHO II herbicides
Gramecoop	Paraquat	H	WHO II herbicides
Gramurón	Paraquat + Diuron	H	WHO II herbicides
Gesaprim	Atrazine	H	other herbicides
Diurón	Diuron	H	other herbicides
Evigras	Glyphosate	H	other herbicides
Round-up	Glyphosate	H	other herbicides
Goal	Oxyfluorfen	H	other herbicides
Sagecoop	Simazine	H	other herbicides
Terbutilazina	Terbuthylazine	H	other herbicides
Gardoprim	Terbuthylazine	H	other herbicides
Benlate	Benomyl	F	F + FN + AD
Cupravit verde	Copper oxichloride	F	F + FN + AD
Atemi	Cyproconazole	F	F + FN + AD
Coopecide 101	Copper hydroxide	F	F + FN + AD
Kocide 101	Copper hydroxide	F	F + FN + AD
Cobre Sandoz	Cuprous oxide + Mg + Zn	F	F + FN + AD
Bayleton 25 CE	Triadimefon	F	F + FN + AD
Vidate	Oxamyl	I,A,N	nematicides
Temik	Aldicarb	I,A,N	nematicides
Thimet	Phorate	I,A,N	nematicides
Nemacur	Fenamiphos	N,I,A	nematicides
Counter	Terbufos	I,N	nematicides
Terbufos	Terbufos	I,N	nematicides

.../ contd.

* A = acaricide, AD= adjuvant, F = fungicide, FN = foliar nutrient or micro-nutrient, H = herbicide, I = insecticide, MF = mineral fertilizer, N = nematicide

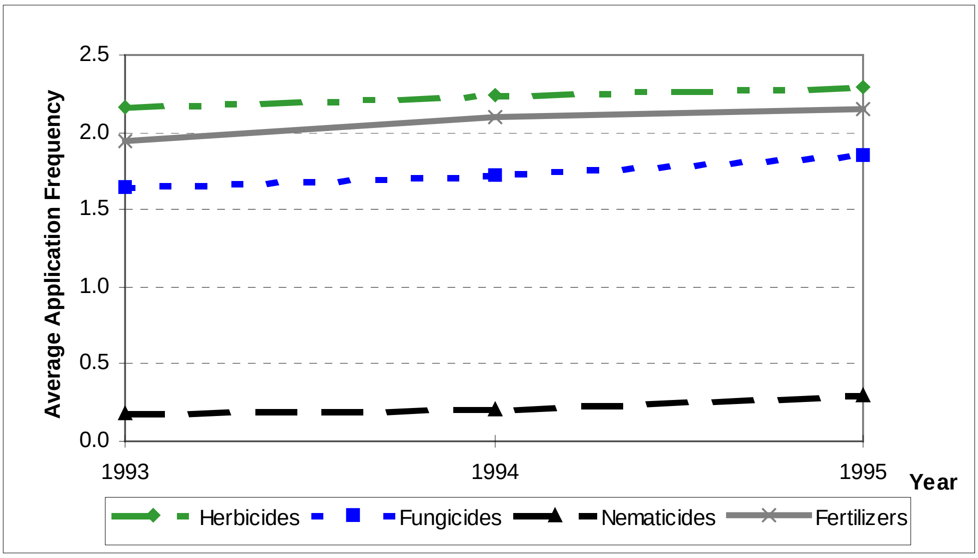
Table A 6-1 (contd.): Agrochemicals used in coffee production

