Economic Analysis of Crop Protection in Citrus Production in Central Thailand

Frauke Jungbluth

A Publication of the Pesticide Policy Project
Hannover, November 2000
Special Issue Publication Series, No. 4

Pesticide Policy Project Publication Series
Special Issue No. 4, November 2000

Institut für Gartenbauökonomie,
Universität Hannover

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

Economic Analysis of Crop Protection in Citrus Production in Central Thailand

Dissertation at the Faculty of Horticulture
University of Hannover

1999

Editors of the Pesticide Policy Project Publication Series:

Prof. Dr. H. Waibel
Institut für Gartenbauökonomie
Universität Hannover
Herrenhäuser Str. 2
30419 Hannover
Germany
Tel.: +49 - (0)511 - 762 - 2666
Fax: +49 - (0)511 - 762 - 2667
E-Mail: waibel@ifgb.uni-hannover.de

P. Keller
Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Abt. 4543
Postfach 5180
65726 Eschborn
Germany
Tel.: +49 - (0)6196 - 791442
Fax: +49 - (0)6196 - 791115
E-Mail: peter.keller@gtz.de

Publication of the Institute of Horticultural Economics,
Herrenhäuser Str. 2, D-30419 Hannover

Printing: Uni Druck Hannover, D-30419 Hannover

ISBN: 3-934373-04-6

Acknowledgements

This study would not have been possible without the numerous individuals and institutions contributing through their profound knowledge and expertise. I would like to thank all of them for their willingness and kindness to support and contribute to this study. Without the willingness of numerous Thai farmers to provide information on their cropping patterns and systems, this study would not exist. To them, my biggest gratitude.

During my stay in Thailand the support of the following institutions is gratefully acknowledged: The Department of Agriculture, The Thailand Development Research Institute and the Thai-German Plant Protection Programme. I am grateful to all of them for making my stay in Thailand possible and for their strong support during the research. Among these, I like to thank especially Mr. Ocha Prachuabmoh and Mr. Wit Namrungsri from the Entomology Division of the DOA, where I found a homebase, Dr. Nipon Poapongsakorn of the Sectoral Economics Program of TDRI who supported the second part of my research and Dr. Guenther Baumann of the TGPPP who as always been a strong source of information and support.

To Jaree Kiatsupimol, Jaruvan Jansai, Nat Rathanadilok, Lakchai and Patcharee Menakanit, Sarut Sudi Aromna, Saranchit Krairisiksh, Boonrat Sookmark and Chainarong Tongpuy my deepest thanks. Their assistance, support and friendship contributed to my research in various ways, and made my time in Thailand a very pleasant and memorable one. I am very grateful for having had the opportunity to conduct my research in Thailand.

This study would not have been possible without the financial support of the Pesticide Policy Project through GTZ and the long commitment of Prof. Dr. H. Waibel to achieve greater awareness of the main issues surrounding crop protection and its policies. I would like to thank Prof. Dr. H. Waibel to have given me the opportunity to be part of the team working on those issues and to have accompanied my research from the beginning. My thanks also goes to my colleagues of the Institute of Agricultural Economics in Göttingen and the Institute of Horticultural Economics in Hannover.

Khop khun maa ka

Table of Contents

Appendix

List of Tables

List of Figures

List of Abbreviations

BAAC	Bank of Agriculture and Agriculture Cooperatives
Baht	Thai Currency
BPH	Brown Plant Hopper
c.i.f.	cost, insurance, freight
CL	Cluster
DOA	Department of Agriculture
DOAE	Department of Agricultural Extension
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIFAP	International Group of National Associations of Manufacturers of Agrochemical Products
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH
ha	hectare
IPM	Integrated Pest Management
N	Number of farmers
NEB	National Environmental Board
NGO	Non Governmental Organization
NN	Nakhon Nayok
mill.	million
MRL	Maximum Residue Level
MOAC	Ministry of Agriculture and Cooperatives
MOPH	Ministry of Public Health
PIC	Prior Informed Consent
PPSD	Plant Protection Service Division
PT	Pathum Thani
rai	Thai Measurement = 0.16 hectare
RSS	Residual Sum of Squares
SB	Sara Buri
TDRI	Thailand Development Research Institute Foundation
t	tons
TGPPP	Thai German Plant Protection Programme
TVC	Total Variable Costs
US$	United States Dollar
WHO	World Health Organization

Currency Exchange Rate:

1 US$ = 25.6 Baht.................... (at Dec. 11th, The Economist, 14th Dec. 1996)

1 Introduction

1.1 Problems and Objectives of the Study

As a consequence of the adoption of monoculture with high yielding varieties and high levels of fertilizer use, the use of chemical pesticides has become the main instrument of pest control[1]. However, the very nature of pesticides implies external effects to human health and to the environment, thus from an economic point of view creating a divergence between the private and the social optimum of use.

The on-going support of pesticides in national agricultural policies has created an environment where perceptions of pesticide benefits are taken for granted and external effects of pesticide use are not sufficiently taken into account. Therefore, there is the danger that agricultural production systems develop on a pesticide-dependent path, creating the necessity of increasing pesticide use levels.

Traditionally focusing on rice production, the agricultural sector in Thailand is today becoming more diversified. This development is dominated by the rapid growth of the horticultural sector. In this sector the intensity of pesticide use is comparativey high and contributes to the overall trend of increasing use of chemical pesticides in Thai agriculture.

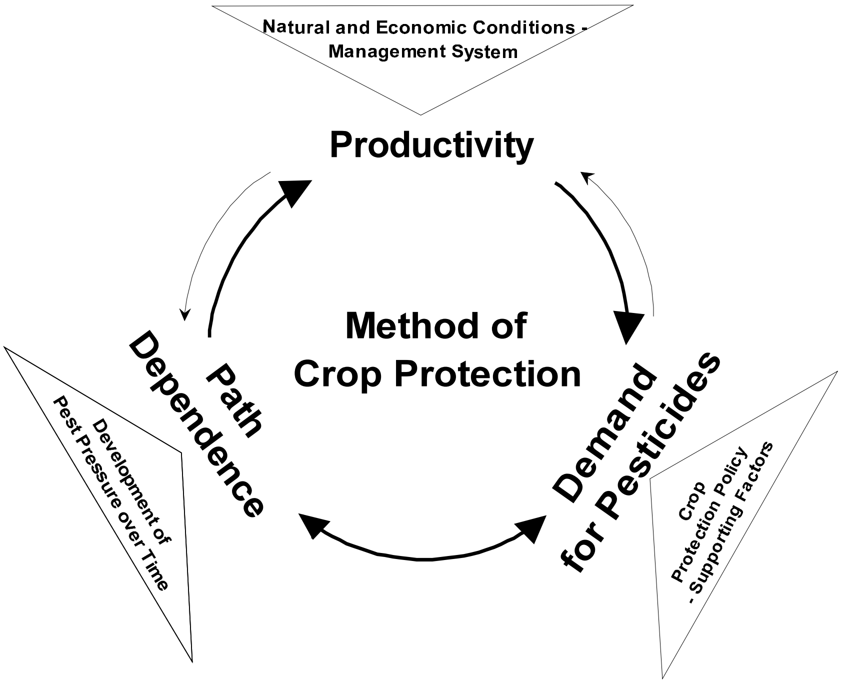
In terms of production value citrus represent one of the most important crops of the horticultural sector. The typical production method of citrus in the central area of Thailand is characterized by monoculture with high external input use. Although several factors indicate that the intensity of pesticide use results in negative effects, chemical pesticides are still the first technological choice in pest control. Problems like resistance built-up, pest resurgence, induced flowering and multiple fruiting raise doubts about the sustainability of the current management strategies applied. Therefore, this study aims at analyzing the economic implications of crop management systems currently used in citrus. Special emphasis is given to the economics of crop protection in citrus, also taking into account the policy framework that often pre-condition the use of chemical inputs.

---

[1] The term 'pesticides' refers to all chemical pesticides used in plant protection, and includes insecticides, herbicides, fungicides, fumigants, rodenticides and plant growth regulators.

Figure 1.1 indicates the relation between and the influence of relevant factors on the existing crop protection strategy in citrus production.

Figure 1.1: Relation among Factors Influencing the Choice of Crop Protection Method in Citrus Production



Source: Author's Compilation

The productivity in the citrus sector is influenced by the management system and the natural and economic conditions prevailing. Resulting from the selected management system and its productivity, a demand for crop protection measures develops. These measures are influenced by agricultural and crop protection policies. In turn, the crop protection measure selected by the farmer determines a possible path-dependency, and vice versa.

This simplified presentation of the complex relationships relevant for an economic assessment of crop protection leads to the identification of three main objectives for this work:

- to describe the impact of the policy framework on current crop management strategies
- to assess the economics of current management systems in citrus production with a special focus on pesticide use
- to identify indicators of a possible path-dependency of chemical crop protection in citrus

1.2 Structure of the Study

Chapter 2 analyzes the institutional and political background on crop protection in Thailand. It describes the conditions under which crop protection in Thailand is taking place. The institutional aspects of crop protection can be regarded as one major determinant for current developments in crop protection. Various factors in support of pesticide use and their impact on agricultural production as well as an assessment of the external costs related to pesticide use are discussed in Chapter 2.

Chapter 3 introduces the theoretical background of the economics of crop protection. In the first section, the changing views on the incorporation of pesticides in production functions are reviewed. A discussion follows on differences of pesticides in comparison to other input factors in the economic assessment. Issues concerning benefit assessment of pesticides, crop loss assessment, risk and information factors, resource costs and the concept of path-dependency are addressed.

The production of citrus in the central region of Thailand is introduced in Chapter 4. The traditional, commonly used citrus production system is described and its problems are discussed. The selected study area as well as contents and methodology of the farm survey are presented in Chapter 5. The final section emphasizes on a descriptive analysis of the farm survey.

Chapter 6 introduces the method of cluster analysis, which is used to develop a typology of crop management systems. These clusters, grouped according to pesticide intensity, are used to identify patterns of input use among farmer groups. The factors are examined causing the difference among clusters.

In Chapter 7, a production function is estimated for citrus production in the study area. The discussion of the appropriate functional form of the yield-age relationship is followed by a multiple regression analysis. In the final section the existence of path-dependency is discussed by analyzing the time-dependence of pesticide use levels.

Finally, Chapter 8 summarizes and discusses the findings with respect to the hypotheses formulated. Furthermore, based on the results of the economic analysis, conclusions are drawn with respect to necessary reforms at both political and institutional level targeting the reduction of the current levels of pesticide use.

2 Crop Protection Policy in Thailand

Thailand's crop protection policy describes the framework of the economic analysis of the citrus sector. Several factors indicate that subsidies for chemical pesticides continue to exist in crop protection policy of many countries (FARAH, 1993). Examples include direct intervention in domestic pricing, low tariffs, poor enforcement of regulations, and research, education and extension frameworks that favor pesticide use. In addition, an imbalance exists within the research, education and extension apparatus, such that curricula and work programs emphasize chemical control over non-chemical options.

The analysis of crop protection policy in Thailand is based on the framework presented in AGNE et al. (1995). A more detailed analysis of the crop protection situation in Thailand can be found in JUNGBLUTH (1996). The chapter is divided into two sections. In the first section the situation and development of the agricultural sector and the pesticide market are discussed. Furthermore, institutional constraints and farmer's perspectives are reviewed. The second section concentrates on a discussion and assessment of external effects of pesticide use.

2.1 Analysis of Crop Protection Policy

2.1.1 The Agricultural Sector: Characteristics and Trends

Along with the rapid expansion of Thailand's overall economy came a structural adjustment and a diversification of the agricultural sector[2]. Although manufacturing is the leading sector in the country's overall development, the agricultural sector remains important in terms of capital accumulation, employment and contribution to government's revenues through export earnings. Thailand is still one of the world's leading rice exporters. The sector continues to be important for the economy in terms of employment and its role to alleviate poverty (WORLD BANK, 1994) .

The agricultural sector's share of the total gross domestic product (GDP) declined steadily in the last decade to 10.7% in 1996, although it continued to increase slightly in total value (BANK OF THAILAND, 1998). The manufacturing sector contributes most to the GDP while agriculture and service show a

---

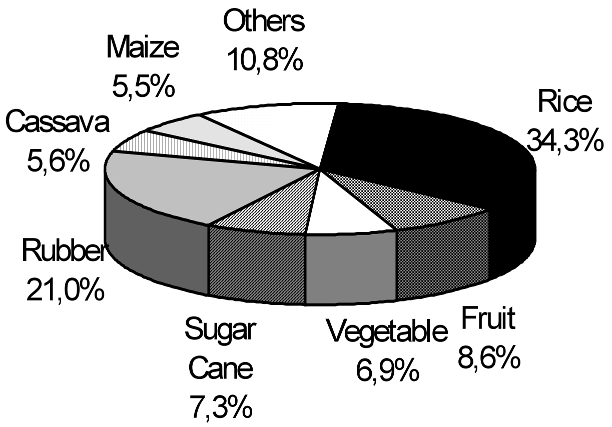
[2] A map of Thailand is shown in Appendix I. Appendix II provides background information on Thailand's agriculture.

declining trend[3]. POAPONGSAKORN (1994) raises three main points for changes in the agricultural sector: (a) The diversification of agricultural production, (b) the migration of agricultural laborers into other sectors, and (c) a lack of manpower in the central region.

The total cultivated area in Thailand is 22.9 million hectares (44.6% of the total land area; 513,115 km^2). Rice still remains the most important agricultural crop and is planted on around 44% of arable land. Figure 2.1 summarizes the farm value of important agricultural products. Fruit and vegetables have a share of around 16% of total farm value while rice holds a share of 34%.

Figure 2.1: Important Agricultural Crops by Farm Value (1995)

(Total farm value 305,825 million Baht)



Source: Office of Agricultural Economics, Agricultural Statistics, 1995/96

In particular, the most important changes in the development of agriculture are taking place in the rapidly growing horticultural sector. The Ministry of Agriculture strongly promotes fruit production. A production restructuring program (MINISTRY OF AGRICULTURE, 1994) has been adopted to transform land cultivated with rice, cassava, coffee and pepper into fruit orchards[4]. Fruit and vegetables gain increasing importance in terms of crop value[5]. These

---

[3] Refer to Figure II.2 in the Appendix.

[4] The major objective of the program is to transform 1.4 million rai of the acreage currently occupied by the above mentioned crops due to their marketing problems. Farmers receive low interest loans and additional assistance in factor inputs (BANGKOK POST, 1993).

[5] Refer to Figure II.1 in the Appendix.

crops show a high intensity of pesticide use which contributes to the overall trend of increasing agrochemical use in the country[6].

The seventh National Economic and Social Development Plan of Thailand (1992-1996) emphasized on efficient use of natural resources, support of research, development and technology transfer in agriculture, restructuring of agricultural production according to local conditions and market demand, support of agro-industry and improvement of agricultural and cooperative development systems (TDRI, 1995). Crops promoted by the government are vegetables and cut flowers as well as fruit trees, fast growing trees, cattle dairy and mixed farming.

2.1.2 Pesticide Market and Pesticide Use

In 1993, the pesticide market reached a sales volume of 247 million US$ (LANDELL MILLS, 1994). Herbicides hold a share of 51%, insecticides 38% and fungicides 10% (WOOD MACKENZIE, 1993)[7].

Figure 2.2 shows market share by crop and pesticide product class[8]. For the herbicide market the plantation crop and the rice sector are of great importance. Most important for the insecticide market are the rice and the horticultural sector. Citrus holds a large share of the insecticide and fungicide market.

As fruit and especially citrus belong to the group of pesticide intensive crops it is expected that pesticide use will increase again, if the new policy of the Ministry of Agriculture successfully changes land planted with food crops into fruit growing areas. This development is stimulating overall pesticide use due to the increasing importance of the fruit sector in agricultural exports and consumer demands for unblemished products.

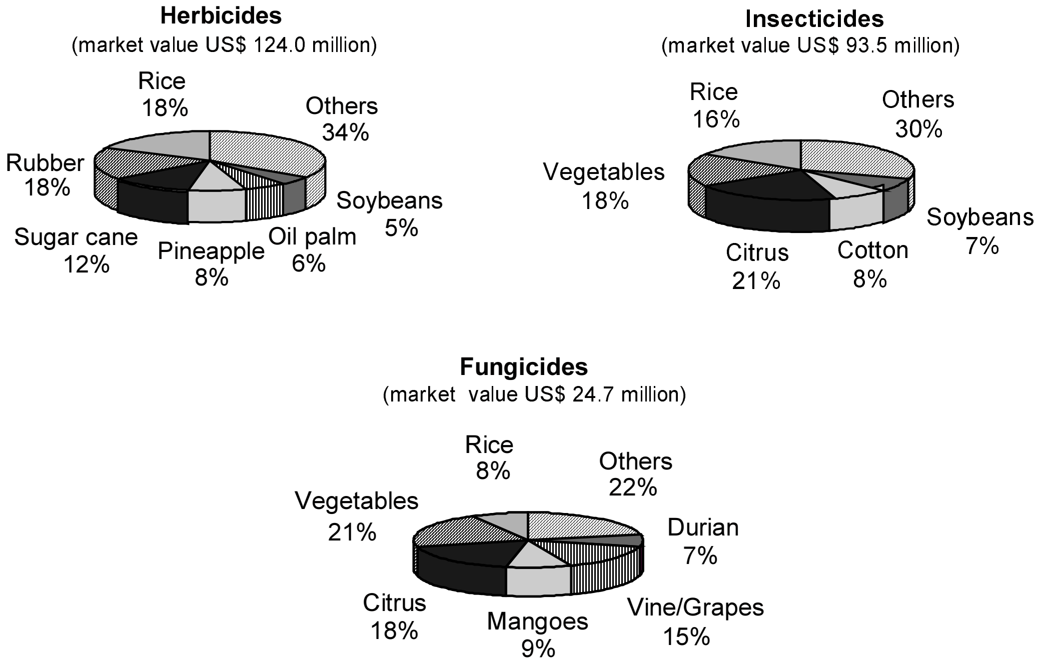
---

[6] Refer to Table III.1 in the Appendix.

[7] Unfortunately, there is no newer market research based data available for the pesticide market situation.

[8] The ten most imported pesticides have a total import share of 70% for insecticides, up to nearly 90% for herbicides as well as for fungicides, respectively are shown in Table III.3 in the Appendix.

Figure 2.2: Market Share by Crop and Product Class (1994)



Source: Landell Mills, 1994

Table 2.1 shows the average intensity of insecticide use for various crops. The intensity of insecticide use per hectare is calculated using the total insecticide market volume split into the respective crops and the area planted. Fruit and vegetables have by far the highest average intensity of insecticide use.

Table 2.1: Average Insecticide Use by Crops of Economic Importance (in US$ pesticide market value/ha)

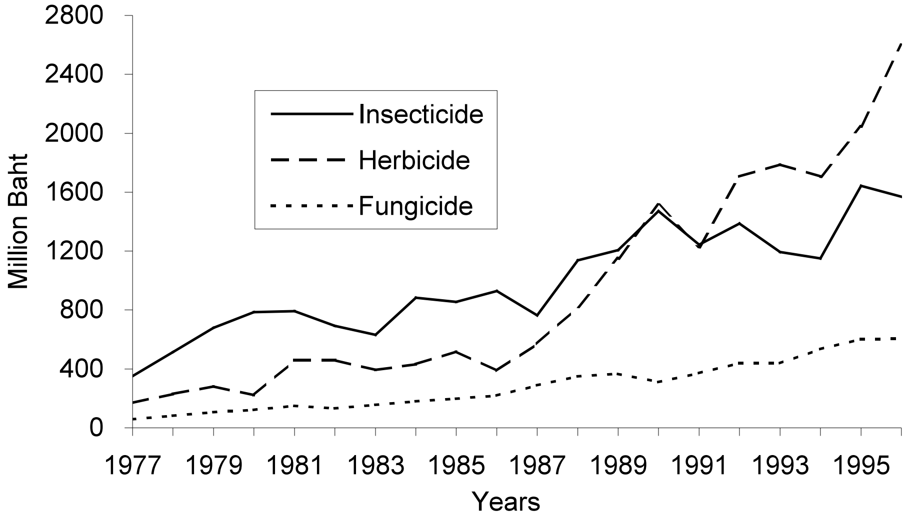
Crop	Planted area (ha)	Percentage share of insecticide market[1]	Insecticide market volume (million US$)[1]	Average intensity of insecticide use (US$/ha)
Rice	10,112,833	16%	14.96	1.5
Citrus	83,696[2]	21%	19.64	234.7
Vegetable	80,106[3]	18%	16.83	210.1
Cotton	59,117	8%	7.48	126.4
Soybeans	454,000	7%	6.55	14.4
Others	11,266,795	30%	28.05	2.5
Total	22,179,364	100%	93.5	4.2

Source: [1] = Landell Mills, 1994, [2] = Fruit Statistics, DOAE, 1994, [3] = Vegetable Statistics, DOA, 1993, others: Office of Agricultural Economics, 1994; Author's Calculations

Many companies import and sell pesticides in Thailand[9]. Apart from numerous traders the most remarkable fact of the Thai pesticide market is the large amount of trade names. For example, monocrotophos is being sold under some 173 different trade names, methyl parathion under 168 and cypermethrin under 180 trade names (REGULATORY DIVISION, 1994). This confusing number of trade names in the pesticide sector complicates market transparency for users and the monitoring and control of the market by governmental agencies.

Figure 2.3 shows pesticide import trends. Insecticides comprising the majority of imports for many years have been exceeded by herbicide imports since 1988.

Figure 2.3: Value of Pesticide Imports (1977-1996)



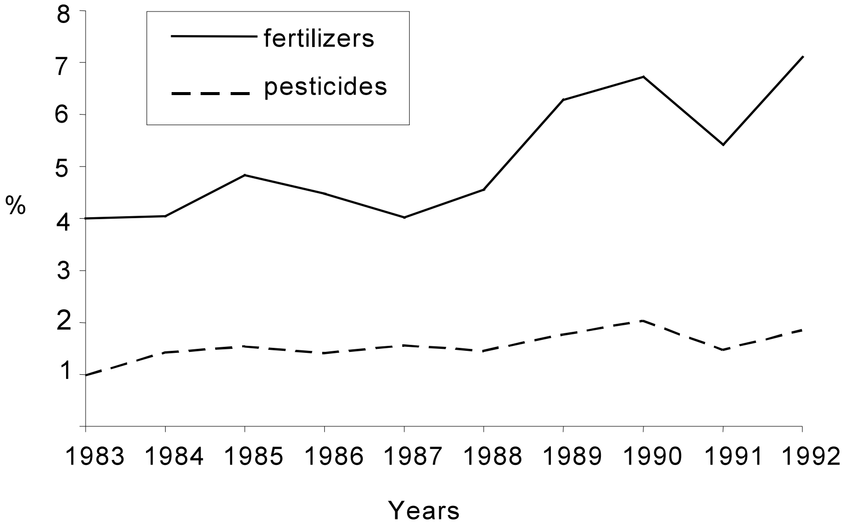
Source: Regulatory Division, Pesticide Statistics, various issues

As most of the pesticides used in Thailand are imported the development of pesticide imports is closely related to development trends of pesticide use. The use of pesticides and fertilizers is increasing in relation to crop value which implies that the input intensity of agricultural production is rising (Figure 2.4). In other words, more pesticide and fertilizer inputs are used to obtain the same crop value.

---

[9] Currently, 69 formulating and repackaging plants, 438 distributors and around 5,000 retailers conduct business in Thailand (DOA, personal communication, 1996). Refer to Table III.2 for the main manufacturers and their main products and to Figure III.1 showing the market shares of major pesticide producers and major importing countries in the Appendix.

Figure 2.4: Fertilizer and Pesticide Imports in Percent of Crop Value



Source: Office of Agricultural Economics, Agricultural Statistics, various issues, Author's Calculations

Still a large amount of pesticides imported to Thailand belongs to the group of more hazardous pesticides. In 1992, according to WHO classification more than 60% of the imported pesticides belong to the classes 'extremely' and 'highly hazardous' (SINHASENI, 1994) (Table 2.2). Real pesticide prices have consistently decreased. The price of methyl parathion, a WHO class I pesticide and one of the most common has declined by 50% in real terms. This may indicate one reason for the extended use of the very dangerous but cheap pesticides[10].

Table 2.2: **Quantity of Imported Pesticides by WHO Classification** (1992)

	Hazardous Class	Quantity (tons)	Percentage
Ia	Extremely Hazardous	1,765.2	23.50
Ib	Highly Hazardous	2,979.6	39.67
II	Moderately Hazardous	2,494.7	33.21
III	Slightly Hazardous	267.0	3.56
III+	Unlikely to present hazard in normal use	4.7	0.06

Source: Sinhaseni, 1994

---

[10] For an overview on the development of pesticide prices refer to Figure III.2 in the Appendix.

2.1.3 Institutional Framework

Pesticide legislation is based on the Hazardous Substances Act which is the main act regulating pesticide use in agriculture. At the moment around twenty laws exist related to the control of chemicals in all areas of pesticide use (BOON-LONG, 1995). Although progress has been initiated with the new act, implementation is slow and difficult. Some reasons for inconsistencies in common practice and law enforcement are an insufficient monitoring and control of the pesticide market, a lack of market transparency due to a large number of companies trading with pesticides and a time lag between constitution of legislation and its implementation[11].

2.1.3.1 Tax Policy

Import taxes consist of import duties, business taxes and municipal taxes. The tax structure related to pesticides has been favorable compared to other inputs and has therefore helped to keep pesticide prices low. Import duties of pesticides do not consider the toxicity of the pesticide. Before 1991 effective total tax rates for pesticides have been 6.9% compared to 32.4% for fertilizer and 27.6% for agricultural machinery (WAIBEL, 1990). Since 1991, pesticides for agricultural use have been exempted from import duty, business and municipal taxes (CUSTOMS DEPARTMENT, 1995)[12]. The tax exemption is an indirect subsidy to pesticide imports and effectively lowers pesticide prices.

2.1.3.2 Import, Trade and Use Regulations

The Regulatory Division of the Department of Agriculture is in charge of the process of pesticide registration and the supervision of use of pesticides. At the same time, the division is responsible for controlling the pesticide market concerning the quality and the date of expiration of pesticides. Pesticide quality control and analysis of pesticide residues in agricultural products is the duty of the Toxic Substances Division of the DOA. Currently there are 298 active ingredients registered in Thailand, and these are sold under more than 2,000 trade names.

The registration process faces two main problems. On the one hand the agency lacks adequate personnel and budget and on the other hand there exists a strong dependency on other divisions of the department for

---

[11] Refer to POAPONGSAKORN et al. (1999) for a discussion on approaches to pesticide policy reform.

[12] In 1995 the import duty on fertilizer was also reduced to 10% (formerly at 30%). Agricultural machinery is taxed with around 28%.

registration related research and requirements which are not classified as priority issues in their work descriptions. Pesticide market inspection is currently conducted by only few inspectors for the whole country. Inspection is therefore limited to a very small sample size and only a few quality control tests can be conducted. This represents a serious shortcoming of the current legislation, as the quality of pesticides is a major concern related to inappropriate pesticide use.

Starting in July 1995, training for retailers has been made compulsory for license holding. However, the usefulness of a two day training which superficially touches upon many aspects is open to question. Retailers have a large impact on farmers' pest management decisions as retailers are often the only or main source of pesticide recommendations and information for the farmer (KHUANKAEW, 1995).

2.1.3.3 Research and Extension

Public agricultural research and extension in Thailand are mainly conducted by the Ministry of Agriculture and Cooperatives (MOAC) and universities. Approximately, 95% of the total government budget for agricultural research and extension goes to the MOAC, while around 5% are dedicated to the universities (TDRI, 1995). Two departments within the MOAC cover almost all aspects of agricultural crop production policy. They share more than 50% of the MOAC's budget for research and extension.

The Department of Agriculture (DOA) is in charge of agricultural research projects and responsible for the development of technologies to be tested and transferred to the farmers by the Department of Agricultural Extension (DOAE). Funding for research followed rather than led market signals (SIAMWALLA et al., 1992). The ratio of government expenditures on extension work to its research is approximately 1.7:1 (SIAMWALLA et al., 1992).

Plant protection issues are dealt with by the Plant Protection Service Division (PPSD) and the Bio-control Center of DOAE as well as several divisions of Department of Agriculture (DOA) (Regulatory, Toxic Substances, Entomology, etc.). In the DOA most research in the field of pesticides concerns pesticide efficacy and application techniques.

FARAH (1993) stated that 98% of the research budget was allocated for chemical pesticides. This has changed over time. During the years 1991-1995 the total budget of the DOAE nearly doubled (OFFICE OF AGRICULTURAL ECONOMICS, 1994), while the IPM related budget increased to currently nearly 20 million Baht (IPM in vegetables, fruit, leguminous plants, rice and maize).

Additionally, a budget for bio-control research and extension was allocated which increased more than eight times over the last five years. However, these IPM related budgets are still only 20% of the budget dedicated to outbreak control.

2.1.3.4 Outbreak Budget

The DOAE oversees a regular budget for the purchase of pesticides. This budget is meant to combat sudden pest outbreaks and pesticides are given to farmers at no cost. The budget is allocated within the country according to previous years' evidence of pest outbreaks. The calculation of the yearly outbreak budget request of PPSD is based on estimated areas infested for rice, field crops and the horticultural sector multiplied by the calculated pesticide expenses per area. The volume of the outbreak budget is based on 10% of the cropping area roughly, i.e. to assure pest control as a special measure of food security and stabilizing agricultural production.

The outbreak budget financed pesticides are distributed them to farmers and extension offices throughout the country and their use is often not further investigated. In 1995 the outbreak budget amounted to 78 million Baht (around 24 million Baht for rice, 40 million Baht for field crops, 6 million Baht for horticultural crops and 8 million Baht for fruit) and rose to approximately 80 million Baht a year later. Recently, the outbreak budget contains also a component for bio-control products.

If a pest outbreak occurs the necessary budget may be several times higher than the regular annual amount as happened in 1989/90 when an outbreak of the Brown Plant Hopper emerged. The usefulness of such a budget is questionable since the past experience showed that, when a pest outbreak occurred, the allocation of pesticides to the infested area has been observed as too slow.

2.1.3.5 Credit Policy

The Bank of Agriculture and Agricultural Cooperatives (BAAC) is the key institution for the implementation of agricultural credit policy (TDRI, 1995). In 1992, short-term credit opportunities for agricultural inputs including pesticides managed by the BAAC were created (GRANDSTAFF, 1992). In 1993, short term loans amounted to 41.8% of total lending. The demand for loans was highest in rice production (31.6%) followed by cassava and maize, but lending for fruit and vegetable production shows an increasing trend (BAAC, 1994). TDRI (1995) states that this trend can be interpreted as an encouragement for agricultural diversification. Within the governmental restructuring program farmers receive partly free agricultural inputs as well as short- and long-term credits through BAAC.

A credit policy which explicitly includes pesticides in its credit program has a supporting effect on pesticide use. Pesticides are included regardless of their necessity or taking into account non-chemical crop protection methods.

2.1.3.6 Information and Training

Information is an essential factor in crop protection[13]. There are several kinds of information needed - at the policy level, at the research and at the farmer level. Two kinds of information related to pesticide use are needed. One concerns the benefit and costs of the use of a certain pesticide while the other can be seen as the need for general information about possible alternatives to pesticide use.

Additionally, information about pesticide quality can seriously affect pesticide use levels. Quality tests conducted by the DOA indicate that a large amount of pesticides do not fulfill minimum standards. Expired or degraded products can be found in numerous retail shops (GRANDSTAFF, 1992). For example, in 1995 the industry started a product quality monitoring program.

Three of four paraquat samples were below standard, while in another trial two of six glyphosate and paraquat samples were below standard (GIFAP, 1996). It has been reported that farmers apply increased dosages due to the experience that the recommended amount was found not to be effective.

The main basis for the DOA recommendations of pesticide use are efficacy tests. Assessment of crop loss is not conducted on a regular basis for every crop. For some crops economic threshold levels exist. However, pesticide recommendations of the DOA seem to be far too complex for common use and are not a major factor in farmers' decision making in crop protection. In general these measures encourage pesticide use as the available information promotes the use of pesticides.

In addition to the government extension service, training is also held by the pesticide companies by conducting safe use training. As the name indicates, the focus lies on the safe use of pesticides and on the training on application methods.

---

[13] Refer to section 3.2.4 for a theoretical discussion on the role of information in crop protection.

The training takes place during one half day and per capita costs are around 150 Baht. Overall there is a budget of 1.3 million US$ dedicated for a three year safe use project, of which around 500,000 US$ are for safe use training (GIFAP, 1996). No evaluation results have been made available so far on the impact of these training courses.

2.1.3.7 Farmer's Perception

In a survey of 373 randomly selected pesticide formulations conducted in 1983, 44% of the samples differed significantly from the indication on the label (TAYAPUTCH, 1992). Taking this into account, farmers have limited opportunities to control the amount of active ingredients sprayed on their land. About half of Thai farmers apply higher than recommended concentrations and do not pay adequate attention to labels and protective clothing (GRANDSTAFF, 1992; SINHASENI, 1994).

As stated in a report of FAO-JICA (1995) a strong preference for cheap pesticide products still exists in Thailand. This explains partly the enormous share of pesticides classified as most hazardous in the Thai pesticide market which tend to be cheap on international markets.

Often the farmer's lack of awareness is seen as one major reason for pesticide problems. Several studies about farmers' awareness conducted in Thailand in 1985 (GRANDSTAFF, 1992) concluded that more than half of the farmers applied dosages higher than recommended on the label. Almost all of the farmers regularly mixed two or more pesticides for one application. THONGSAKUL (1990) states that application of pesticide mixtures is a common practice in vegetables. Decisions about pesticide mixtures are made either by retailer recommendations or according to the established practice in the area (SONGSAKUL, 1991). In studies reviewed by GRANDSTAFF (1992) the majority of farmers spray pesticides frequently, especially in the horticultural sector, and harvest their crops for marketing before the end of the recommended waiting period. The studies concluded that even though the farmers state their concern about possible health hazards, their behavior in spraying, mixing and handling of pesticides and pesticide disposals indicates a lack of real knowledge or awareness of actual danger.

2.1.4 Discussion

According to the analyses of the crop protection situation in Thailand, pesticide supporting factors could be identified, which can be categorized as price factors, institutional factors and information factors.

The most obvious price factor is the tax exemption for pesticides. Furthermore, the supply of free pesticides through the outbreak budget and the enclosure of pesticides in credit programs of the BAAC can be regarded as price factors. This also applies for the governmental program to convert former rice land into fruit growing area.

Institutional factors comprise the research and extension focus which is still dominated by chemical crop protection. The weak enforcement of existing rules and regulations as well as the lack of new incentives for improved pesticides regulations and monitoring of the pesticide market can be attributed to institutional shortcomings creating an environment which strongly favors pesticide use and lacks the increase of market transparency.

Among information factors supporting the use of pesticides there are the lack of information on crop protection alternatives as well as the misinformation regarding pesticide efficacy, pesticide benefits and impacts. This applies to the farm level as well as to the institutional level. A reconsideration of benefits of pesticide use would then in a second step require a consideration of external costs in the institutional set-up. A lack of information could also be determined in the farmer's knowledge and attitudes towards application and mixing of pesticides.

The political and institutional framework of crop protection in Thailand supports pesticide use and therefore pesticide intensive strategies. Current developments in the agricultural policy do not yet imply that a change of political directions is likely to occur in the near future.

2.2 External Costs of Pesticide Use

This section discusses existing evidence of external effects related to pesticide use in Thailand. These include: Health effects, residues in food and the environment, resistance and resurgence, the governmental budget for research and extension related to pesticides and the monitoring and control of the pesticide market. In addition other external effects exist. However, these can not be estimated as sufficient information on their related costs is not available. Other external effects which have to be considered in calculating the net social benefit are, for example, the destruction of beneficial insects, the reduction of biodiversity, pollution of drinking and surface water, non-agricultural consequences. In the following some results on externalities of pesticide use in Thailand and the results of an assessment of external costs conducted in JUNGBLUTH (1996) are presented. The assessment of external costs is summarized in Table 2.4 (p. 21).

2.2.1 Occupational Pesticide Poisoning

In Thailand the Division of Epidemiology of the Ministry of Public Health has the primary responsibility for collecting poisoning data. Since these data rely on case reports of governmental hospitals and some private clinics, the actual poisoning cases are most likely understated (SINHASENI, 1990). A survey of poisoning cases among agricultural workers by WONGPANICH (1985) concluded that only 2.4% of poisoning victims are reported to hospital[14].

Eighty percent of the women questioned in a survey by KHUANKAEW (1995) state that they have been poisoned. They reported acute effects like dizziness, muscular pain, headache, nausea, weakness and difficulty in breathing. According to a survey of 445 tangerine growers in Pathum Thani (POLRAT, cited in SINHASENI, 1994) there is a significant relationship between pesticide poisoning incidence and the amount of powder pesticide formulation used. Almost 50% of the growers had a history of poisoning symptoms and only half of the poisoned patients went to government clinics.

For an assessment of health costs the expenses for medical treatments and the income loss due to lost work days have to be calculated. Imputed costs of fatalities would also have to be considered. Additionally, long term effects of pesticide poisoning are also contributing to health costs. But no information about the extent and related costs of long-term effects is available.

For a more realistic calculation health costs assessed in a study by WHANGTHONGTHAM (1990a) for poisoning cases in citrus production in Central Thailand have been used to arrive at more realistic data on poisoning cases. According to the survey, 25% of poisoning cases are treated in hospitals, 52% in private clinics and 23% in health offices. The costs related to these treatments are 550 Baht for hospitals (three days treatment), 120 Baht for clinics and 70 Baht for health offices. The costs per lost labor day are calculated with 100 Baht, the loss of labor days amounts to three days for hospital treatment and 0.5 days for both clinic and health office treatment. The average costs for medical treatment and lost labor days assessed amount to 328.5 Baht[15].

To relate the poisoning cases to the insecticide market volume, three assumptions have to be made. Firstly, the reported poisoning cases are mainly due to insecticide use and are therefore related to the quantity of insecticides

---

[14] Refer to Figure III.3 in the Appendix. Figure III.4 in the Appendix shows poisoning cases differentiated by the type of chemical.

[15] (550*0.25)+(120*0.52)+(70*0.23)+(300*0.25)+(50*0.52)+(50*0.23) = 328.5 Baht

used. Secondly, poisoning incidents are not location specific and finally, the hazardousness of the pesticides used is comparable for all crops. Table 2.3 explains the calculations of acute health cost assessment.

Table 2.3: Calculation of Acute Poisoning Cases and Health Costs

	Calculations	Result
(I)	1,824 insecticide poisoning cases / 149,734 rai	0.0121816 *insecticide poisoning cases / rai*
(II)	*(I)* / 39.116 US$ insecticide use / rai	0.0003114 *poisoning cases / US$ insecticide use*
(III)	*(II)* * 93.5 million US$ insecticide market volume	29,118 *insecticide poisoning cases*
(IV)	*(III)* * 100 / 64	45,497 *total poisoning cases*
(V)	*(IV)* * 328.5 Baht health costs	14,945,723 Baht *acute health costs per year*

(I)	Poisoning cases are set into relation to the tangerine growing area of Pathum Thani (149,734 rai).
(II)	The cases per rai are related to the intensity of insecticide use in citrus (235 US$/ha = 39.166 US$/rai, refer to Table 2.1, p.7)
(III)	The derived poisoning cases per US$ insecticide use are related to the total insecticide market in Thailand (93.5 million US$).
(IV)	From the resulting insecticide poisoning cases in Thailand total poisoning cases are derived (only 64% of poisoning cases result from insecticides).
(V)	Total poisoning cases are related to the average health costs per person and poisoning case.