Product name	Active ingredient(s)	Type*	Aggregate
20-20-20	nitrogen, phosphate, potassium	FN	F + FN + AD
Bayfolan		FN	F + FN + AD
Boro/Poliboro	boron	FN	F + FN + AD
Metalozato Multiminerales	various minerals	FN	F + FN + AD
Multimicro Multiminerales	various minerals	FN	F + FN + AD
Nitrofoska		FN	F + FN + AD
NuZ	nitrogen, zinc	FN	F + FN + AD
Urea	nitrogen	FN	F + FN + AD
Zinquel	zinc	FN	F + FN + AD
NP 7		AD	F + FN + AD
WK		AD	F + FN + AD
FC 15-15-15	nitrogen, phosphate, potassium	MF	mineral fertilizers
FC 18-5-15	nitrogen, phosphate, potassium	MF	mineral fertilizers
FC 20-7-12	nitrogen, phosphate, potassium	MF	mineral fertilizers
Magnesamón	nitrogen, magnesium	MF	mineral fertilizers
Nutrán	nitrogen	MF	mineral fertilizers
Urea	nitrogen	MF	mineral fertilizers

* A = acaricide, AD= adjuvant, F = fungicide, FN = foliar nutrient or micro-nutrient, H = herbicide, I = insecticide, MF = mineral fertilizer, N = nematicide

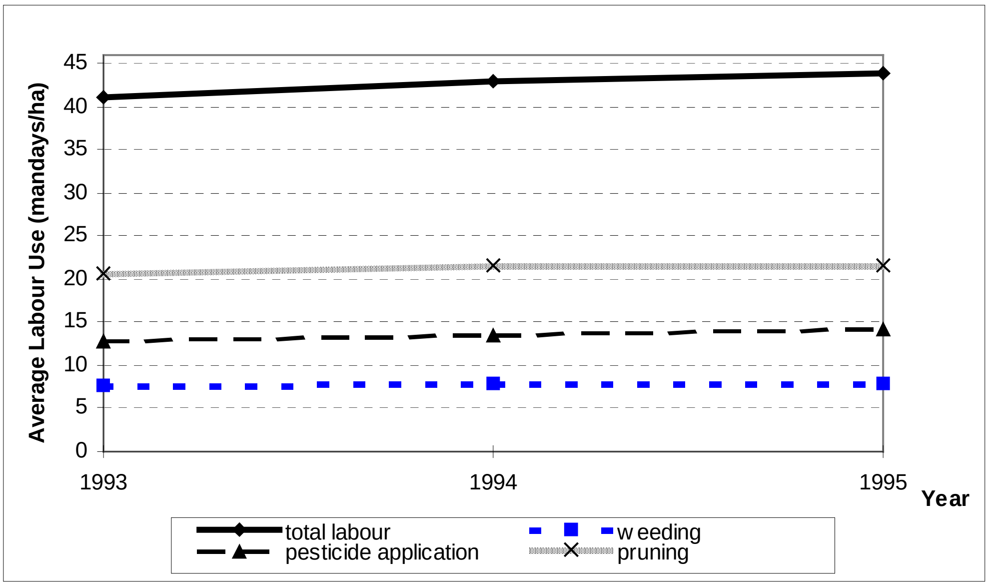
Source: author's field survey and product labels

Figure A 6-1: Application frequency of agrochemical inputs between 1993 and 1995



Source: author's field survey

Figure A 6-2: Average labour use in Costa Rica's coffee production (mandays/ha)



Source: author's field survey

Table A 6-2: Variable costs of coffee production according to the area grown with coffee (in 1995 CRC)

	coffee area ≤ 5 ha		coffee area > 5 ha	
	CRC	in % of variable cost	CRC	in % of variable cost
pesticides	**14704.94**	**5.57%**	**24882.87**	**8.58%**
WHO II herbicides	2247.37	0.85%	3287.57	1.13%
other herbicides	4130.56	1.57%	9704.15	3.30%
fungicides	6370.49	2.41%	8879.91	3.06%
nematicides	1956.52	0.74%	3161.34	1.09%
pesticide application	**14518.22**	**5.50%**	**19286.19**	**6.65%**
herbicide application	7336.25	2.78%	10319.07	3.56%
fungicide and foliar nutrient application	6754.48	2.56%	8540.41	2.95%
nematicide application	427.49	0.16%	426.71	0.15%
fertilization	**49524.68**	**18.77%**	**57186.11**	**19.73%**
foliar nutrients	2766.73	1.05%	5127.22	1.77%
fertilizer	41361.47	15.67%	46102.03	15.90%
fertilizer application	5396.48	2.05%	5956.86	2.05%
manual labour	**37141.54**	**14.08%**	**31074.90**	**10.72%**
manual weeding	10456.07	3.96%	7436.86	2.57%
pruning etc.	26685.47	10.11%	23638.04	8.15%
interest	**18475.50**	**7.00%**	**21198.08**	**7.31%**
harvesting	**129515.69**	**49.08%**	**136252.90**	**47.00%**
variable costs	**263880.57**	**100.00%**	**289881.05**	**100.00%**

Table A 6-3: Revenue, variable costs and gross margin

	coffee area ≤ 5 ha		coffee area > 5 ha	
	CRC	in % of revenue	CRC	in % of revenue
revenue	539650.59	100.00%	613207.66	100.00%
variable costs	263880.57	48.90%	289881.05	47.27%
gross margin	275770.02	51.10%	323326.61	52.73%

Appendix 7: Parameter Estimates obtained for the System of Input Demand Functions

Table A 7-1: Parameter estimates obtained in the seemingly unrelated regression

Parameter	Estimate	Approx. Std Err	'T' Ratio	Approx. Prob>|T|
A1	-0.2592	0.1918	-1.35	0.1769
A2	0.0818	0.2364	0.35	0.7294
A3	-0.0325	0.2438	-0.13	0.8939
A4	-0.3017	0.4429	-0.68	0.4960
A5	0.0227	0.0976	0.23	0.8160
A6	0.8223	0.1018	8.08	0.0001
B11	-0.4923	0.4442	-1.11	0.2680
B12	0.2531	0.1921	1.32	0.1878
B13	-0.5654	0.3273	-1.73	0.0844
B14	0.7964	0.4547	1.75	0.0802
B15	0.0067	0.1000	0.07	0.9464
B16	0.0246	0.0750	0.33	0.7427
B22	-0.2345	0.1597	-1.47	0.1422
B23	0.2362	0.1744	1.35	0.1758
B24	-0.2857	0.2504	-1.14	0.2542
B25	-0.0436	0.0673	-0.65	0.5175
B26	0.0741	0.0603	1.23	0.2195
B33	-0.8143	0.4792	-1.7	0.0896
B34	1.2929	0.5182	2.49	0.0128
B35	-0.2384	0.1070	-2.23	0.0261
B36	0.0217	0.0877	0.25	0.8048
B44	-2.0945	0.7194	-2.91	0.0037
B45	0.2693	0.1410	1.91	0.0564
B46	-0.0627	0.1187	-0.53	0.5973
B55	-0.1290	0.0582	-2.22	0.0267
B56	0.0917	0.0378	2.43	0.0155
B66	-0.1619	0.0516	-3.14	0.0017

Explanation: A = intercepts, B = own-price and cross-price effects, D = dummy variables

1 = WHO II herbicides, 2 = other herbicides, 3 = fungicides + foliar nutrients, 4 = nematicides, 5 = mineral fertilizers, 6 = labour

.../ contd.

Table A 7-1 (contd.): Parameter estimates obtained in the seemingly unrelated regression