Source: Author's Calculations

Considering, as indicated in the study, that 86% of the total poisoning cases of tangerine growers in Pathum Thani (2,121 cases) are caused by insecticides, the number of insecticide related poisoning cases would amount to 1,824. Furthermore, considering that 64% of all poisoning cases are related to insecticides while 36% are related to herbicides and other pesticides (MINISTRY OF PUBLIC HEALTH, 1996)[16], the calculated number of insecticide poisoning cases (29,118) is used to derive the total number of pesticide poisonings in the country.

The calculation results in a total number of 45,497 poisoning cases. If these cases are weighted with the average health costs per poisoning case, total health costs sum up to almost 15 million Baht per year.

---

[16] Refer to Figure III.4 in the Appendix.

2.2.2 Residues in Food Products

Survey and monitoring of pesticide residues in the environment have been conducted since 1976 (TAYAPUTCH, 1988)[17]. Several studies indicate that there is a strong evidence of pesticide residues in the environment. Residues of Methyl-Parathion, a heavily used insecticide in various crops, have increasingly been found in agricultural products. Effects in soil and groundwater as well as health effects to humans have been observed (GRANDSTAFF, 1992; SINHASENI, 1990; TAYAPUTCH, 1988)[18].

Another study of the Division of Toxic Substances on residues in fruit and vegetables found that around 37% of the vegetables were contaminated with organophosphorous insecticide residues. 73% of tangerine samples were contaminated with pesticide residues (around 10% exceeding the MRL) which consisted mainly of malathion, monocrotophos and methyl parathion (PALAKOOL, 1995)[19]. A recent study on residues in agricultural products (SUKMAK, 1997) revealed that of 155 vegetable samples 30% were contaminated, of which 10% exceeding the MRL. For fruit out of 150 samples 58% were contaminated, of which 15% exceeding the MRL (9% of total sample).

The Division of Toxic Substances found 10% of the samples of tangerine and 20% of kale as well as 10% for cowpea over the MRL. Additionally, it is assumed that the sample is representative and that products exceeding the MRL should not be marketed. The farm value for all fruit was 29,504 million Baht and 20,667 million Baht for vegetables (THAILAND IN FIGURES, 1996). If 10% of the products would be banned from sales as the standards suggest For vegetables the loss amounts to 2,067 million Baht and to 2,950 million Baht for all fruit. These calculations together with the costs of monitoring may serve as an upper boundary for the actual costs of pesticide residues. If effective market control existed, the risk for the producer of not being able to market his products would increase and as a likely result it could be assumed that cases of residues would decrease.

---

[17] Table III.5 in the Appendix provides a summary of the compounds analyzed in residue analysis.

[18] A recent study (SRIPLAKICH, 1997) concluded that the cumulative data on pesticide contamination in surface, ground and drinking water implies that pesticide use should be more restricted.

[19] A study on pesticide degradation in agricultural products (TUMRONGSIKUL, 1997) found that almost all pesticide applications used according to the recommendation were safe for consumption except carbosulfan. Carbosulfan was detected in orange 21 days after the last application, 0.18 mg/kg in the whole fruit exceeding the MRL which is by 0.1 mg/kg.

The costs of residue monitoring, directly related to pesticide use, have to be attributed to external costs of pesticide use because without the use of pesticides residue control would be unnecessary. The budget of residue control in the Toxic Substances Division of DOA is taken into account. If only budget costs are considered, it is implied that no further costs occur due to residues. The calculation of budget costs serves as a lower boundary for residue related costs in Table 2.4. The 'real' costs involved will be located somewhere in-between these boundaries.

2.2.3 Resistance and Resurgence

SETBOONSARNG (1993) states that BPH outbreaks are the most recent example of the build-up of pest populations[20]. Data from Thailand show a strong correlation between increased use of pesticides and the BPH infested area (GRANDSTAFF, cited in IRRI, 1994). Another study tested the efficacy of pyrethroids in cotton[21]. Within one decade efficacy decreased from around 80% to nearly zero percent (SINCHAISRI, 1988).

Dependency on pesticides is another factor which may be added to the external costs. The dependency on pesticides can be most clearly shown in the area of vegetables where problems of pest resistance lead to an overdosing of pesticides by a factor of up to eight times the recommended rate (WAIBEL and SETBOONSARNG, 1993). A recent study of vegetable growing concluded that farmers seem to accept the fact that pests build resistance after a short period of time (JOURDAIN and RATTANASATIEN, 1995). The period between introduction of a new pesticide product and first occurrence of resistance build-up is shrinking, as the same product is intensively used by almost all farmers in one region

At present it is impossible to assess the costs related to resistance of pesticides as no data are available which would indicate the relation between evidence of resistance and the costs involved. Costs of resistance build-up could be expressed as an increase in pesticide use over time for a specific crop with stable pest effectiveness or the increasing share of pesticides in total production costs.

The calculation of resurgence costs is based on the costs which occurred during the last BPH outbreak in 1989/90. Assuming that such a severe BPH

---

[20] Other reasons for the increase of BPH are seen in susceptible varieties, narrow planting distances and intensive use of fertilizer (RUMAKOM, cited in OOI 1992).

[21] Refer to Figure III.5 in the Appendix.

outbreak would occur every ten years on average and also assuming that the damage would be similar to the one observed in 1989/90, annual costs for resurgence amount to 57 million Baht yearly[22]. However, the 'real' costs are assumed to be much higher as crop losses should be considered as well as the fact that studies indicate that resurgence costs increase over time (OERKE et al., 1994).

2.2.4 Summary Assessment of External Costs of Pesticide Use

The discussion of externalities in this chapter indicates the difficulties in assessing costs not included in the market price of pesticides. A high share of external effects could be detected in the vegetable and fruit sector. It is assumed that these cropping systems induce most of the problems. External costs not only relate to the costs of effects to human health and the environment but also to costs related to research, regulation and control of the pesticide market. The calculated additional costs to society for every monetary unit spent on pesticides are summarized in Table 2.4.

It can be assumed that the actual costs are likely to be higher as only a small range of all external costs could be considered in the assessment. The budget costs calculated are costs which have to be paid by society for research and extension work on pesticides and their monitoring and regulation. Costs as those assessed for residues are hypothetical costs because in reality contaminated products are not always likely to be removed from the market.

---

[22] Derived from the 1989/90 outbreak (WHANGTHONGTHAM, 1990b):

Additional support of rice farmers	500 million Baht
Supply of rice seeds	74 million Baht

Total for every ten years 574 million Baht; 57.4 million Baht per year.

Table 2.4: Assessment of External Costs of Chemical Pesticide Use

Type of costs	Derived from	Estimated annual costs (million Baht)
Health	- *Estimated acute poisoning cases related to quantity of pesticide used from case study results*	15
Residues in food	- *Residue analysis in fruit (f) and vegetable (v)*	2,950 (f) 2,067 (v)
Resistance and Resurgence	- *Costs related to BPH outbreak in 1989/90*	57
Research budget related to chemical pesticides	- *Budget of Entomology Division, DOA, for research in pesticide related issues*[1]	25
Pesticide quality and residue monitoring budget	- *Budget of Toxic Substances Division, DOA*[2]	48
Budget for pesticide regulation and market monitoring	- *Budget of Regulatory Division, DOA*[2]	46
Budget for govern-mental extension related to chemical pesticides	- *Budget of PPSD, DOAE*[3]	285
Total		
Lower boundary[4]		476
Upper boundary[5]		5,493

Source:
[1] Annual report, Entomology Division, DOA, around 40% of the total budget (63,235,520 Baht) are spent for pesticide related research
[2] DOA, personal communication
[3] DOAE, personal communication, Author's Calculations
[4] lower boundary excludes residue costs estimations
[5] upper boundary includes all costs listed above

The comparison of the result in Table 2.4 (5,493 million Baht) to total pesticide market sales (247 million US$ = 5,928 million Baht, LANDELL MILLS, 1994) indicates that an additional 0.93 Baht of external costs are incurred for every Baht spent on pesticide purchases. This comes close to a relationship of 1:1. In comparison, PIMENTEL (1993) in an assessment of pesticide use related to social and environmental costs in the United States calculated a relation of 1:2. In Germany, a study (WAIBEL and FLEISCHER, 1998) concluded that for every German mark spent on pesticides an additional 0.23 marks must be paid by society. It should be emphasized again that the assessment of external costs conducted in this chapter may as well overestimate some costs as it underestimates other costs due to a lack of some data.

2.3 Summary

The situation analysis of the Thai crop protection sector revealed that the current situation is characterized by a continuous increase in pesticide imports and pesticide use. The development of the agricultural sector has been more diversified lately. Intensification of production as well as an increase in production area is highest in the fruit and vegetable sector. Still a high share of pesticides used belong to the most hazardous pesticides, thus increasing the danger of pesticide poisonings. Prices of pesticides decreased over the last years. An in-depth case study analysis of crop protection on the farm level in one of the pesticide-intensive cropping systems is the next logical step. The further analysis, therefore, concentrates on the citrus production sector - one of the cropping systems with high pesticide use.

The previous discussion has several implications for further research. It can be concluded that the overall policy framework supports pesticide use. As the citrus sector is one of the growing and intensively producing sectors it is hypothesized that consequences of pesticide subsidies in terms of price and institutional factors can be studied in this sector. Before an empirical analysis on the economics of crop protection in citrus will be conducted, the theoretical background of pesticides in crop protection is reviewed in the next chapter.

3 The Economics of Pesticides in Crop Protection

This chapter discusses the role of pesticides in crop protection and reasons for their over- and misuse. The first section discusses the historical development of the incorporation of pesticide use in production functions. The second section concentrates on the question why pesticides have to be treated differently from other agricultural input factors. Benefits and costs of pesticide use, crop loss assessment, resource costs, risk and information factors will be discussed as well as market and institutional failure related to external effects are discussed in the third section. The final section concentrates on the relevance of path-dependency in crop protection and its impacts as well as the special role of pesticides in perennial crops. The relevance of the theoretical discussion for application in the case study of citrus in Thailand are summarized in the final section.

3.1 Production Functions and Pesticides

The incorporation of pesticides into the production function has three major difficulties. Firstly in the case of pesticides, it is difficult to specify a direct measure of the input output relation. Neither the expression of pesticide inputs in terms of quantities nor costs can take full account of the multitude of combinations in active ingredients, application quantities, price differences of pesticides with similar mode of action or targeted pests. Secondly, unlike standard factors of production (land, labor, and capital) direct productive inputs like fertilizer, pesticides do not increase potential output. Instead, they are targeted to reduce potential crop losses (LICHTENBERG and ZILBERMAN, 1986). Pesticides can, therefore, be defined as inputs reducing crop loss but not directly enhancing yields. Thirdly, pesticide use in previous periods may influence pest pressure in later periods, i.e. causing what entomologists call the problem of secondary pests (VAN DEN BOSCH, 1989, KENMORE et al. 1984).

One of the earliest attempts to estimate pesticide productivity in production functions has been made by HEADLEY (1968). The production function was derived from cross sectional data using a Cobb-Douglas function on an average farm enterprise. Output is expressed in value terms and, therefore, the partial differentiation of the respective input factor provides its marginal value product. Headley argues that pesticide expenditure is a good proxy for the input of the specific pesticide used. He concludes that the marginal value product of pesticide expenditure is about 4, suggesting that pesticides are underused.

The study of FISCHER (1970) of Canadian apple production also aimed to clarify the role of pesticides in pest control. He assumed a production function of apple orchards, where the value of production is dependent on the value of pest control, the value of other inputs and the capital invested. The purpose of the model is to estimate production elasticities of the analyzed regions and marginal productivity of the input factors (pest control/others). Results also indicate a marginal productivity of pesticides of greater than one.

CAMPBELL's study (1976) focused on the estimation of marginal productivity of pesticides from a Cobb-Douglas production function derived from cross sectional farm input and output data. He argued that the physical production function can be written in value terms since farmers can be assumed to be price takers. He introduces a function of anticipated output upon which farmers base their input decisions. These decisions may differ from actual outputs due to the influence of climate or other disturbances in the production process. He also arrives at a marginal product of greater than one for pesticides.

However, by incorporating a damage control function into the production function LICHTENBERG and ZILBERMAN (1986) took account of the fact that pesticides do not directly enhance productivity. They argued that the use of pesticides implies certain difficulties not occurring in connection with other inputs and that the damaging agent involved adapts to the control measure taken in time. The output, therefore, can be divided into potential output and losses caused by damaging agents. The productivity of pesticides can be defined in terms of their contribution to damage abatement. Abatement should then be defined in terms of its impact on the destructive capacity of the relevant damaging agents. The proposed abatement function in the production function $G(X)$ represents the proportion of the destructive capacity of the damaging agent eliminated by the application of a certain level of the damage control agent (X). The function is monotonically increasing and comprises variables representing damage control inputs.

The production function $Q = F\,[Z,\ G\,(X)]$ can be characterized as a function of directly productive inputs Z and damage abatement $G(X)$. In pest management a decreasing marginal productivity of abatement is probable because further reductions in damages tend to decline as pest populations get smaller. The authors conclude that the use of a standard Cobb-Douglas specification to estimate pesticide productivity tends to overestimate the marginal productivity of the pesticide (due to the restriction of the rate at which the marginal effectiveness curve declines) and underestimates the marginal productivity of natural and omitted factors and that traditional specifications produce misleading predictions when pesticide productivity is changing over time (i.e. due to resistance).

CARRASCO-TAUBER and MOFFITT (1992) used the Lichtenberg and Zilberman framework to provide an empirical utilization of damage control specifications based on the study of Headley. They analyzed 1987 cross sectional data and compared three damage control specifications (Weibull, logistic and exponential) with a conventional Cobb-Douglas function. The analyses showed results similar to those found by Headley for the estimated values of marginal product of pesticides of the Cobb-Douglas, Weibull and logistic damage control specifications. Only the exponential form showed a marginal productivity of pesticides of less then unity suggesting pesticide overuse. The authors concluded that there is neither strong theoretical evidence nor empirical reason for the preference of a specific abatement function to other specifications.

A further analysis by CHAMBERS and LICHTENBERG (1994) tried to generalize the Lichtenberg/Zilberman specification by applying a multi-output specification of the damage control technology from a dual approach. In their analysis of aggregate time series data they arrive at inelastic abatement elasticites, derived from pesticide-elasticity estimates, implying that even relatively large changes in price will have small effects on abatement levels and thus pest damage. This result is in accordance to Lichtenberg and Zilberman's prediction about the behavior of abatement. They concluded that the chosen specification aims to enhance flexibility of modeling the production technology and offers the possibility to capture pest damage indirectly from pesticide input data.

The study of CARPENTIER and WEAVER (1997b) established further evidence for an upward bias in past estimates of pesticide productivity. They argued that pesticides represent an input which indirectly contributes to the productivity of other inputs and that the importance of pesticides is conditional upon the occurrence of pests and their actual damage. From the society's point of view pesticides are not adjusted to social optima. Therefore, in their study a reconsideration of the marginal productivity of inputs was proposed. They specified a less restrictive Cobb Douglas function in which temporary fixed effects (quasi fixed endowment) are allowed as well as time-varying regression parameters:

$$y_{it} = \gamma_t + \gamma_i + \sum_{k=p,e,d} \alpha_{kt} x_{kit} + u_{it}$$

where y_{it} = natural logarithm of yield, x_{pit} = natural logarithm of pesticide use, x_{eit} = natural logarithm of fertilizer use, x_{dit} = natural logarithm of other variable input use and u_{it} = random disturbance. γ_t can be interpreted as a parameter for technological progress and α_{kt} as resulting from technical change or other temporally correlated effects. This specification involves two principal structural hypotheses: (i) the existence of fixed firm (heterogeneity in the allocation of land across farms) and time effects and (ii) a functional form in which the role of pesticides is symmetric with that of other inputs (CARPENTIER and WEAVER, 1997a).

The specification allows jointness in pest treatment and private input process. A separate specification of damage abatement is considered inappropriate in the case of multiple pest occurrence by the authors. The study of panel data indicated that an omission of the temporally fixed and time varying effects results in substantial overestimation of productivity by a factor of three for pesticides, two times for fertilizers and one and a half times for other variable inputs. Their results find estimates of marginal pesticide productivity that are consistent with (i) slight overuse of pesticides and (ii) substantially larger estimates of the own-price elasticity of pesticide demand than reported by past estimates (CARPENTIER and WEAVER, 1997a). The authors argued that if producers are profit maximizers, omission of firm-correlated specific effects imply substantial underestimation of the own price elasticity of demand for the considered inputs. This suggests that in the case of an imposition of an ad valorem tax, a reduction of those inputs would occur adopting less intensive technologies.

SAHA et al. (1997) further advanced the Lichtenberg and Zilberman approach. They argued that functional forms like Cobb-Douglas or translog require all inputs to be strictly positive. However, in the case of damage control zero inputs but positive outputs are plausible. Other functional forms like the quadratic or generalized Leontief can accommodate zero input levels on the one hand. On the other hand, both specifications imply that inputs have no effect on output variance. In the case of pesticides which are used to reduce potential losses it is unlikely that their use has no effect on the output variability. The study proposes a production function comprising a vector of direct production inputs and a vector of damage control agents: $Q = F\,[Z, G\,(X, z)]$, where z = a subset of direct production inputs enters the abatement function. This specification allows a subset of inputs (z) to have dual roles – in the direct production function and the damage abatement.

Various forms of production functions have been tested. Results are in support of Lichtenberg and Zilberman that incorrect model specification leads to substantial overestimation of pesticide marginal productivity. The authors concluded that it is necessary to model pesticides and fertilizers differently from direct inputs with fertilizers having both direct and damage abatement effects. If this is not the case, overestimation of marginal productivity of damage control inputs and interactive inputs occurs.

The discussion on the various attempts to incorporate pesticide in production functions shows that as long as the functional relation between pesticide input and its damage control impact are not properly analyzed, it is difficult to infer the correct specification of the production function. However, results of these empirical analyses suggest that treating pesticides only as a direct input factor tend to overestimate marginal productivity of pesticides. Empirical findings of the early studies on pesticide productivity contributed to the overall positive picture pesticides gained in the past.