Parameter	Estimate	Approx. Std Err	'T' Ratio	Approx. Prob>|T|
D11	1.1494	0.0875	13.14	0.0001
D12	-0.0811	0.0818	-0.99	0.3215
D13	-0.0073	0.0783	-0.09	0.9262
D14	0.0247	0.0671	0.37	0.7128
D15	0.3047	0.1561	1.95	0.0512
D21	-0.3364	0.1080	-3.11	0.0019
D22	1.1106	0.1010	11.00	0.0001
D23	0.0166	0.0942	0.18	0.8604
D24	0.0728	0.0826	0.88	0.3783
D25	0.1790	0.1931	0.93	0.3540
D31	0.2108	0.1112	1.9	0.0583
D32	-0.0638	0.1040	-0.61	0.5397
D33	0.7550	0.0985	7.66	0.0001
D34	0.5688	0.0852	6.68	0.0001
D35	0.2052	0.1986	1.03	0.3016
D41	0.0610	0.2021	0.3	0.7628
D42	-0.1384	0.1889	-0.73	0.4637
D43	0.2807	0.1756	1.6	0.1103
D44	2.6161	0.1543	16.96	0.0001
D45	0.3767	0.3610	1.04	0.2970
D51	-0.0474	0.0447	-1.06	0.2890
D52	0.0443	0.0419	1.06	0.2895
D53	0.0675	0.0405	1.66	0.0964
D54	0.1434	0.0344	4.17	0.0001
D55	0.9797	0.0798	12.28	0.0001
D61	0.0531	0.0466	1.14	0.2547
D62	-0.1700	0.0436	-3.9	0.0001
D63	-0.0756	0.0410	-1.84	0.0656
D64	0.1105	0.0357	3.09	0.0020
D65	0.3259	0.0832	3.92	0.0001

Explanation: A = intercepts, B = own-price and cross-price effects, D = dummy variables

1 = WHO II herbicides, 2 = other herbicides, 3 = fungicides + foliar nutrients, 4 = nematicides, 5 = mineral fertilizers, 6 = labour

Appendix 8: The Short Term Impact of a Pesticide Tax on a Pesticide Intensive Crop in Costa Rica

As an illustration of the impact of a pesticide tax on the consumer price, or, in case the price increase cannot be passed on to the consumer, on the profitability of a pesticide intensive crop, this section will analyse the cost structure of one of the most pesticide intensive crops produced in Costa Rica: Chrysanthemums. In the following discussion it has to be kept in mind that pesticide-intensive crops in general cause more external costs than pesticide extensive crops. Therefore, from a social point of view, it is justified that these crops should be more affected by taxation than crops that cause less negative side-effects.

Table A 8-1 displays a simple example that elucidates the impact of a 10% pesticide tax on the consumer price for Chrysanthemums. It is based on the cost structure for the total production costs of Chrysanthemums provided by the Central Bank of Costa Rica (BCCR)[1]. The cost structure does not take into account any non-chemical pest control options, nor does it consider the possibility of reducing pesticide use. As pointed out earlier, these very restrictive assumptions are not realistic, because in many crops pesticides are overused, i.e. a reduction in use would increase the profitability of the crop, and second, in many cases pesticides can be substituted. Therefore, cost structures overestimates the price and income effects related to a pesticide tax.

Nonetheless, the cost structure is the only information available and is useful to illustrate a worst case scenario for a highly pesticide intensive crop. In Chrysanthemum production pesticides account for 20% of the total production cost, which is significant. A 10% ad valorem tax would increase the total cost of production by 2%. If this price increase was fully passed on to the consumer, the average farm gate price for Chrysanthemums would increase by 1.7% and the consumer price in Costa Rica by approximately 1.3%.

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1 It is difficult to obtain data on the actual production cost of highly pesticide intensive crops. However, the Central Bank of Costa Rica (BCCR) provided average profits and production costs for various crops, which are used for sectoral analyses. Based on this information, the most pesticide-intensive crop available was selected to assess the impact of a pesticide tax on its profitability.

Table A 8-1: Chrysanthemum production costs and consumer price in Costa Rica: the short-term effect of a 10% tax on pesticides

Production costs	**without tax**	**10% tax**	
	US$	US$	increase in %
pesticides	20.00	22.00	10.0%
other production costs	80.00	80.00	0.0%
total cost of production	100.00	102.00	2.0%
farm-gate price	120.00	122.00	1.7%
consumer price	150.00	152.00	1.3%

Source: BCCR, Estructura de Costos de Producción, 1995

In case this increase in production cost could not be passed on to the consumer and no options for pesticide substitution were available (as assumed in this example), a price increase for pesticides would fully affect the income from Chrysanthemum production. In the aforementioned example the profit is equal to the expenditure for pesticides (without pesticide tax). Hence, a 10% increase of pesticide costs would lead to 10% decrease in profits from Chrysanthemums. This is quite significant, but as stated earlier, an overestimate. And it must be kept in mind that the high profit margins which are at present obtained with a number of pesticide-intensive horticultural crops are partly a result of the toleration of external effects such as the intoxication of workers and the pollution of the environment. Furthermore, it has to be stressed that Chrysanthemum production is an extreme example which is not representative for Costa Rica's agriculture.

Appendix 9: Factors to be Considered in a Pesticide Use Reduction Programme for Costa Rica

A pesticide tax as an isolated measure would most likely have a limited impact on pesticide use in agriculture and find little support in the farming community. Therefore, the identification of factors that stimulate pesticide use in a country is a prerequisite for the design of a pesticide use reduction programme. This section presents the results of an expert survey on the determinants of pesticide use in Costa Rica and then uses this information to propose an option for a pesticide use reduction programme.

Institutional Determinants of Pesticide Use in Costa Rica

The institutional factors that influence pesticide use in Costa Rica were evaluated by 26 pesticide experts from ministries, national and international government organizations, research institutions and from the private sector who expressed their opinions on these issues in a questionnaire. All those institutions which directly participate in the formulation and execution of pesticide policies in Costa Rica were represented and, in addition, scientists and experts from international organizations.

The institutional factors proposed in the questionnaire had been identified in numerous interviews on crop protection policy in Costa Rica. The questionnaire served to evaluate the impact of a number of determinants of pesticide use on a scale from -5 to +5. A negative value implies a discouraging effect, a positive value indicates a stimulating effect on pesticide use. Thus, -5 is equivalent to the strongest reduction, and +5 to an extreme stimulation of pesticide use. Factors that do not have an impact at all were given a zero. Figure A 9-1 summarizes the average values assigned to the different determinants of pesticide use[2]. Institutional factors and information were qualified as the most important determinants of pesticide use. Tax exemptions for pesticides as well as for complementary inputs, and external effects of pesticide use were considered relevant, too, even though

[2] In addition to the evaluation of the given determinants of pesticide use, the experts were asked to add any other factors they considered important. Some of them mentioned the need to combat pests and diseases as a major reason for pesticide use, which is true. However, this study focused on the institutional and economic determinants of pesticide use. Pest occurrence can only indirectly be influenced by institutional and political changes and therefore has been neglected in this research.

Figure A 9-1 does not reflect the importance attributed to external effects.