3.2 The Special Role of Pesticides in Economic Analysis

3.2.1 Benefits and Costs of Pesticide Use

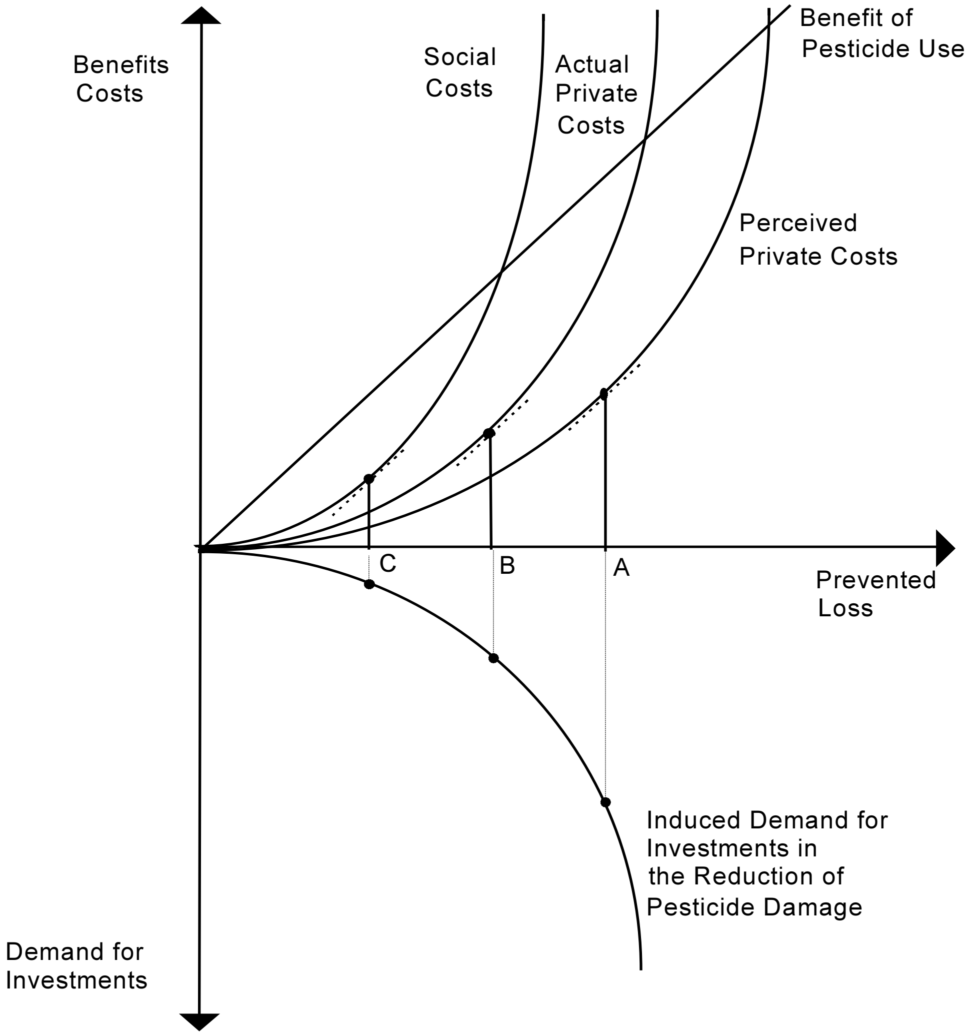
Neoclassical theory holds that farmers use pesticides like other inputs, in other words up to the point at which marginal productivity equals the factor price. This conclusion is largely based on the assumption that producers have complete and instantaneous information and that adjustment is without cost. In practice, however, these assumptions are not tenable in the case of pesticide use. Empirical studies have shown that farmers overuse pesticides from a private economic point of view (ROLA and PINGALI, 1993, KENMORE, 1996). These findings reflect that farmers are confronted with asymmetric information regarding the productivity impact of pesticides, and that decisions relating to pesticide use involve a higher degree of subjectivity than for other inputs.

Considering the social costs and benefits of pesticide use, in the absence of accurate measures of crop loss, measurement of the benefits of pesticide use is limited to rough estimates at the farm, national and international levels. Estimation of the social costs of pesticide use, including damage to human health and the environment and the destruction of biological control agents, is even more complex. Scientific research on the impact of pesticides on the environment, on chronic health effects is still in its infancy.

Policies at the national level have a strong influence on the economics of pesticide use. Several factors point to ongoing incentives for pesticide use resulting from these policies. A distinction can be drawn between price factors, institutional factors and information factors (WAIBEL, 1998). Price factors are measures which are visible in the pesticide market and directly affect farmers' demand for pesticides. Institutional factors include those factors which increase pesticide use due to misguided government activities to mitigate environmental and health damage resulting from pesticide use rather than preventing those costs by limiting pesticide use. Often there is a lack of information and transparency in the decision making process. The establishment of regulatory institutions aims at registration, restriction or even banning of chemical compounds. If these institutions are non-existent or ineffective pesticide prices are reduced. Among information costs there are the costs leading to unrealistic crop loss estimations due to inappropriate research designs and the persistence in static concepts (WAIBEL, 1994).

The individual farmer applies pesticides to the level at which he or she believes net benefits are maximized. As pesticide use aims to reduce crop loss, maximizing net benefits implies that the marginal value product of pesticide use is equal to the prevented crop loss in monetary terms. This is shown in Figure 3.1 as Point A. Farmers make subjective assessments of potential crop loss, the effectiveness of the chosen control method and the costs associated with this method *(perceived private cost curve)*. However, farmers face information constraints with regard to the potential for crop loss and the effectiveness of control measures, resulting in overuse of pesticides. Better information on these variables would bring about an adjustment of the farmer’s subjective assessment of preventable loss and private costs. As a result, the private cost curve would shift to Point B in the figure, thus increasing the farmer’s net returns as denoted by the distance between the cost *(actual private cost curve)* and the benefit curve.

Figure 3.1: Private and Social Optimum of Pesticide Use



Source: WAIBEL, 1994

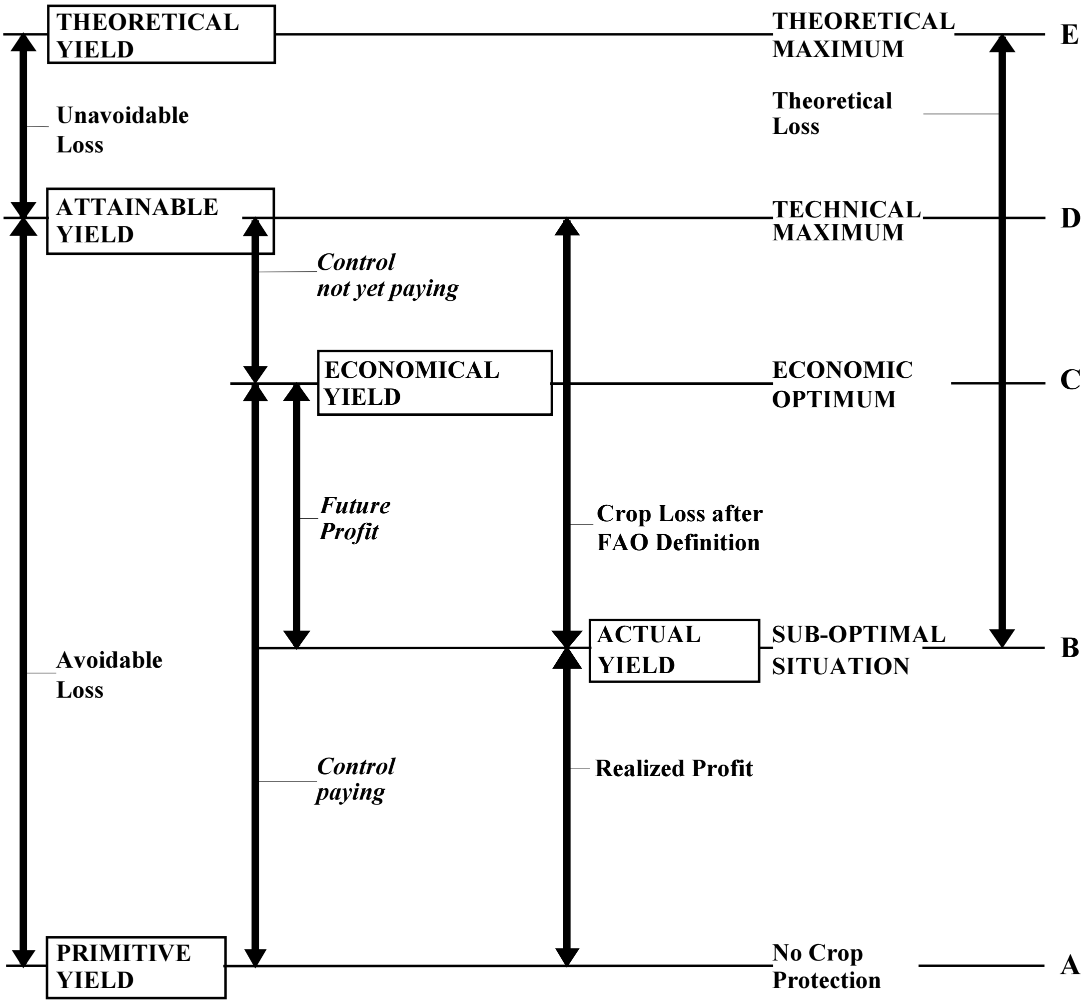
Society’s goal is to maximize net social benefits. Because of the external effects associated with pesticide use, net social benefits are lower than net benefits accruing to the individual farmer. The individual farmer does not take into account the costs imposed by these externalities and the implied mitigation costs. When these negative externalities are included, the cost curve shifts upwards *(social cost curve)* and reduces the optimum level of pesticide use to Point C. Pesticides will therefore be used at levels that exceed the social optimum. The costs associated with negative health effects and environmental degradation exceed the social benefits associated with prevention of crop loss. Costly public investment in additional mitigation efforts, such as residue monitoring, health care facilities and farmer training programs, is also required (AGNE et al., 1995).

3.2.2 Crop Loss and Economic Analysis

Typically, crop loss is assessed on the basis of trial data obtained from research stations. Often a comparison is made between a 'no spray' plot and a 'maximum protection' plot. This common method of assessment ignores the great temporal and spatial variation in incidence of pests and diseases. Loss estimates for the same chemical and crop, therefore, vary substantially depending on planting times, plot selection and prevailing pest populations and disease incidence in the specific season selected for study. WAIBEL (1998) points out that crop loss assessment often is derived from unrealistic trial designs and loss data from extreme situations. For example, many experiment stations are continuously cropped at high levels of input use, factors conducive to the build-up of pest populations. An example for such generalized crop loss assessments are the trial data published by OERKE et al. (1994) where crop losses have been calculated on the difference between technical maximum yields and actual yields obtained by common practice. The resulting estimates of crop loss do not account for the wide range of yield constraints that are unrelated to pests and diseases, including soil structure and fertility, sunlight, water control, plant density, and so forth. In economic terms, 'maximum protection' is unlikely to coincide with profit maximization. In addition, comparisons frequently ignore the incorporation of non-chemical management methods that may be more economically efficient.

Figure 3.2 presents an overview of different estimates of yield and potential loss, and the relationship between yield and loss. Level A represents the situation in which no control methods are used. This is referred to as 'primitive yield'. The difference between the theoretical yield (E) and the attainable (i.e. given currently available technology) yield (D) represents an unavoidable loss. The attainable yield does not consider economic factors such as the economic returns to control measures. The economical yield (C) therefore differs from the attainable yield since unprofitable control measures are removed. Factor and output prices play a role in the determination of the economical yield. Costs exceed returns for every control method applied above the economic optimum.

Figure 3.2: Theoretical Determination of Yield and Loss Levels



Source: Zadoks and Schein, 1979

Results of crop loss assessment remain controversial. In Asia studies have shown that intensive rice production systems can be managed cheaply and effectively without recourse to chemical pesticides. An economic study conducted by Rola and Pingali (1993) in the Philippines, for example, found that insecticide use in rice turns out to be uneconomical in most cases. Nevertheless, chemical companies, national and international research organizations continue to come up with high estimates of crop loss in rice. These results depend largely on the objectives of the studies in question and the methodologies adopted (Teng, 1990). Furthermore, Wossink et al. (1998) pointed out that the economic profitability of crop loss measures cannot be concluded from crop loss estimates as it is unknown whether current protection levels are efficient.

3.2.3 The Importance of Risk in Crop Protection

Farmers' pest management practices, their perceptions of control options and their objectives influence management practices (MUMFORD and NORTON, 1984). Since farmers' perceptions of potential loss are subjective, pesticide use decisions involve both risk and the farmers' subjective probabilities on possible outcomes of an action. Agricultural decisions involve uncertainty since yields and profits depend on unpredictable factors like weather, pest populations and disease incidence, product prices and interest rates. The farmer is able to assign subjective probabilities to the outcome of these factors (a priori probabilities). He knows the consequences resulting from the combination of one decision alternative and the environmental factor and is valuing them according to his personal expected utility (BRANDES et al., 1997). ANTLE (1988) highlights two characteristics of uncertainty in pest management:

(a) productivity of pest management inputs depends on a random event - the presence of the pest; if the pest occurs, the input has an effect on production,

(b) because the productivity of pest management depends on the pest population, pest management systems often involve information gathered over time[23].

The individual farmers' risk attitude will affect his or her decisions concerning pest management. Risk attitudes concerning pest problems can lead the decision maker into different directions and management decisions. A risk averse person may try to achieve a certain minimum yield or minimize yield variance. Uncertainty about some variables like pest occurrence, pest density and pest mortality lead to a higher pesticide use under risk aversion in order to save the expected yield (FEDER, 1979).

On the other hand there are also uncertainties about product prices and the expected yield, which may influence the profitability of pesticide use in such a way that pesticide use would have to be reduced[24]. A risk averse farmer may

---

[23] *"A fundamental difference between neoclassical efficiency analysis and the analysis of efficiency under uncertainty is that in the former case the welfare loss from inefficiency depends on the firm's technology and prices. Under uncertainty, efficiency also depends on the firm manager's risk attitudes as represented in the utility function."* (ANTLE, 1988, p.31).

[24] PANNELL (1991, p. 361) concludes that *"risk does not necessarily lead to increased pesticide use by individual farmers. Uncertainty about some variables, such as pest density and pest mortality does lead to higher optimal pesticide use under risk aversion. However, uncertainty about other important variables, such as output price and yield, leads to lower optimal levels of pesticide use. Neglect of these variables in most studies has led to the false assumption that pesticides are always risk reducing inputs."*

try to minimize yield variance, leading to a higher level of pesticide use depending on knowledge of non-chemical management methods. However, risk aversion could also lead to reduce expenditures on crop protection.

As discussed above, farmers do not possess complete *ex ante* information relating to infestation levels, pesticide efficacy and the efficacy of other pest and disease management strategies. Farmers also lack information on end of season market prices. Farmers, therefore, rely on subjective estimates of these variables in making cultivation decisions[25].

The value of controlling a pest, whose incidence varies in an uncertain way, is greater than the average loss caused to them by the pest. Farmers are willing to pay an insurance premium to reduce risk (TISDELL et al., 1984). HEADLEY (1985) concludes that farmers are interested in minimizing the variability surrounding returns and yields. Tradeoffs exist between expected net returns and year to year variability of returns. A high variability in net returns from year to year may induce a risk averse farmer to select a pest management system with more certain outcome even with lower average returns. In the case of soil conservation technologies, KRAMER et al. (1984) found that profit maximization and risk aversion were the most important criteria determining the choice of the technology. However, several studies suggest that there is not sufficient evidence to conclude that pesticides reduce risk (PANNELL, 1991).

KAHNEMAN and TVERSKY (1979) note that people tend to select alternatives that reduce the likelihood of an absolute loss even in cases in which these alternatives are not strictly rational[26]. In other words, losses are weighted substantially more than objectively commensurate gains. This heuristic rule, referred to as 'loss aversion', is also relevant to crop protection. Farmers, seeking to avoid losses due to pests and diseases, may make pesticide use decisions that are not instrumentally rational given their own assessments of the probability of crop loss. In fact, this behavior may result in a potentially more risk positive attitude towards the use of pesticides.

---

[25] These subjective estimates are based on several sources of information. The role of information with regard to pest control is discussed in section 3.2.4.

[26] KAHNEMANN and TVERSKY (1979) distinguish between three effects describing 'irrational' decision making in a utility maximizing framework:

(a) Certainty Effect describing that *"people overweight outcomes that are considered certain, relative to outcomes that are merely probable [...]"* (p. 142)
(b) Common Consequence Effect describing the fact that people act risk averse with regard to losses but risk positive with regard to gains.
(c) Isolation Effect describing that the order of influencing factors leads to varying preferences.

Loss aversion may explain why some farmers persist in applying pesticides even when these applications are no longer profitable. Anxious to avoid loss, these farmers act as if pesticides provided a form of 'insurance' against loss, and make decisions without considering the marginal cost of each additional application.

For pesticide use in Thailand, biased information and perceptions play a vital role as shown in the previous chapter. However, as the purpose of this study is not to establish once more the influence of risk on farmers' decision making, this aspect is omitted from the case study analysis[27].

3.2.4 The Role of Information

One important source of uncertainty in agriculture is the sequential nature of agricultural production. Decisions made before the cropping or planting season begins or early in the season affect outcomes. These outcomes can only be assessed on the basis of subjective probabilities. Farmers' investments in land preparation, seed and fertilizer are based on their predictions relating to factors including weather, pest and disease incidence and output prices later in the season.

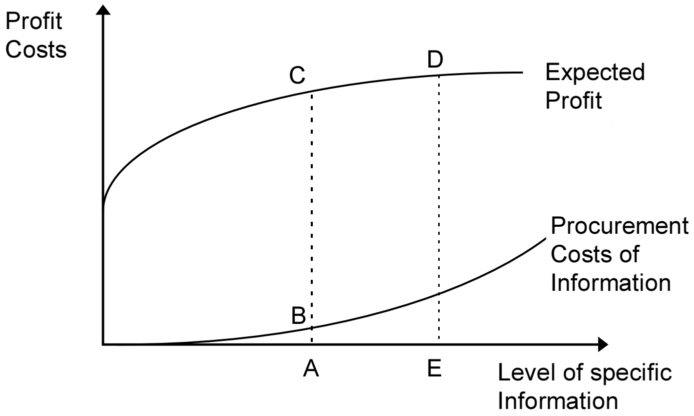
Although uncertainty is a fact of life, better information can help farmers to improve their decisions. However, information is not free of charge. Gaining access to information involves costs in the form of money or time.

An illustration of the effects of the relationship between information and productivity is given in Figure 3.3. If a specific information would be free, producers would use information up to Point E and thus maximize expected returns. However, if costs are involved in obtaining and using information the optimal level of information is represented as Point A. Here the difference between the expected returns and the cost of information is greatest (C-B). Uncertainty in the production process increases the value of information insofar as information reduces the likelihood of sub-optimal decisions. However, the productivity impact of information will also depend largely on the initial situation. For example, if farmers already have reasonable estimates of the likelihood of crop loss, small increments in information will have a negligible impact on net returns. Farmers who consistently overestimate potential crop loss will stand to gain more from modest improvements in the availability of accurate information.

---

[27] Risk aspects of farmers' decision making process in Thailand were mentioned in section 2.1.3.7.

Figure 3.3: The Optimal Level of Information



Source: BRANDES and ODENING, 1992

The incorporation of information costs into economic models of crop management decisions is not as straightforward as it may appear at first glance. One reason for this is the close relationship between information and instrumental rationality. Commonly, the rationality assumption maintains that sub-optimal decisions are attributable to information constraints, and that in the presence of perfect information farmers always maximize expected net benefits. However, it can be questioned whether information constraints always provide an adequate explanation of sub-optimal outcomes. Loss aversion is one example of sub-optimality that is independent of the availability of information[28].

The latter view is supported by the study of CARPENTIER and WEAVER (1997b) analyzing the ways in which farmers use information relating to pest populations. They observed that farmers do not use the information generated during the production process to update their beliefs concerning pest infestation, in fact they behave relatively static in their crop protection method over time. As a result, farmers fail to adapt pesticide use to actual field conditions. Information can be substituted for pesticides depending on its relative costs and availability and the perceived utility of the farmer.

PEARCE and TINCH (1998) describe a situation where imperfect information about the future leads firms and regulators to be overly comfortable with the status quo, leading to inefficiently low levels of investment in research and extension on alternatives to pesticides.

Another problem is the quality of the information available. Information relating to crop protection, for example, varies significantly depending on the source.

---

[28] Refer to section 3.2.3.

Private companies targeting to increase sales volume present farmers with specific product information, promoting the quality of their products. Government crop protection agencies likely overestimate crop loss in order to minimize the perceived severeness if a pest outbreak actually occurs. Such biases in the information ‘market’ raise the costs of obtaining accurate and complete information.

The discussion suggests that information plays a vital role for the decision making in crop protection. Information is one way to reduce risk in agriculture and it improves decision-making. However, as has been argued in the last paragraph, the usefulness of the information depends on its quality. Especially in crop protection biased information on crop losses and pesticides benefits influences farmers' decision[29].