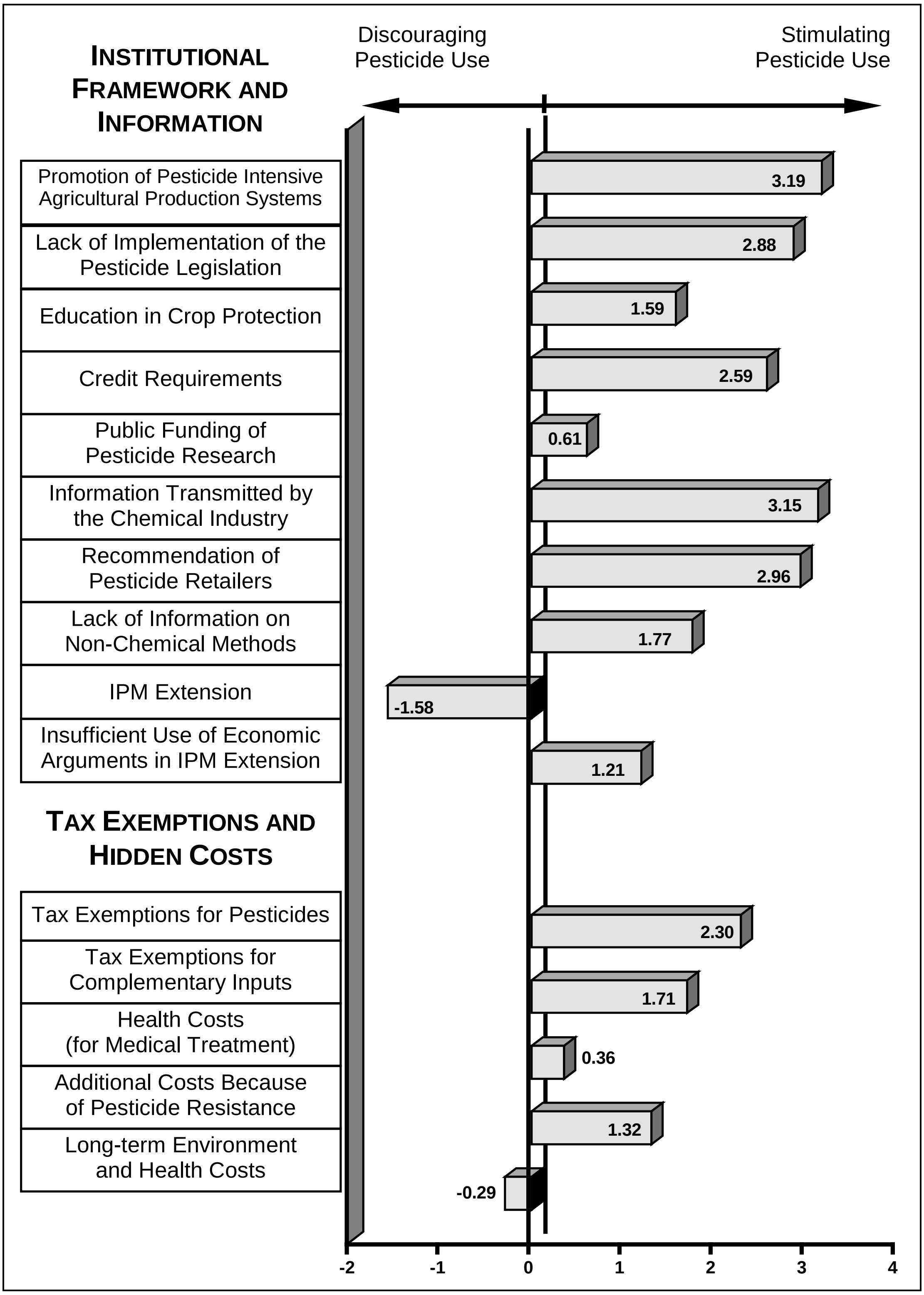
Calculating the mean of the evaluations, the values given to external costs of pesticide use were "flattened", because the range of evaluations for pesticide externalities went from -5 to +5. This was not the case for other factors and is probably due to an ambiguous interpretation of the impact of external effects.

On the one hand, the occurrence of external costs has been seen as a deficiency of the market system which leads to an overuse of pesticides. Following this interpretation, the actual market prices for pesticides are too low, because they do not reflect their external costs. Tolerating external costs of pesticide use by not applying environmental taxes therefore has been interpreted as an indirect subsidy for pesticides. External effects thus have been assigned a positive value, i.e. they are supposed to stimulate pesticide use.

On the other hand, it has been assumed that the mere threat of external effects leads to a reduction of pesticide use. This implies that farmers will try to reduce pesticide use when they are aware of the risks related to it. Under these assumptions the external effects have been assigned a negative, i.e. pesticide reducing, value. Finally, some of the workshop participants evaluated the externalities of pesticide use with a zero, which means they do not influence pesticide use at all.

In conclusion, information, institutional factors and price subsidies were identified as major stimulants of pesticide use in Costa Rica. Among these, "asymmetric information in crop protection" is perhaps the most important complex to be addressed in a pesticide use reduction programme. It was expressed that the information transmitted by pesticide retailers and by the chemical industry strongly stimulates pesticide use, and that it has a much stronger impact than the government activities promoting integrated pest management. Hence, communication of the non-chemical or pesticide saving options in crop protection to the farmer seems to be one of the key issues.