3.3 Relevance of Path-Dependency in Crop Protection

3.3.1.1 Resource Costs of Pesticide Use

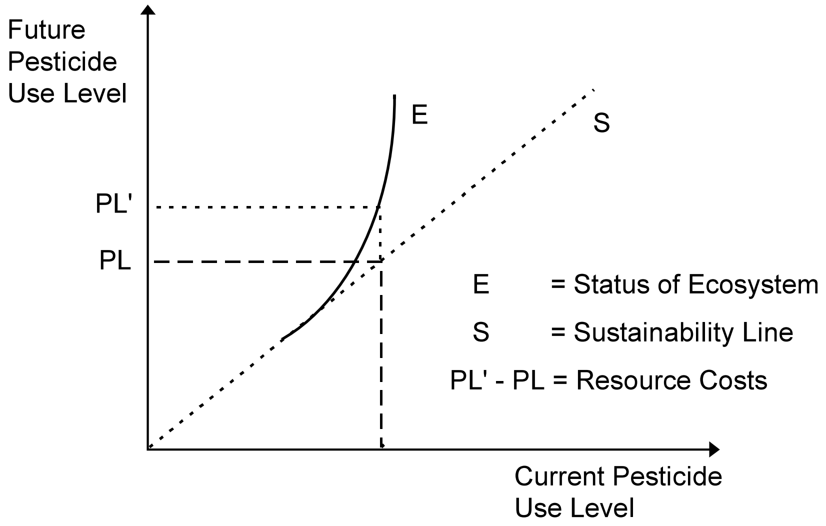
Another factor that has to be taken into account refers to the status and the development of the ecosystem within which beneficial organisms can serve as an important natural control factor. Since pesticides destroy biological control agents and induce pesticide resistance and resurgence, the economics of pest control are best viewed within a dynamic framework that includes pesticide use in earlier periods.

Figure 3.4 illustrates resource costs associated with pesticide use. The level of pesticide use today has an influence on the status of the ecosystem. The ecosystem is changing from a balanced line of sustainability to a curve indicating the existence of resistance and resurgence. To prevent a similar crop loss as in previous periods pesticide use levels must increase or else more and therefore more expensive effective pesticides have to be used. The difference between the level of pesticide use today (PL) and the level in the future (PL') can be called the resource costs.

---

[29] Section 2.1.3.6 discusses information regarding pesticide use in Thailand while section 4.2.2 discusses information with regards to tangerine production in the survey area.

Figure 3.4: **Resource Costs of Pesticide Use**



Source: based on WAIBEL and SETBOONSARNG, 1993

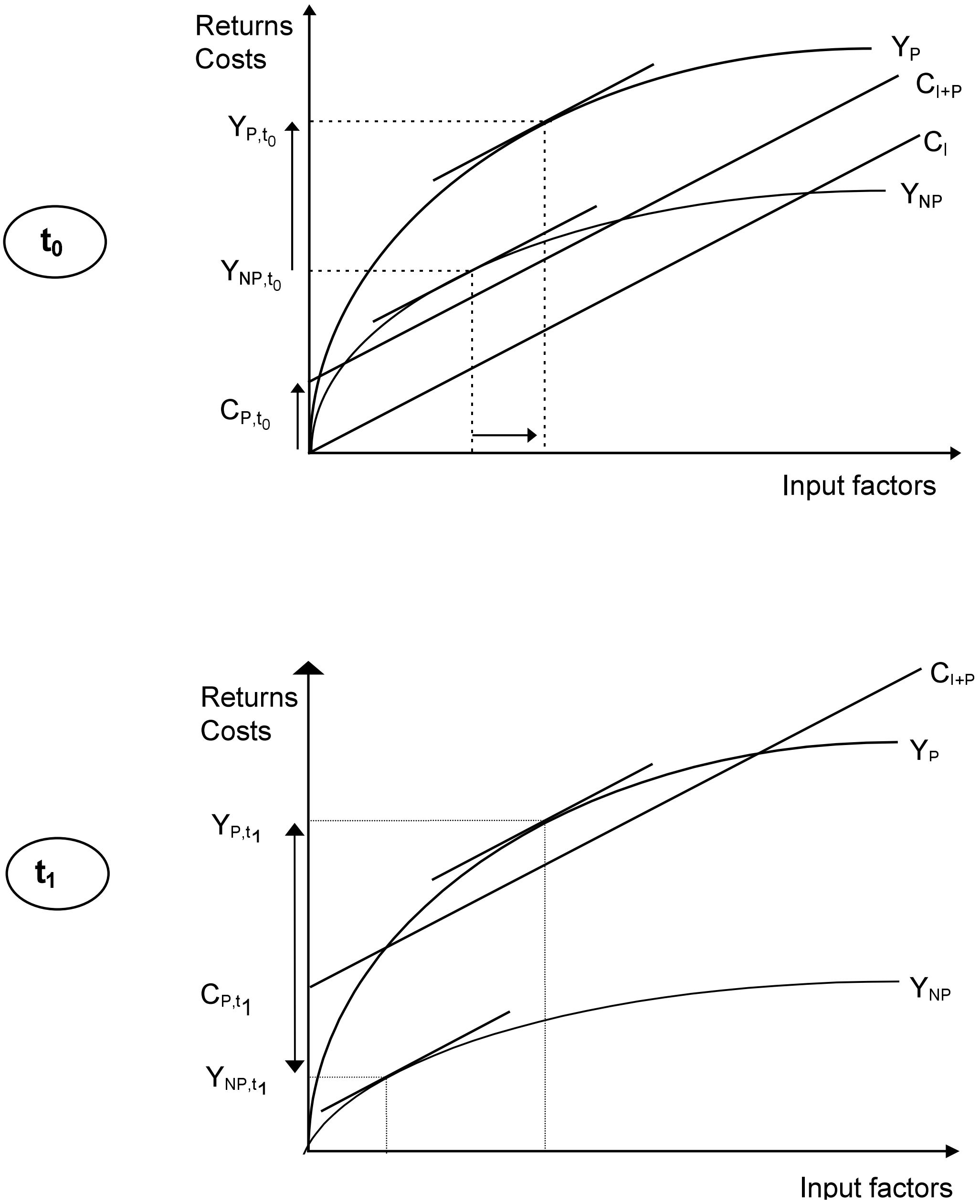
Because pesticides lead to pest resistance, pesticide use in earlier periods reduce their effectiveness in later periods. LICHTENBERG and ZILBERMAN (1986) argue that the standard characterization of this phenomenon is that farmers' typical short-run response to the development of resistance to some pesticides is to increase usage level as compensation for the decrease in pesticide productivity. Thus, an environmentally induced decrease in productivity of a factor will increase demand for it. However, if pesticides were never used, potential crop loss - and hence returns to pesticide use - would be lower. Thus, analysis of the costs and benefits of pesticide use in static terms consistently leads to an overestimation of the benefits of pesticide use.

In Germany's agricultural sector it has been shown that farmers' pesticide expenditures are time-dependent, i.e. the level of pesticide use in prior periods is positively correlated to current levels of use (WAIBEL and FLEISCHER, 1998). In extreme cases such as tropical cotton production, pest resistance can render entire cropping systems unviable (COWAN and GUNBY, 1996).

Figure 3.5 illustrates the problem. With repeated pesticide use, the yield difference between treated and untreated fields increases. Y_P represents a production function using pesticides while Y_{NP} represents the production without pesticides. Pesticide use in previous periods has increased potential yield loss attributable to insect pests. This induces a shift in the input cost curve. As long as the difference in revenues is greater than the cost increment, application of additional pesticides will pay off. Thus, pesticide dependency makes it appear as if there has been an increase in the marginal rate of return to pesticide use. The farmer focusing on short-term maximization of profits is acting myopic as he is not realizing or ignoring long-term effects. The path entered by the farmer can be called a permanent path-dependence (BRANDES et al., 1997).

Pest resistance and resurgence increase control costs and change the relative combination of input factors in favor of higher levels of pesticide use. If technical progress is included in the model (for example, in the form of high yielding varieties) the production function Y_P shifts upwards in t_1. Despite the increasing share of pesticides in total costs, use levels will continue to rise as long as revenues increase.

Figure 3.5: Costs and Returns of Pesticide Use in Current (t_0) and Subsequent Period (t_1)



Y_P = returns with pesticides
Y_{NP} = returns without pesticides
C_I = costs of input factors
C_{I+P} = costs of input factors and pesticides
$Y_{P,\,t_0} - Y_{NP,\,t_0} < Y_{P,\,t_1} - Y_{NP,\,t_1}$

Source: WAIBEL and SETBOONSARNG, 1993

3.3.1.2 The Concept of Path-Dependency in Relation to Pesticide Use

Path-dependency provides an explanation for economic systems that stabilize at different equilibria because of past development paths (BRANDES et al., 1997). In a path-dependent economic sector it is likely that inferior technological standards or structures dominate (BALMANN and HILBIG, 1998). ARTHUR (1989), FARELL and SALONER (1985) and KATZ and SHAPIRO (1985) developed models in which every agent acts rationally, yet an inferior technology dominates the market (COWAN, 1991). Recent studies showed that the phenomenon of path-dependency also applies to the agricultural sector (BALMANN, 1995; BRANDES, 1995, COWAN and GUNBY, 1996). Decisive for a 'locked-in' situation is that the costs of changing to another system are high. The existence of sunk costs, increasing returns to scale and network externalities are generally regarded as reasons for path-dependency[30].

Sunk costs, e.g. for the introduction of a new technology, can result in temporary path-dependency as the costs involved are incurred in the past and can no longer be regained. Adjustments will only take place in the long run, i.e. when the asset has to be replaced. **Increasing returns to scale** induce positive strengthening of the option chosen. In the case of agricultural production REICHELDERFER (1981) names two sources of increasing returns to scale. First, the majority of total costs are fixed costs and the fixed costs per unit of output fall as the size of the facility increases. Second, there will be payoffs to gaining experience in the production process. DOSI (1997) argues that the very possibility that agents can obtain new information and knowledge through their own actions already implies some form of increasing returns.

Network externalities are positive feed-backs between parts of a system induced through interactions[31]. In the case of crop protection, network externalities exist e.g. due to the importance of information from other adopters, the technology itself causing externalities to other users and non-

---

[30] According to BALMANN (1995) a dynamic system can be called path-dependent if it (i) moves towards a local optimum either in dependence of its starting point or due to exogenous factors and (ii) the system is not able to leave the local optimum towards a global optimum over a longer period.

[31] KATZ and SHAPIRO (1985) define network externalities such that the utility of a user deriving from consumption of the good is increasing with the number of other agents consuming the good. This can be adapted to other externalities e.g. that product information is more easily available for more popular brands or that the market share of a product may serve as a signal of product quality. LIEBOWITZ and MARGOLIS (1994) use the term network externality for a specific kind of network effect in which the equilibrium exhibits unexploited gains from trade regarding network participation.

users and increasing payoffs if the technology is adopted by all farmers of an area simultaneously.

COWAN and GUNBY (1996)[32] state that systems operating under the aspects of technological externalities, learning and uncertainty reduction share three features: (i) path-dependency, in the sense that long-run equilibrium can be changed by historical events along the path to it; (ii) inflexibility, in that during the process the ability to affect the final outcome decreases and (iii) the possibility of remaining in a technology that does not provide maximum payoffs.

COWAN (1991) gives an example of technology choice without uncertainty. Assume that two technologies, A and B, are available to perform the same task, and both are subject to increasing returns to adoption. The source of increasing returns in this case is learning, so the net benefit of the next adopter increases with the number of previous adopters of the technology. Each period one consumer adopts one of the technologies. His decision is irrevocable. He receives a payoff defined as the present value of the net benefit of his use of the technology. Assuming that the first adopter in the market will adopt technology *A.* The second adopter will either be the second adopter of technology *A* or the first adopter of technology *B.* Increasing returns to adoption imply that the second adopter prefers technology *A.* All adopters, therefore, choose the same technology, because of a higher initial payoff. The government can intervene in this process by subsidizing one technology and thereby increasing its payoff. This simple model can be specified by looking at technologies without certain payoffs. ARTHUR (1989) concludes that in the case of increasing returns there is no guarantee that the superior technology will dominate the market. A technology, that gains an early lead in adoption, may eventually dominate the market of potential adopters with the other technologies becoming locked out. This example of technology choice applies also to crop protection methods. The farmer can choose between different technologies, broadly this can be limited to two options: the application of pesticides and inclusion of crop protection alternatives. Increasing returns to adoption exist for the chemical crop protection technology due to its strong promotion. BALMANN (1995) points out that there exists additional path-dependence in the selection of research foci as well as in the development of new technologies. How a sector may develop is dependent on the number of

---

[32] See also ARTHUR (1989, p.125).

firms accepting the research risks and which advantages or disadvantages are involved in the development of new technologies.

Payoffs of the different technologies are only partly known and differences between knowledge levels do exist due to unbalanced knowledge gains in the technological choices and due to differing availability of the technologies over time. When the adoption process begins, the benefits of the technologies are not known. The system can now lock into one technology due to reduction in uncertainty or due to the fact that one technology was earlier present in the market. The 'possibly inferior technology' to be chosen requires first that the estimates of the benefits of the 'possibly superior technology' are low. It may occur that the inferior technology will continue to be used and beliefs about it will be taken as truth. Because the superior technology is not being used, the assumptions about it do not change (COWAN, 1991) and research focus targeted towards the 'possibly inferior technology' does not help to change those assumptions. The winning path of a 'possibly inferior technology' can be applied to crop protection. Chemical crop protection, which has been promoted for a long time, has an information advantage over alternative technologies. As the negative implications of this technology appeared with a time-lag, the technology choice was already set and discrepancies between chemical crop protection and alternatives (i.e. Integrated Pest Management, IPM[33]) seemed to be extremely large. As other methods have not been used intensively assumptions about their benefits could not change. While chemical crop protection underwent continuous improvement, other methods have not been developed accordingly. One can, therefore, speak of a path-dependency in the political and institutional dimension of chemical crop protection[34].

Another aspect to increase the probability to become locked-in to one technology are increasing returns. The inferior technology only has to be used until it gains an advantage in gained knowledge. The stronger the increasing returns are the easier the knowledge gain is reached. This also applies to the crop protection issue. There is uncertainty about the exact benefits of switching to IPM measures and the learning lead of chemical crop protection is

---

[33] Integrated Pest Management will be used in the following to describe crop protection methods including non-chemical control measures. WAIBEL and ZADOKS (1996, p. 2) define IPM as a crop protection system which is based on rational and unbiased information leading to a balance of non-chemical and chemical components moving pesticide use levels away from their present political to a social optimum defined in the context of welfare economics.

[34] Sections 2.1.4 and 2.1.5 discuss political and institutional attention chemical crop protection has gained in Thailand.

extremely large - not at least due to strong political promotion. COWAN and GUNBY (1996, p. 530) propose that

> *"the theoretical literature predicts that under these circumstances [increasing returns] the history of pest control should contain important key events that shift the process onto one or another path. It should also be true as the process develops, the chosen path becomes entrenched, and it becomes difficult to change the system to another technology. Finally, the theory presents the possibility, that had the dominant technology been discarded earlier on, and the other developed, aggregate payoffs to users would be higher."*

In addition, in the case of crop protection more aspects than increasing returns and uncertainty between technology choices are of importance. The technologies themselves do influence the system, and therefore the choice of the farmer in one period is not unaffected by choices in previous periods. Furthermore, uncertainty is also related to climatical conditions in specific years. A technology which makes it possible to react immediately to pest or disease outbreaks appears preferable. Yet, these outbreaks sometimes are results of the technology choice itself (i.e. pest resurgence).

It has been discussed from a theoretical point of view that path-dependency plays an important role in the development of crop protection methods and current prevalence of chemical crop protection. Path-dependency can exist on several levels: on the farm level, in marketing channels, the institutional and organizational framework and political priorities. Their role in the historical development of crop protection situation, policies, research and farm level orientation cannot be underestimated. It is suggested that path-dependency is a relevant concept to explain the development of pesticide use in citrus in Thailand. The survey data will, therefore, be analyzed regarding indicators for the existence of path-dependency[35].

3.4 Economics of Pesticides in Perennial Crops

3.4.1 Production Aspects

Beside the specialties of estimating pesticide productivity, pesticide use and other crop protection measures in perennial crops differ in three aspects:

---

[35] In chapter 2 path-dependency aspects have been described on the political and organizational level, while section 6.3 focuses on their analysis in citrus production.

cultivation aspects, aspects of technological change and nature of crop losses[36].

Commercial production of perennial crops is often done in monoculture systems. Pest pressure in monocultural cultivation can be regarded as generally higher than in mixed cropping systems. Monocultural perennial systems, therefore, tend to have a high external inputs demand. The perennial nature of the crop increases further the likelihood of more susceptibility to pests and diseases as little cropping change is possible for a period of at least fifteen years. Normally, even after one cropping cycle the same areas are replanted with the perennial crop thus steadily increasing degradation of natural conditions. The production of perennial crops requires special knowledge. Cultivation mistakes of one year may have negative results for several following cropping years (e.g. the greening disease and its possible control through proper orchard maintenance).

The cultivation of perennial crops often takes place on high intensification levels. Intensification in maximizing the amount harvested per year as well as the number of harvests per year. As in tropical regions the production cycle of various crops is not determined by a low temperature season, crops which naturally allow more than one harvest per year, as for example tangerines, are pushed towards multiple harvests. With an overall more intensive production, the level of pesticide use is likely to also increase to accommodate multiple harvests.

Several aspects of the production of perennial crops require good knowledge of the production system and production possibilities. However, perennial crops are often plantation crops and are cultivated with a high number of laborers. The farmer himself, likely to have access to information and knowledge, is mostly not the person conducting the work on the plantation. Thus, routine spraying of chemical pesticides becomes an easy method of pest control. It is easy to monitor and it is easy to advise to farm workers. Other crop protection methods would require much higher inputs in monitoring and explaining by the farmer. As pest problems occur all year round, routine spraying becomes an easy method of crop protection. Calendar spraying is easy and can be done by farm workers while pest monitoring and consideration of the special pest situation requires more knowledge, depends on the farmer himself and is more time-consuming. As often the farm workers

---

[36] This section takes strong reference to the tangerine production system observed in Thailand. It, therefore, does not claim to be applicable for all perennials produced in monoculture.

are seasonal workers, the incorporation of other than chemical crop protection methods incorporates higher information costs to the farmer as he might have to advise several persons and cannot necessarily rely on knowledge gains.

Among the aspects of technological change there is the short to medium term locked-in a fixed production system. Production system defines the planting material and planting distances as well as the lay-out of the production site. Once having started with planting the perennial crop, the farmer usually sticks to the chosen system of production for the next decade. Therefore, a farmer producing perennial crops is not as flexible as farmers with annual crops. Improvements in planting material, new research findings or new production technologies can only be adapted with a time-lag. Flexibility within the cultivation period is low. No shift to other crops is possible if production problems become severe. This temporally remaining in the productional set-up draws attention to the variable inputs. Problem solving strategies are, to a much higher degree related to variable inputs, especially pesticides.

Pest pressure is believed to be mainly controlled by the use of chemical pesticides. Here, new technologies can be easily adapted and the use of chemical pesticides appears to be a quick short-term solution for the occurrence of pests and diseases. Adjustments of the production system are most likely only taking place if production becomes impossible. This phenomenon has been described by COWAN and GUNBY (1996) for the development of the citrus sector in Israel.

3.4.2 Productivity Aspects

Generally, the productivity of a system (P) can be expressed as a function of natural and climatical conditions (NC) as well as a set of input factors (I) and management strategies (MS). The demand for pesticides (PD) is determined by the output productivity itself, the management system chosen, the pest density (PE), the farmer's assessment of benefits (PA) as well as the pesticide policy directions (PP). The concept of path-dependency (D)[37] can be expressed by the development of pest pressure over time (PE_t), the intensity of pesticide use (P_{MS}), the intensity of extension (E) as well as the option for and the knowledge about adjustment and costs of alternatives (A). These

---

[37] While recognizing that the concept of path-dependency does not entail a measurable factor, it will, if relevant for the crop, have a considerable impact on pesticide demand and the productivity of the production system. Therefore, it has been highlighted in the function as an influencing factor, especially for perennial crops.

three aspects determine the production system and are summarized as follows:

$$P = f(NC, I, MS)$$

$$PD = f(P, MS, PE, PA, PP, D)$$

$$D = f(PE_t, P_{MS}, E, A)$$

For the economic assessment of tree crops, however, it is especially relevant to consider the development of yields over time. When focusing on tree crops one has to consider the perennial nature of trees. Yields are depending on the age of the plantation (age-yield function).

The following general characteristics of the biological yield development of fruit tree crops over time have to be considered when estimating the relation between age and yield (HAWORTH and VINCENT, 1977; WESSELER, 1997):

- zero production during the initial years,
- rapid rise to maximum yield,
- constant yields over a number of years,
- final period with declining yields.

The fact that output is highly depending on the age of the perennial crop makes it more difficult to estimate the productivity of inputs. If the yield-age relation is not considered the productivity of inputs would seem to increase over the years. Thus, comparing the input productivity of orchards has always to be conducted with respect to plantation age. This also applies to pesticide inputs. Therefore, when conducting a production function analysis to take account of the perennial nature of fruit production it is necessary to integrate the plantation age into the function. If one would ignore this relationship in the production function analysis, the estimated production functions would belong to different age-yield relations. A cash-flow analysis of a perennial crop, therefore, should be estimated over the whole cropping cycle to take account of the yield development over time. The productivity of pesticide input, then, has to be judged in relation to the whole cropping period. If no time series data is available one can rely on estimations of age yield functions which are applying to the biological specialties of tree crops as listed above. HAWORTH and VINCENT (1977) estimated various functions and found that a semi-logarithmic function ('Hoerl' function) is able to picture the yield-age relationship in fruit tree crops[38].

3.5 Summary

The way analysts treated pesticides in the production function has changed over the last four decades. Whereas the early analyses concentrated on the direct influence of pesticides in the production process and concluded to high marginal returns of pesticide use, increasing concerns about pesticide use in later years made a reconsideration of the benefits of pesticide use appropriate. Later studies have treated pesticides as an indirect input to the production function with the argument that pesticides are loss preventing, but not yield enhancing factors. These studies corrected overestimated marginal productivity of pesticides. However, the questions of the appropriate variable in the production function for pesticide use and the appropriate functional form have not yet been resolved.

There are four arguments for a special role of pesticides compared to other inputs. Firstly, there are factors in the political and institutional set-up which support pesticide use. Secondly, the analysis of pesticide benefits and costs generally does not include external effects and the socially optimal level of pesticide use. Thus an environment is created where the actual private pesticide use level exceeds the optimum from a private user's as well as from the society's point of view. Reasons for the discrepancy between the actual benefits of pesticide use and the perceived benefits by the farmer are threefold. Crop loss estimates do mostly not consider an adoption process of the production system but focus on a “treat” / “no-treat” comparison. As no complete information is available in the agricultural production process, pesticides are seen as a tool to reduce the likelihood of pest infestations. The informational aspects stand in close relation to risk factors. As production includes risk and uncertainty, levels of pesticide use depend on the farmers' risk or loss aversion. However, risk aspects can be substituted by an increased procurement of information. The not seldomly biased information also influences the directions of farmers' decision.

Resistance and resurgence problems let pesticides appear to be a good solution for the prevention of additional crop losses. It is generally not taken into account or not sufficient knowledge exists, that pesticides themselves are

---

[38] The 'Hoerl' function and its regression results for the survey data are discussed in section 7.1.

the cause for many existing problems. The degradation of the ecosystem creates a situation in which, over time, pesticides are regarded as increasingly necessary.

The dynamic perspective of pesticide use, therefore, bears the danger to contribute to a pesticide intensive development path. This path-dependent development can be determined in research efforts on alternative technologies as well as in use decisions on the farm level.

Based on the economic theory of pesticide use, the following chapters concentrate on an economic assessment of current management strategies in citrus production. The hypotheses derived from the theoretical background for the analysis can be formulated as follows:

- Pesticides in citrus production in Thailand are used above their economic optimum from an private and social point of view.
- Cross-sectional differences in management strategies in citrus production regarding levels of input and especially pesticide use cannot solely be explained by economic maximization criteria.
- The citrus production in the central region of Thailand is in a situation of locked-in for pesticide use. Therefore, options for future management decision are limited and a pesticide dependent path is likely to continued.

To capture the complex nature of pesticides and variance of its use, a differentiation of the survey data according to management strategies seems necessary. This differentiation allows the comparison of structural homogenities within the groups while enabling to analyze differences between groups. It has been decided to use cluster analysis to structure the survey data into groups with different management strategies.

In the following chapters, pesticide use in citrus production will be analyzed and indicators presented that can document an over- and misuse of pesticides. The complex management system of citrus is discussed in the next chapter and clusters of management patterns will be identified. The last chapter will investigate the productivity of pesticides and indicators for path-dependency in crop protection of citrus production.

4 Citrus Production in Central Thailand

Among the many different citrus species, the study concentrates on Tangerine (C. reticulata), the most important citrus crop in Thailand in terms of product value. Major characteristics of tangerine production in the study area, a description of the current production system and its problems as well as pesticide use practices are discussed.

4.1 Development of Citrus Production in Thailand

Fruit production in Thailand has gained increasing importance in the last decade. Low prices for rice are relatively stable and high prices for fruit and vegetables can be seen as one reason for this development (SIAMWALLA et al., 1992). Currently around 37 species of fruit are commercially grown, among which citrus is of outstanding importance (BAUMANN, 1995). There are several citrus species grown in Thailand. The most popular are lime (C. aurantifolia), tangerine (C. reticulata) and pummelo (C. maxima)[39]. Of these, tangerine takes first place in terms of area and farm value. SETHPAKDEE (1997) states that 40% of the citrus planted and 76% of total citrus production are contributed by tangerine. Tangerine (in Thai: Som keaw wan) is considered a native species to Indochina and Southern China from where it was carried to Thailand around the 18th century.

Unlike other South-East Asian countries, fruit in Thailand comes mainly from commercial orchards rather than from homegardens (VERHEIJ et al., 1991). Fruit growing is regionally concentrated, partly due to climatic conditions, and partly to political factors[40]. An overview of the most important fruits in terms of farm value is given in Table 4.1.

---

[39] The name tangerine is often used synonymously with mandarin. Mandarins are the most varied group and can be classified into five groups: Satsuma (C. unshiu), mediterranean mandarin (C. deliciosa), king mandarin (C. nobilis), common mandarin (C. reticulata) and small-fruited mandarins (SPIEGEL-ROY and GOLDSCHMIDT, 1996).

[40] Refer to section 3.1.2 and 3.1.4.1.

Table 4.1: Thailand's Ten Principal Fruits by Farm Value (1992)*

Fruit	Planted Area (rai bearing fruit)	Production (t)	Farm price (Baht/kg)	Farm Value (Mill. Baht)
Durian	403,956	711,371	28.1	19,997
Mango	951,712	1,110,992	15.4	17,109
Rambutan	343,906	607,558	10.2	6,179
Tangerine	206,320	680,970	8.9	6,027
Tamarind	212,113	139,475	38.9	5,433
Longan	146,034	112,997	32.3	3,654
Banana	510,214	922,999	2.9	2,714
Longkong	38,464	47,079	55.2	2,598
Pineapple	566,870	2,228,854	1.1	2,541
Lychee	51,766	46,167	44.9	2,075

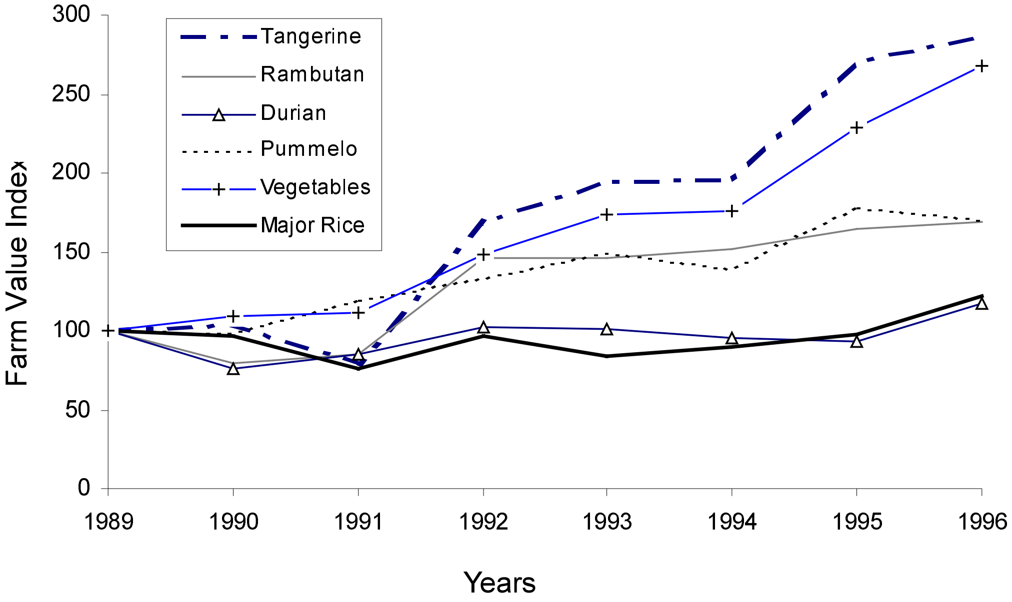
* More recent data are not available

Source: Thailand in Figures, 1995

The importance of fruit has increased in local markets as well as for export. The value of exports of fruit and fruit products increased to 17,075 mill. Baht in 1995 and makes up 4.2% of total agricultural exports (OFFICE OF AGRIC. ECONOMICS, 1997). In contrast to other fruits exports of tangerine are low since local demand is high. Approximately 90% of the tangerine production is for fresh fruit consumption, 5% is exported to neighboring countries and 5% is for industrial use (PARADORNUWAT, 1995a). Figure 4.1 pictures the development of the farm value index for selected fruits and vegetables. The index combines higher prices and increasing production.

Vegetables are summarized in one index. Increases of the index are highest for tangerine and vegetables. The index more than doubled in the last seven years. Rice stays on the same level over the years as does durian.

Figure 4.1: Farm Value Index of Selected Crops (1989 - 1996)*



* 1989 = 100

Major rice = rice harvested in the major rice growing season, some areas allow more than one rice harvest

Source: Office of Agricultural Economics, 1996

Table 4.2 gives an example of the main production locations of two important citrus fruits and their distance to Bangkok metropolitan area. Whereas the majority of tangerine is grown in the provinces directly neighboring the center area, for example only 30% of pummelo is produced in the center.

Table 4.2: Share of Production Areas of Tangerine and Pummelo in Distance to Bangkok Metropolitan Area*

Fruit	Area (rai)	Area (in percent)
Tangerine		
Region I	125,817	61
Region II	11,601	6
Region III	24,961	12
Total Planting Area	206,320	
Pummelo		
Region I	17,683	30
Region II	8,289	14
Region III	7,575	13
Total Planting Area	58,591	

* The region's number indicate the relative distance to Bangkok (smaller number indicate shorter distance) one major trading center for fruits

Region I: Bangkok, Nonthaburi, Pathum Thani, Nakhon Pathom, Samut Sakorn, Samut Prakarn, Nakhon Nayok

Region II: Chonburi, Sara Buri, Ayuthaya, Suphan Buri, Ratchaburi, Samut Songkram, Sing Buri, Ang Thong, Prachinburi, Chaochengsao

Region III: Rayong, Chantaburi, Kanchanaburi, Petchaburi, Lopburi, Nakhon Ratchasima, Nakhon Sawan Uthai Thani, Trat, Chainat

Source: Author's Compilations, DOAE, 1994

SETHPAKDEE (1997) states that most of the citrus fruit produced in Thailand are of medium quality and names several constraints to improved fruit quality: (i) the common practice to have several harvests a year assures regular income and minimizes the risk of low prices, however, (ii) it also prevents growing high quality crops as the management system is not targeted to one fruiting stage and (iii) furthermore, climatic influences increase the difficulties of high quality crop production.

SPIEGEL-ROY and GOLDSCHMIDT (1996) summarize accordingly that the main difficulties of citriculture in the tropics are the distortion of the productivity cycle and the resulting reduced fruit quality. In regions with high temperatures and humidity trees tend to flower sparsely resulting in lower productivity. While the uninterrupted high temperatures enhance fruit growth and maturation, certain aspects of fruit quality suffer like the internal quality and the development of a highly pigmented rind.

4.2 Tangerine Production in Central Thailand

4.2.1 Tangerine Production Pattern

At present, citrus species are grown in many provinces throughout Thailand. The main growing areas of tangerine are the central region and the provinces Chiang Mai, Phrae and Nan in the north. Former growing areas like Petchabun, Chantaburi and Surat Thani provinces do not produce citrus any more due to disease problems and a decline in production can be observed in the provinces of Phrae and Nan (BAUMANN, 1995). The largest and most important planting area is located in the central region, in the three provinces Pathum Thani, Sara Buri, Nakhon Nayok.

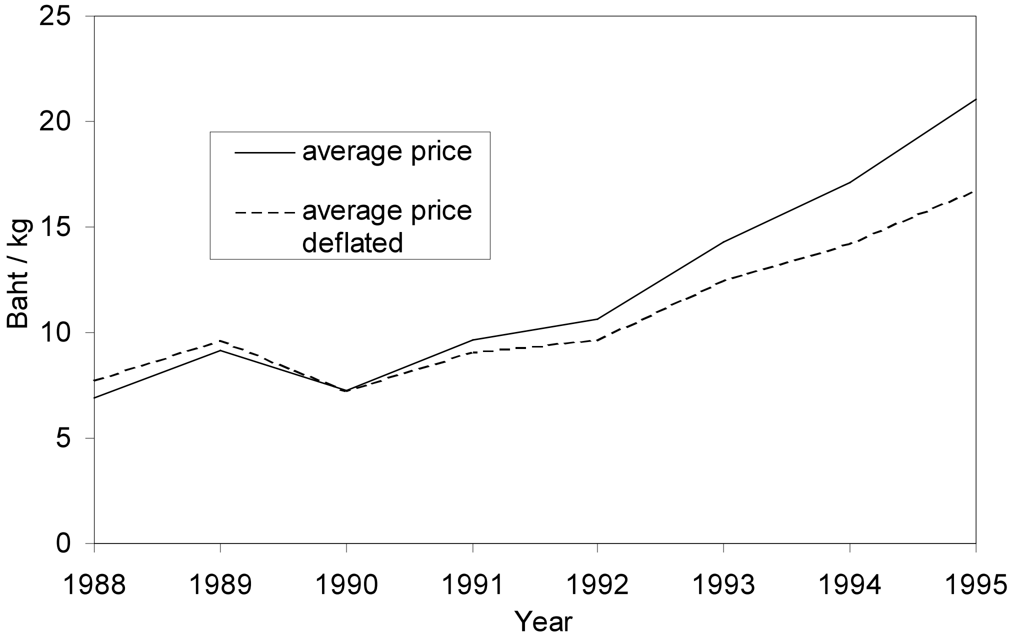
Table 4.3: Tangerine Production in Thailand per Region (1992)

Region	Planted Area (Rai)			Yield per Rai (kg)
	Bearing	Not Bearing	Total	
Northern	24,530	8,028	32,558	3,260
North-East	47	57	104	475
Central Plain	115,422	31,205	146,627	3,822
Eastern	36,559	4,016	40,575	2,432
Western	11,046	482	11,528	3,251
Southern	18,716	1,574	20,290	1,861
Whole Kingdom	**206,320**	**45,362**	**251,682**	**3,300**

Source: DOAE, 1994

Tangerine is a favorably consumed fruit in Thailand and has a special importance in religious festivals like the Chinese New Year. The average price for tangerine has been increasing continuously over the last decade (Figure 4.2). Viewed on an annual scale prices fluctuate from 17 Baht per kg up to almost 27 Baht per kg (Figure 4.3). Main harvest times are April/May and July. At these times prices are at their lowest. There is a peak in prices in February due to high demand for the celebration of Chinese New Year and limited fruit supply.

Figure 4.2: Tangerine Prices at Wholesale Market in Bangkok (1988-1995)



Source: Department of Statistics, 1996

Figure 4.3: Monthly Tangerine Prices (1995)

Source: Department of Statistics, 1996

4.2.2 Technical Aspects of Tangerine Production

The major characteristics of tangerine cultivation in the central region are listed below (PARADORNUWAT, 1995a):

- Trees are mostly grown by marcotting[41].
- Trees are planted on raised beds or small ridges between canals.
- Tree size is around 3 - 5 meters.
- The average life span of the trees is around 15 - 20 years if trees are healthy.
- Typical planting distance is 3 - 4 meters between plants and 7 - 8 meters between rows are common, adding up to around 40 - 50 trees per rai.
- Fruit production starts around 4 - 5 years after planting. One tree can have up to three harvests per annum. This implies several fruiting stages at the same tree simultaneously.
- Fruit size is small to medium with a green skin. The fruits are harvested after flowering around 9 - 11 months.

These major characteristics of the survey area have several implications for the development tangerine production in the area and the economic analysis of crop protection which will be discussed in the following sections. But beforehand, a short introduction on the technical side of tangerine production in the area is given.

Most of the work in the orchards is done manually. Mechanical operations include spraying of pesticides, fertilizer and irrigation. Steel boats are driven on the canals between the planted rows. These boats are also used for harvesting. In former times spraying was conducted with knapsack sprayers while now most farmers use boats equipped with spraying machines.

Orchards in the central region usually are converted paddy fields with a single row of trees planted on raised (cambered) beds flanked by ditches. This canal system has been introduced mainly due to regular flooding problems. The entire planting area is supported by large irrigation canals assuring continuous water supply resulting from the history of the area as an irrigated rice growing region.

---

[41] Marcotting is a technique of propagating using an undetached stem to which the rooting medium is applied by securing it in an appropriate container, for example, a polythene bag (syn: air layering).

Farm sizes vary substantially in the area. Sizes range from very small farms on former rice land recently converted (with around 5 to 10 rai) to very large orchards (with around 100 to 300 rai of tangerine), some already cultivated twenty years or more. Tangerine is the primary crop in the three provinces, few other crops are cultivated (vegetables in another part of Pathum Thani, rice is of declining importance in the area). Farmers generally specialize on tangerine production not additionally growing other crops[42,43].