Figure A 9-1: Determinants of pesticide use and their impact according to an expert survey in Costa Rica



Source: AGNE (1996)

Among the institutional factors mentioned, the lack of enforcement of the existing legislation and policies that promote pesticide intensive crops were seen as major stimulants of pesticide use.

Suggestions for Components of a Pesticide Use Reduction Plan

The expert opinion on the determinants of pesticide use in Costa Rica suggests three issues that should be addressed in a pesticide use reduction programme: information, institutions and prices. Price issues have been treated extensively in this thesis. The institutional factors needing to be addressed are the consideration of environmental aspects when promoting highly pesticide intensive crops and a better law enforcement. In some areas, the implementation of the existing legislation could easily be improved (e.g. in residue monitoring), while in other areas the cost of enforcement would be prohibitively high (e.g. for the enforcement of pesticide use restrictions).

Changing the information environment seems to be one key to successful pesticide use reduction. Information refers first of all to the information on crop protection that reaches the farmer. Training programmes should be designed for farmers, which effectively communicate non-chemical crop protection methods. Here, the necessary experience may be drawn from the work done with farmer field schools in Asia (KENMORE, 1996).

Furthermore, more information on non-chemical crop protection should be made available to the institutions that deal with agriculture, i.e. to ministries and extension services, but also to rural schools and agricultural universities. More research on non-chemical methods in crop protection would most probably increase the number of alternatives to pesticide use. In addition, more research on the external effects of pesticide use would allow an assessment of the cost of pesticide use to society and to define appropriate environmental tax rates for the different types of pesticides.

At the 1995 workshop on crop protection policy in Costa Rica, the following measures were proposed to reduce pesticide use:

- support for IPM research,
- education of farmers,
- education of consumers,
- prohibition of advertisements for pesticides, and
- creation of awareness on occupational health issues in rural worker organizations.

Some of these go beyond the priority areas specified above, but are nonetheless worthwhile being considered in the discussion on pesticide use reduction programmes.

Table A 9-1: Institutions involved in the policy evaluation

Type of Institution	Number of Evaluators	
Ministry	■ ■ ■ ■ ■ ■ ■ ■ ■	9
Other Government Institution	■ ■ ■ ■ ■ ■	6
Research Institution	■ ■ ■ ■ ■ ■ ■	7
Private Sector Institution	■ ■ ■ ■	4
TOTAL		26

Table A 9-2: Evaluation of the determinants of pesticide use in Costa Rica: mean, range, and mean absolute deviation of the evaluations

DETERMINANTS OF PESTICIDE USE	Mean	Mean Absolute Deviation	Range
Institutional Framework and Information			
Promotion of Pesticide Intensive Agricultural Production Systems	+3.19	1.21	-2 to +5
Lack of Implementation of the Pesticide Legislation	+2.88	1.09	-1 to +5
Education in Crop Protection	+1.59	2.10	-3 to +5
Credit Requirements	+2.59	1.26	0 to +5
Public Funding of Pesticide Research	+0.61	2.11	-2 to +5
Information Transmitted by the Chemical Industry	+3.15	1.43	-3 to +5
Recommendation of Pesticide Retailers	+2.96	1.21	-4 to +5
Lack of Information on Non-Chemical Methods	+1.77	1.30	-4 to +3
IPM Extension Programs	-1.58	1.22	-3 to +5
Insufficient Use of Economic Arguments in IPM Extension	+1.21	1.46	-4 to +3
Tax Exemptions and Hidden Costs			
Tax Exemptions for Pesticides	2.30	1.22	-2 to +5
Tax Exemptions for Complementary Inputs	1.71	1.32	-2 to +5
Health Costs (for Medical Treatment)	0.36	1.08	-2 to +4
Additional Costs Because of Pesticide Resistance	1.32	1.80	-3 to +5
Long Term Environment and Health Costs	-0.29	1.84	-5 to +5

GTZ/University of Hannover PESTICIDE POLICY PUBLICATION SERIES:

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Summaries of the publications and other project related information is also available at:

http://www.ifgb.uni-hannover.de/institut/projekte/gtz/ppp