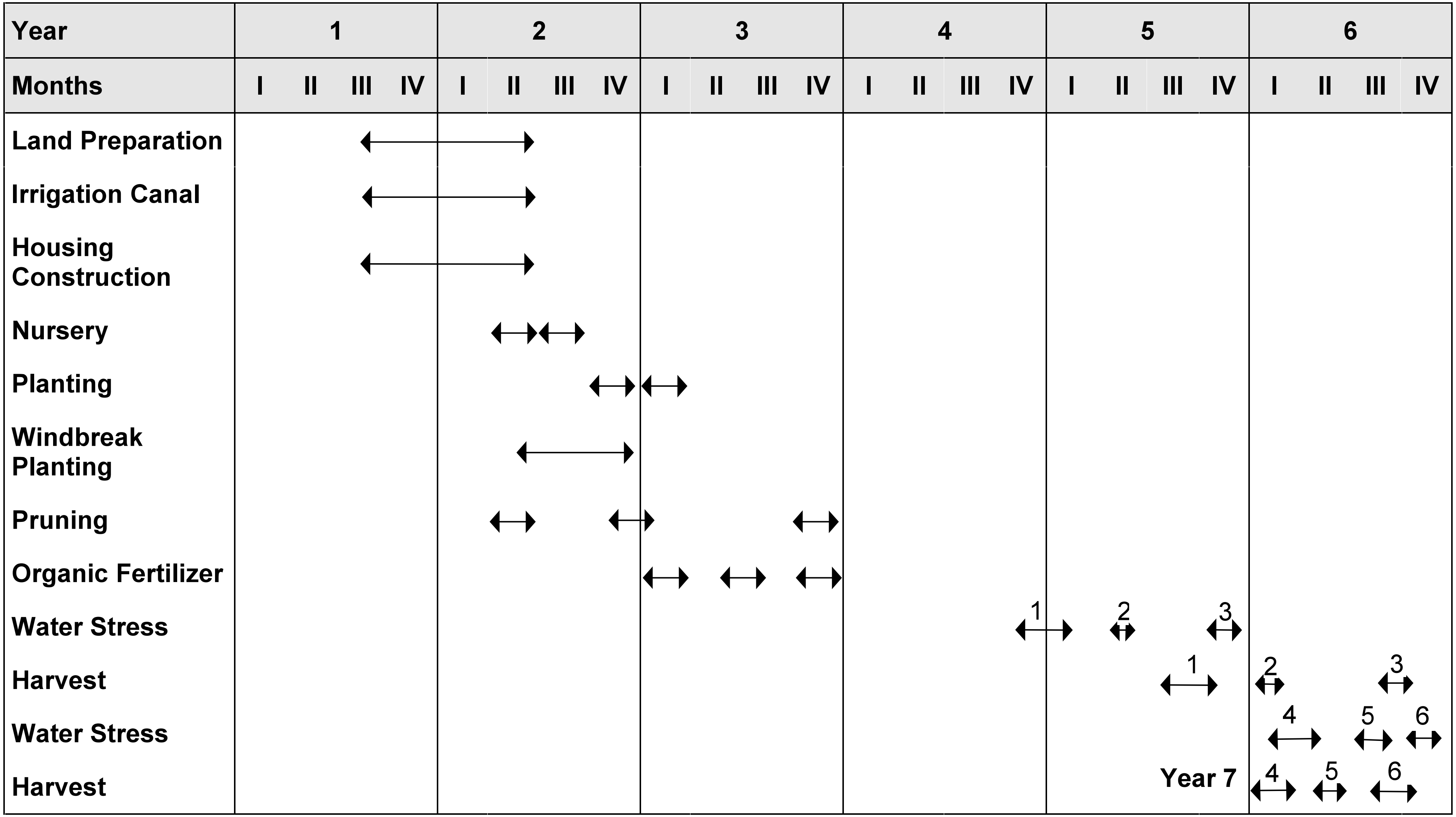
The time frame for the establishment of an orchard and the production cycle are shown in Figure 4.4. The first two years are spent on land preparation, construction of irrigation canals and nursery establishment. This consists basically of digging large canals with a tractor and the smaller ones manually, plowing of the beds and preparation of the planting holes.

---

[42] This characteristic of the area is relevant for some cultivation problems discussed in the next section.

[43] Table IV.2 in the Appendix gives an overview of the costs involved for the establishment of a tangerine orchard of 100 rai in the Rangsit area. At the end of year two the planting of tangerine stocks takes place. In year three the first water stress is put on the plants bringing the first harvest in year four. The first harvest brings about 5 - 10 kg per tree.

Figure 4.4: Tangerine Production Cycle



Source: Paradornuwat, 1995b

With increasing rainfall drainage becomes more important and heavy soils are more unsuitable (VERHEIJ et al., 1991). The ditches play a vital role, not only because of drainage and transport, but also because the water is used to surface-irrigate the beds and to spray chemical pesticides by boats.

Pruning is usually done after each harvest[44]. To support the branches of the small to medium sized tangerine trees supporting sticks are tied to the large branches to prevent them from breaking. This is done normally once a year. Sticks are made from bamboo and have to be replaced every 1 - 3 years. Farmers generally produce their own planting material through air layering. This method shortens the growing period (in comparison to seed propagation) and helps to achieve early fruiting. Weed control is conducted approximately every three months. Usually this is done by hand weeding, but herbicide use is increasing due to labor shortage. Some farmers use mulching material to slow weed growth.

To induce a bloom, water stress is put on the trees. The water is pumped out of the canals and the plants are without water for around 14 days. After the dry period the water is pumped in the canals again and irrigation is resumed for two to three days. This induces blooms[45]. The water stress is conducted 10 - 11 months before the intended harvest. Farmers try to induce flowering every 120 days (GROUP DISCUSSION, 16.4.96). To influence blooming is not easy in the dry and hot season and is easier in colder weather. Therefore, not all farmers are willing or able to target a harvest for the celebration of Chinese New Year. For that harvest, the flowering has to be induced in March/April which are the hottest and driest months in Thailand making the effort a comparably risky practice. High returns are gained from this specific harvest due to high market prices.

Fertilizer application takes place three times per year on average. Organic manure, lime and rice husks are applied once a year. Additionally, liquid leaf fertilizer is applied together with pesticides. Recommendations for fertilizer application are around 20-50 kg/plant organic manure and 100-200 g/plant chemical fertilizer (JIRAPORNCHAROEN, 1993). The main pesticides used are

---

[44] Pruning can be defined as the removal of unwanted growth in order to stimulate desired growth. Opinions about the advantage of pruning differ. However, it is mostly recommended for citrus to shape the framework of the young tree and to eliminate unwanted branches (VERHEIJ et al., 1991).

[45] Water stress can be defined as the major flower-inducing signal under semi-tropical and tropical conditions. Flowering invariably occurs following the renewal of rain subsequent to a period of drought (SPIEGEL-ROY and GOLDSCHMIDT, 1996).

insecticides followed by fungicides, plant growth regulators and herbicides[46]. In the early growing stages pesticides are generally applied more frequently.

4.2.3 Major Problems of Tangerine Production in the Study Area

A decline in the yield-span of tangerine orchards can be observed in the last years. Most of the trees have a yield-span significantly lower than the possible 20 - 25 years, and a decrease in yields often already occurs in orchards aged twelve years (GRENZENBACH, 1994)[47]. At this age, the plants should normally be in their most productive years. The rapid decline of the productivity of young trees in the orchards is regarded as the main cause of low yields.

The decline of productivity is mainly caused by the use of own root stocks bringing about the spread of three main diseases: (i) microorganisms causing Citrus Tristeza Virus disease, (ii) greening disease[48], confined to the plant cells and propagated through air layerings and (iii) phytophtora root rot, a fungal disease, is spread when the soil is used for air layers (BAUMANN, 1995)[49].

The large monoculture area, almost entirely grown with tangerine of one variety, is one further reason for cultivation problems. The occurrence of pest infestations is not hindered by other crops and their natural living organisms making pest resurgence relatively common compared to other regions. The common use of marcots for planting carries diseases to new orchards and excludes possible improvements of the varieties grown (VERHEIJ et al., 1991). The most commonly used variety is quite susceptible to phythopthora disease and citrus tristeza virus. Tangerine grown on resistant rootstocks would control the disease more easily[50].

---

[46] Plant growth regulators are used to control tree growth, flowering and fruiting as well as stabilize levels of production. They can also be used to improve fruit quality by controlling the physiology of maturation (IWAGAKI, 1997).

[47] VERHEIJ et al. (1991) state that tangerine orchards have to be given up 8-15 years after planting due to disease problems.

[48] ROISTACHER (1995) states that greening disease is one limiting factor for the life span of citrus trees in Thailand. It destroys about 10% of the trees each year in the southern part of the country.

[49] The Citrus Tristeza Virus does not show obvious damage in tangerine, however contributes to the stress of the trees. Greening is responsible for high tree losses in tangerine orchards under upland conditions and can be seen as the most devastating citrus disease in Thailand. Phytophthora is very serious on tangerine under lowland conditions due to the high susceptibility of the variety grown and the poor aeration of heavy paddy soils converted into orchards (BAUMANN, 1995).

[50] As criteria for the selection of citrus rootstocks for Thai production conditions have been identified: low susceptibility to phytophtora root rot, tolerance against tristeza, tolerance of poor aeration, tolerance of low pH, early good and regular yielding, positive influence on fruit quality (THAI GERMAN PLANT PROTECTION PROGRAMME, 1996).

One particularly severe problem is the spread of the greening disease over the area. If not managed carefully greening can render a whole plantation unproductive. Greening has an effective vector in South East Asia, the citrus psyllid (VERHEIJ et al., 1991, ROISTACHER, 1995; BAUMANN, 1996). Infected trees have a reduced life-span and lower yields. A disease eradication program aimed at providing growers with healthy disease-free planting materials has been started in recent years (SETHPAKDEE, 1997). However, supply of this planting material is still very limited.

The study area is not perfectly suited for tangerine cultivation as it consists of heavy, low-pH soils[51]. Frequent flooding worsens this situation and contributes to increased disease pressure. Increased resistance is another indicator of difficulties in the existent system. Intensive production with up to three harvests per year puts additional stress on the plants. Figure 5.1 summarizes the key production problems.

Table 4.4: Key Problems in the Study Area

Key Pests	Leaf Miner
	Thrips
	Red Mite
	Rust Mite
	Heliothis amigera (American Bollworm)
Key Diseases	Tristeza, Greening
	Phytophthora, Canker
Stress Factors	Clay Soils, Sulfur acid Soils
	Large Monoculture Areas
	3 harvests per year
	Fruit Drop

Source: Thai-German Plant Protection Programme, 1993

---

[51] SPIEGEL-ROY and GOLDSCHMIDT (1996) outline that with a careful adjustment of rootstocks and cultural practices citrus can be grown satisfactorily on a wide range of soils. In general, deep, well-drained sandy loams are best suited for citrus production. Good drainage is the most essential characteristic of a good citrus soil, without it poor aeration and injury to roots are the result. In regions of heavy rainfall roots are most susceptible to fungal infection. Lack of drainage also contributes to salinity effects which, in turn, may reduce yields.

For tangerine farming the governmental extension service is weak. The focus of government extension is still on small rice producing farmers or the farmers who have recently switched to fruit growing within the restructuring program. This opens space for sales persons from the industry to act as extensionists promoting their products.

In summary, there are five major indicators for production problems in the study area:

- the large monoculture area,
- the susceptible variety and its reproduction techniques,
- current pesticide intensive management systems,
- depletion of soils through long history of tangerine growing in the
- and the heavy reliance on chemical pesticides as the major pest control measure.

4.2.4 Major Pest of Tangerine in the Production Cycle

The growth stages of tangerine and major pests at the respective stages are listed in Table 4.5. For the first two months the development is shown in days while in the later stages it is based on a monthly schedule. The flowering occurs at the end of the first month. In the first three months pest create most problems for the production. Occurrence of the same pests at later stages has a limited harmful effect on the crop[52].

---

[52] Table IV.1 in the Appendix has a complete list of pests in tangerine in Thailand.

Table 4.5: Major Pests of Tangerine according to Production Stage

Age of fruit (m)	**1**				**2**		
Age of fruit (d)	**1**	**7-10**	**15-18**	**20-23**	**25-40**	**45-50**	**60**
Production stage	**young shoot, 1-2 mm long**	**young shoot, 1-2 cm long**	**shoot with young flower**	**fully bloom**	**premature leaves, very young fruit**	**mature leaves, young fruit**	**full mature leaves, young fruit**
Major pests	*thrips*	*thrips, leaf miner*	*leaf miner, american boll worm*	*thrips, leaf miner*	*thrips, mites leaf roller, american boll worm, canker*	*mites, thrips, american boll worm, canker*	*mites, thrips*

Age of fruit (m)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Growth stage	**young fruit Ø 2-2.5 cm**		**young fruit Ø 3 cm**		**young fruit Ø 4 cm**	**premature fruit Ø 5-6 cm**		**mature fruit**	**fully mature fruit**
Major pests	*thrips* *mites* *scab*	*canker* *mites* *rust mite* *thrips*		*fruit splitting* *rust mite* *mites* *sunburn (winter)*		*anthracnose, premature dropping, fruit splitting, rust mite*			

Source: based on PARADORNUWAT, 1995a

According to discussions with farmers the highest yields are obtained between the ages of 10-12 years[53]. On rented land less replanting and replacement of trees is conducted as contracts last around 15-20 years and it is uncertain if the contract will be expanded and an investment in younger trees will pay off. Trees are planted with higher density on rented land to gain higher profits in shorter time. Tenure can be prolonged for another two years depending on the status of the trees. The farmers report few extension activities from the government service. However, farmers meet in groups and discuss problems, if necessary consulting experts from universities or pesticide companies.

4.2.5 Pesticide Use and Pest Problems

Few literature and references exist on pesticide use in tangerine production in Thailand. Therefore, information draws from the available sources and institutions working on these issues. VERHEIJ et al. (1991) state that whereas integrated pest control has been adopted with great success in several

---

[53] This paragraph draws on a group discussion held with tangerine farmers in Sara Buri province, 16.4.1996.

subtropical areas, commercial growers in South-East Asia still rely on heavy spraying. Pesticides are also the main method of pest and disease control in the survey area. It is believed that around ten spraying rounds would be sufficient to cope with the existing problems without changing the management system (BAUMANN; PARADORNUWAT, personal communication) instead of the forty applications averaged by farmers. (BAUMANN, 1995). A paper of the THAI GERMAN PLANT PROTECTION PROGRAMME (1996) concludes that the current pesticide practices are the result of product promotion of the chemical companies and the recommendations of the local pesticide dealers.

Various factors could support a more sustainable integrated production system. BURGSTALLER (1995) summarizes that careful monitoring of pests and the use of selective pesticides and improved spraying technologies can only contribute to more sustainable production if also healthy planting material allows a good development of young trees. These measures in combination of cultural practices like pruning, irrigation and fertilization can help to reduce pesticide use drastically.

The following factors are believed to be relevant in the survey area (BAUMANN, PARADORNUWAT, personal communication)[54]:

- reduction of pesticide application rates and amounts sprayed
- increased pest monitoring, especially for psylla (insect vector of greening disease)
- use of 'disease free' rootstocks, no seedling production through air layerings
- improved management to control greening disease
- no spraying against mites
- reduce stress on plants by reduced water stress, virus free planting material

According to expert opinion (BAUMANN, personal communication) crop losses can be expected to be lower than perceived by farmers[55]. Losses due to insects are relatively low due to the fact that the fruit is also sold with skin damage without profit loss and most of the insects are only dangerous at a

---

[54] A list of recommended cultural practices to reduce pesticide use is shown in the Appendix, Table IV.3.

[55] Except for phytophtora and greening disease.

certain production stage (PARADORNUWAT, 1995). The most important stage is the young fruit stage for pest control. An impact of excessive pesticide use can be seen in reduced populations of natural enemies in the area (Thai-German Plant Protection Programme, Tangerine Team, 1995).

Determinants of current production systems have been identified in the previous discussion. While the following section introduces the study area and the research methodology of the farm level survey of tangerine production, the last section provides a first descriptive analysis of the survey.

5 Descriptive Analysis of Tangerine Production in the Study Area

This chapter intends to provide a descriptive analysis of the tangerine production in the study area. The first section introduces the study area and the research methodology used for the field survey. The second section discusses first descriptive case study results. In the first part determinant variables in tangerine production systems are presented. To introduce current management systems and problems related to tangerine cultivation a general overview of the production situation and farmers' perceptions are given in the second part.

5.1 Study Area and Research Methodology

The study area, located north-east of Bangkok, covers the three provinces of Pathum Thani, Sara Buri and Nakhon Nayok (refer to Figure V.1 in the Appendix). Within these three provinces the tangerine area is concentrated in seven sub-provinces (Amphur): Nong Seua, Lamlukka, Thanjaburi in Pathum Thani, Wihandaeng and Nong Khae in Sara Buri and Ongkarak and Baan Na in Nakhon Nayok.

The study area has been chosen because it is the largest production area, its large uniformity and the possibility to observe all production related problems. Climatic conditions and other external influencing factors can be regarded as almost equal in the study area. Thus, differences in the performance of tangerine farming can be attributed mainly to differences in management systems.

Table 5.1 gives an overview of the three provinces, their districts and the number of questionnaires derived from the three provinces. A total of 210 farmers were surveyed, of whom 205 have been entered into the analysis[56]. In relation to growing areas the largest fraction of the survey is derived from Pathum Thani, followed by Sara Buri and Nakhon Nayok. Within these sub-provinces Nong Seua has by far the largest tangerine growing area with 81,744 rai. The total tangerine area comprises 143,053 rai (24,000 ha). Pathum Thani can be considered as the oldest tangerine growing area of the three provinces. Tangerine has been grown here for more than 20 years.

---

[56] Five questionnaires have been excluded from the sample as they have been incompletely answered.

Farmers then moved from Pathum Thani to Sara Buri where orchards are slightly younger and partly owned by the same farmers who expanded their orchard sizes. Nakhon Nayok can be considered as the youngest region for tangerine growing. Orchard establishment there has increased over the last five years and therefore, several young plantations can be found. However, a wide range of orchard sizes and different ages can be observed over the entire region.

Table 5.1: Overview of the Survey Area

Province	Amphur	Tangerine Growing Area (rai)	No. of Questionnaires
Pathum Thani	Nong Seua	81,744	
	Lamlukka	4,905	103
	Thanjaburi	12,628	
Sara Buri	Wihandaeng	17,600	66
	Nong Khae	15,390	
Nakhon Nayok	Ongkarak	4,521	36
	Baan Na	6,265	
Total		143,053	205

Source: Author’s Compilations, DOAE Planning Division, 1995

The purpose of the survey was to describe the management system and to quantify the production costs of tangerine in the three provinces[57]. A stratified random sample has been applied selecting only farmers with at least six month of experience with tangerine growing and a minimum of ten rai orchard size. Where complete lists of farmers were available they were used for the random sampling. In areas where lists were not completely available, lists of local extension service and farmer groups have been used for the selection.

The survey was conducted from March to July 1996. The questionnaire has been designed in cooperation with local experts and was pretested twice. After the first pretest, conducted with twenty farmers in Pathum Thani, in-depth interviews with four farmers were held and the questionnaire was adapted. The second pretest was intended to introduce the survey team to the questionnaire and the area. In addition a group discussion was held to discuss

---

[57] Refer to the questionnaire in Appendix VIII.

the major concerns of the farmers related to tangerine production[58]. The survey team was introduced to the questionnaire design and its use. Interviews in general lasted from one to two hours. Farmers were informed in advance and appointments were made. The questionnaires were discussed with the survey team in the evenings and to the extent possible data was entered immediately. Therefore, inconsistencies could be detected quickly.

In the questionnaire special attention was given to the use of pesticides. The year has been divided into the production cycle of tangerine, differentiating five development stages. The differentiation according to the production cycle allows farmers to recall their spraying behavior in the absence of farm records. Farmers were asked which specific pesticide or fertilizer, which quantities and how often they are used in relation to the fruiting stage on a monthly basis. With this method detailed information on farmer's practices regarding pesticide and fertilizer use could be obtained. This procedure allows the differentiation of pesticides used by fruit stages, by pesticide categories and WHO-classes. Furthermore, it allows a detailed calculation of the costs involved. The price of individual pesticides and fertilizers were taken from local traders. Using this method a complete overview of pesticide use and costs was obtained. Apart from pesticide use, information on pest pressure, information flows, crop loss perceptions and opinions related to IPM measures have been gathered. In another step farmers were asked to rank information sources for pesticides according to their importance.

5.2 Tangerine Production in the Study Area

5.2.1 Variables Influencing Tangerine Production

Based on theoretical background, expert opinion, group discussions, in-depth interviews with tangerine farmers and conclusions drawn from the analysis of the agricultural policy situation variables influencing tangerine production have been identified [59].

Table 5.2 gives an overview of the variables that were included in the survey of tangerine farmers. These variables are hypothesized to be useful in explaining the complexes of crop productivity, demand for pesticides, path-

---

[58] 16 April 1996

[59] Agricultural policy aspects and their influences on pest management are discussed in section 2.1. For relevant variables regarding pesticide use refer to section 3.2 and 3.5. Variables important in the tangerine production process are discussed in section 4.2.

dependency and socio-economic status. Their relevance and impact on the tangerine production process will be investigated in further statistical and economic analyses.

Table 5.2: Variables for the Economic Analysis of Crop Protection in Tangerine Production

Crop Productivity	• age of plantation • climatic conditions • microclimate and condition of orchard • planting distance • inputs depending on management system, e.g. pesticides, fertilizer, organic manure, planting material, labor, machinery • number of harvests • number of trees replanted
Demand for Pesticides	• expected profit of tangerine growing • years of growing tangerine • price of pesticides • price of tangerine • costs of non-chemical alternatives* • degree of knowledge on crop protection alternatives • personal assessment of pesticide benefits • perceived efficacy of pesticide chosen • management system • dependency on information of resource persons
Path-Dependency in Pesticide Use	• increase in pesticide use over the years • increasing input costs • higher spraying frequencies • size of tangerine orchard • resistance build-up • increasing pest pressure • higher wage rate for pesticide application • cropping diversity • availability of technology and information on non-chemical alternatives
Socio-economic Status of Tangerine Farmers	• farming experience • age of farmer • education • income sources • opinion on information sources • innovation potential • opinion on major production problems

* For a discussion on alternatives to pesticides refer to section 4.2.

Source: Author's Compilations

5.2.2 Tangerine Farming in the Study Area

This section presents a first analysis of the situation of tangerine farmers in the study area. The overall situation of the survey farmers, land status, pesticide and fertilizer use, harvesting as well as future plans are discussed.

5.2.2.1 Overall Situation and Land Status

General background information of the farmers is shown in Table 5.3. The age of tangerine farmers shows a large variability with a mean of forty years. The majority of farmers have attended primary and/or secondary school. Education reaches from primary school to university education. As only farmers who have been growing tangerine for more than six months are included in the survey, plantation ages range from less than one up to 20 years. Orchard sizes vary considerably with a mean of 86 rai[60]. However, the majority of farmers have orchard sizes around or below 50 rai. One hundred fifty four farmers have orchards bearing fruit, while in 51 orchards fruiting has not yet started.

Table 5.3: General Background Data

Variable	Range	Average
Age of Farmer	21 - 73	42.7
Time of Tangerine Growing (years)	0.6 - 47	11.2
Age of Plantation (years)	0.6 - 20	7.4
Orchard Size (rai)	10 - 950	86.5
Distribution:	< 50 rai	47%
	50 - 150 rai	36%
	> 150 rai	17%

Source: Own Survey

More than 60% of farmers (131 farmers) grew other crops before they started tangerine growing. This was mostly rice (62%), followed by vegetables (15%). As reasons for changing the crops grown farmers named low income (79%) as the main reason. Ten percent indicated that they were inspired by their neighbors to shift to tangerine production. For the majority of farmers tangerine growing is their only enterprise (66%). Almost 80% of the farmers grow

---

[60] One rai is equivalent to 0.16 ha.

tangerine on their own land, of which 10% cultivate additionally on rented land. The remaining 20% cultivate on rented land only.

Pest and disease problems are pointed out as one of the three major production problems by 60% of the farmers. Fifty-seven percent name the soil conditions and the bad rootstocks as a problem, while 40% raise the problem of high investment costs. Almost the same share of farmers report that labor shortages are becoming a major problem.

5.2.2.2 Harvesting and Yields

Seventy-six percent of the farmers have orchards in production. The rest of the farmers have young plantations, that have not yet started bearing fruit. Among harvesting farmers, 60% have two harvests per year and 21% are able to obtain three harvests, the rest harvests only once a year. For 13% of the farmers the survey year was their first year of harvesting. The main harvesting seasons are February - April, where 60% of the farmers harvest. July/August and October/November are also peak seasons although with lower outputs. Forty percent of the farmers have harvests in January at the time when prices are at their peak. However, harvesting activities are reported all year round.

Table 5.4 shows the distribution of yields by growth stages and provinces. Nakhon Nayok does not yet have orchards in the growth stage of 15 to 20 years. Overall, annual tangerine yields have a mean of 1,300 kg per rai 7.6 t per hectare respectively[61].

Table 5.4: Yields by Growth Stage and Province (in kg per rai)

Growth Stage[a]	Pathum Thani			Sara Buri			Nakhon Nayok		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
I	0	2,400	384	0	2,791	364	0	3,000	207
II	0	5,500	1,381	500	5,000	2,062	222	4,000	1,787
III	550	4,800	2,078	700	4,000	2,157	-		1,250
IV	250	4,600	1,928	333	4,167	2,100	-	-	-

a = Growth Stages: I = 0 - 4 years, II = 5 - 9 years, III = 10 - 14 years, IV = 15 - 20 years

Source: Author's Calculations

---

[61] Around 25 tons per hectare are referred to as the maximum yield for tangerine in South East Asia (VERHEIJ et al., 1991). Three percent of farmers (6 farmers) in the study area currently have yields around 5,000 kg per rai.

Thirty-eight percent of the farmers considered their harvest as low, 15% as normal and 10% as high compared to previous years harvests. The average tangerine price obtained was 15.4 Baht per kg, ranging from 7-28 Baht. Thirty farmers grade their fruits before marketing and therefore obtain prices above average. Most of the farmers try to target their harvests to maximize prices. Nearly half of all farmers feel that yields have decreased over the last five years, while 29% believe they are increasing[62]. Marketing is almost entirely done through middleman who buy the fruit directly in the field. The traders weigh the tangerine baskets in the field and transport the fruit to Bangkok's wholesale markets. The two major sources of market information are other farmers (56% of the farmers) and local traders (75% of the farmers).

5.2.2.3 Pesticide Application, Pesticide and Fertilizer Use

Pesticides are applied frequently. Application rates range from 9 to 72 times per year with an average of 35 applications. The majority of pesticides used are insecticides. Very few farmers use herbicides, the main tool for weed control is manual weeding. However, the use of herbicides is reported to increase due to labor shortages.

Fifty percent of the farmers apply pesticides with a sprayer equipped motorboat. Other farmers use hand-pulled boats or knapsack sprayers. Almost all farmers spray a mixture of several pesticides - pesticide cocktails. The main reason is to save time or labor costs and to control many pests with one application. Recommendations for the cocktail mixture are mainly derived from own experience (43%), recommendations from pesticide salesman (25%), instructions from the label of the pesticide (23%) and friends and neighbors (18%)[63]. 36% of the farmers pay higher wages to the person applying pesticides since the work is more hazardous than other tasks work. These wages can be up to twice the normal wage.

Table 5.5 indicates the sources of information concerning which pesticide is bought, quantities and quality of the pesticide. Farmers were asked which were their major sources of information. Which pesticide is bought is mainly

---

[62] It might be expected that the statement of harvest development is related to the plantation age. However, there is no significant correlation between the age of the plantation and the statement of increasing or decreasing yields.
(corr = 0.057/ t-value = 0.47)

[63] Relating these results to the discussion about the use of pesticide cocktails in section 3.2.6 lets assume that the knowledge on the actual amount of a.i. and the effectivity of the cocktails is limited due to insufficient information, pesticide quality inadequacies and mixtures of pesticides of unknown effect.

influenced by pesticide retailers, friends and neighbors (55.6%). As the pesticide salesmen have a strong presence in the area and retailer shops serve also as information center, the influence on opinion formation is expected to be high.

Dosages are mostly taken from the information on the label. However, 16% of the farmers still consult their retailer. The quality of the pesticide is judged based on recommendations of retailers, friends and neighbors. The results emphasize the important role of retailers, friends and neighbors regarding the information of pesticides. The strong dependence on information of retailers and salesmen suggests that the given information unilaterally focus on pesticides without much discussion of alternatives. It can be regarded as the role of the governmental extension to inform more objectively about crop protection methods, however, as Table 5.5 shows, they are seldom used as information sources.

Table 5.5: Farmers' Sources of Information on Pesticides* (in % of farmers)

Type of information	Pesticide retailer	Friends, neighbor	Pesticide salesman	Label	Extension	Own experience
Pesticide	55.6	47.3	26.8	17.1	9.3	17.1
Use quantities	15.6	13.2	3.4	80.9	0.5	6.3
Qualities	32.7	39.5	7.3	21.9	4.9	22.9

* three answers possible per farmer, N = 205

Source: Own Survey, Author's Calculations

Table 5.6 analyses how changes in pesticide use patterns are related to perceptions on pesticide efficacy and pest development. Changes reported are in the majority increases in pesticide use or the change to more selective pesticides. The first line shows the percentage results related to rows while the second line represents the column percentage results. More than half of the farmers reported that pesticide use patterns had changed over the last five years (54.4%). Of these farmers, 56.6 % indicated that pesticide efficacy remained the same and 76.4 % indicated that pest development was the same.

Ninety-two percent of the farmers reporting same efficacy levels did not change their pesticide use patterns. Seventy-three percent of all farmers consider the efficacy of pesticides as more or less the same. Most of the farmers reporting lower pesticide efficacy belong to the group of farmers who changed their pesticide use patterns (86.8%). The results of the analysis on changes in pesticide use patterns can be regarded as consistent with perceptions on pesticide efficacy. Almost half of the farmers report that pest problems increased over the last five years (43.6). However, seventy percent of the farmers who are reporting increasing pest pressures did not change their pesticide use patterns. Perceptions on increasing pest pressure do not result in pesticide use changes.

Table 5.6: Changes in Pesticide Use Pattern in Relation to Pesticide Efficacy and Pest Development as assessed by Farmers (in %)*

Changes of Pesticide Use Pattern		Pesticide efficacy		Pest development	
row percent/ column percent		*same*	*lower*	*same*	*increasing*
yes	54.4	56.6 41.4	43.4 86.8	76.4 74.3	23.6 29.4
no	45.6	92.1 58.6	7.9 13.2	32.6 25.7	67.4 70.6
Total		72.8	27.2	56.4	43.6

* N = 195

Source: Author's Calculations

Some of the main pesticides used are listed in Table 5.7. An overview is given of the pesticide prices and WHO-categories. The majority of insecticides comes from the WHO categories Ib and II, while fungicides mainly stem from category IV. However, prices vary substantially, especially for insecticides. This originated from different dosages per hectare (high priced pesticides have generally smaller dosage levels).

Table 5.7: Main Pesticides Used, their Prices and WHO-Category

Pesticide Name	Common Name	Pesticide Category	WHO-Category	Price (Baht/l/kg)
dimethoate	dimethoate (40%)	insecticide	II	94
cypermethrin	cypermethrin (25%)	insecticide	II	500
cypermethyl	cypermethrin (35%)	insecticide	II	660
metamidophos	metamidophos (60%)	insecticide	Ib	139
cascade	flufenoxuron (5%)	insecticide	IV	1,350
lannate	methomyl (40%)	insecticide	Ib	330
monocrotophos	monocrotophos (60%)	insecticide	Ib	175
confidor	imidacloprid (5%)	insecticide	II	1,500
carbosulfan	carbosulfan (25%)	insecticide	II	220
carbendazim	carbendazim (50%)	fungicide	IV	240
captan	captan (50%)	fungicide	IV	100
copper	copper oxychloride (77%)	fungicide	III	100
mancozeb	mancozeb (80%)	fungicide	IV	120
glyphosate	glyphosate (48%)	herbicide	IV	180
grammoxone	paraquat (45%)	herbicide	II	100

Source: Own Survey

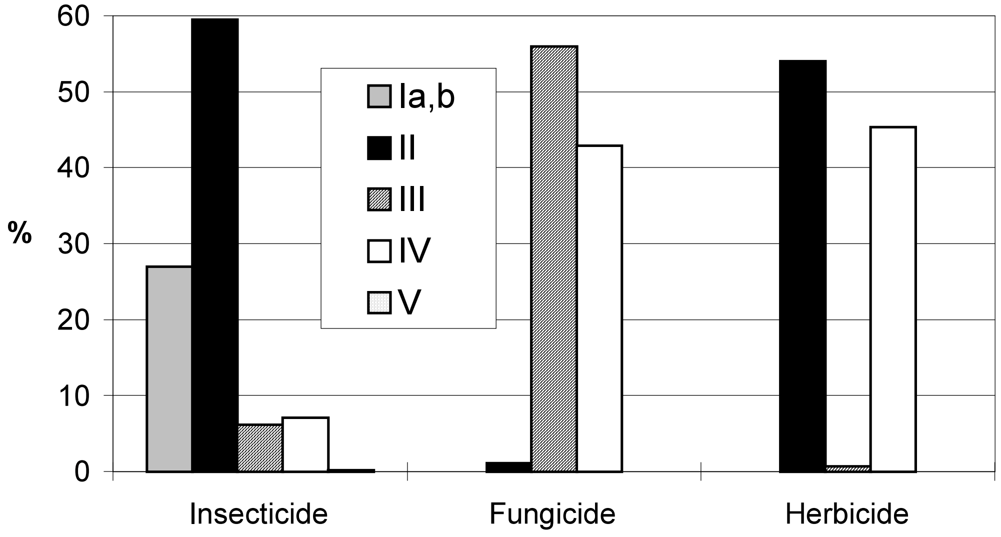
The majority of insecticides used belong to the more hazardous group according to WHO classification. Health hazards in relation to the use of these hazardous pesticides are highly probable[64]. The problem becomes more obvious considering that hardly any protective clothing is used for application and that pesticide contaminated water in the orchard canals is used for household purposes of farmers or farm workers. Figure 5.1 shows the pesticide categories divided into WHO-classes. Over all categories, almost 57% of the pesticides stem from hazardous and most hazardous categories. The share of the more hazardous pesticides is highest for insecticides (86.5%). Herbicide use concentrates basically on two types of herbicides explaining the peaks of WHO class II and IV. Fungicides comprise mainly out of class III and IV pesticides. The group of other pesticides[65] (not shown in the figure) consists out of group IV and V pesticides. Class Ia and Ib pesticides are used in insecticide applications only.

---

[64] Refer to WANGTHONGTAM (1990a) reporting similar results and section 2.2.1.

[65] The group of other pesticides summarizes plant growth regulators, adjuvents, trace elements and vitamins.

Figure 5.1: Pesticide Use according to WHO-Classification (in % of applications per year)



Ia,b = extremely and highly hazardous, II = moderately hazardous, III = slightly hazardous, IV = unlikely to present acute hazards in normal use, V = not listed

Source: Author's Calculations

Only 24 farmers report non-chemical methods among which the spraying of water is the most common (8% of all farmers). Additionally, some farmers use traps or other monitoring methods. Reasons for not using other crop protection methods are mainly that farmers are afraid that they might loose their crop (45%)[66]. 30% believe that other methods are not working, while 34% claim that they do not have sufficient knowledge to use other methods. As major pest and disease problems in the area are considered: thrips, leafminer, phythopthora, mite and canker (in order of frequencies). It is interesting to note that only 15% of the farmers consider greening as a major problem in their orchards whereas greening is considered as the most devastating factor in tangerine production by experts[67]. Farmers estimate crop loss caused by pests at 25% on average. If no pesticide were used this assessment increases to more than 80%. Seventy eight percent of farmers said that they would not change their spraying patterns if pesticide prices were higher.

In the study area, common practice is to use fertilizer around two or three times per year. Almost 45% of farmers gather information on the condition of the soil before using fertilizer. This information is mainly derived from the outlook of the soil (35%), pH-meter (29%) and soil test from the extension

---

[66] Multiple answers possible.

[67] Refer to section 4.2.2.

service (24%). In addition to soil fertilizers, foliar fertilizers are frequently used. They are applied in combination with pesticides. Almost all farmers use organic fertilizers. These are basically animal manure (used by all farmers), rice husks (12%), bones (27%) and lime (12%)[68].

As reported by the farmers information about integrated pest management methods is scarce. More than fifty percent of farmers said that they do not know exactly, whereas 30% of the farmers understand that IPM means the use of predators and traps, biological pesticides and effective micro-organisms. Half of the farmers feel that IPM methods would have a negative effect on yield.

5.2.2.4 Costs and Returns

The first analysis of the farm survey indicate that management systems of tangerine production across farms differ mostly in pest and disease control, harvesting times and output levels. Labor and capital intensity do not differ much among farmers and are almost unrelated to orchard size or plantation age suggesting the non-existence of scale effects. Differences in costs and returns are discussed in this sections and the following chapter.

All monetary values of input and output factors are referred to in costs per rai and year. The cost of pesticides, fertilizer and organic manure are retrieved from the application level according to fruiting stages. The prices for pesticides and fertilizers are taken from local traders. Organic manure prices are based on farmers recall. Costs for replanting are calculated from the annual amount of trees replanted, in the case of missing data a 10% replacement of total trees planted has been assumed. The prices of trees for replanting have been taken from the survey. Credit costs are expressed in annuities of credits borrowed. Costs of machines and equipment are summarized in the machine costs and are linear depreciated according to their economic life usage (unless indicated differently a life of ten years has been assumed). Total variable costs comprise of costs for pesticides, fertilizer, organic material and replanting costs. As costs for machines and equipment are not regarded as determining factors of production differences, they are treated separately. Revenues are calculated on the individual yield level related to the average tangerine price of all farmers (15.43 Baht).

---

[68] Refer to a complete list of all pesticides and fertilizers, their categories, WHO-class and prices in the Appendix, Table IV.1.

Table 5.8 summarizes the average labor costs of all farms by type of labor. Irrigation, pesticide application, weeding and the establishment of supporting sticks are the most time consuming works.

Table 5.8: Average Labor Costs (in Baht per rai and year)

Labor	Total
Pesticide application	381.69
Fertilizer application	57.42
Irrigation	711.58
Weeding	494.78
Application of organic manure	111.10
Supporting sticks	404.40
Pruning	210.31
Cleaning of canals	269.03
Harvesting	410.22

Source: Author's Calculations

For the calculation of costs and returns in tangerine production of the survey farmers and give an overview of the performance over the different plantations ages the orchards are divided in four growth stages according to their plantation ages (Table 5.9). The costs and returns calculated represent the average values for the respective growth stage.

Table 5.9: Costs and Returns by Plantation Age (average of all farms, in Baht per rai)*

Growth Stage	Age of Tree	Costs of Pesticide Use	Costs of Fertilizer Use	Total Variable Costs^{+}	Pesticide Costs (in % of TVC)	Revenue
Stage I	0 – 4	2,788	1,838	7,860	34.1	4,956
Stage II	5 – 9	4,729	2,108	11,032	41.4	25,784
Stage III	10 – 14	4,403	2,305	10,954	38.3	32,018
Stage IV	15 - 20	4,618	2,157	10,361	42.2	30,869

* = all data significant at the 0.001 level, $^{+}$ = including labor costs

Source: Author's Calculations

Pesticide costs are almost constant over the last three growing stages. This also applies to fertilizer inputs. Pesticide costs account for around 40% of total variable costs. They are, therefore, the largest cost item attributing to total variable costs. Variable costs do not differ largely between growing stages with the exception of the youngest stage. While profits are negative in the first years, they increase rapidly after the first harvests. Mean revenues of the first stage are positive due to a share of farmers already in production.

The overview of costs and returns suggests that there is little differentiation in the intensity between growing stages. It is expected that the differntiation between the production intensity of different management strategies, independent of the plantation age, is higher. The following chapter, therefore, focuses on the analysis of differences between management strategies by determining and comparing farm sub-groups with similar strategies.

6 Management Strategies in Tangerine Production

The identification of different tangerine management strategies and their determinants are the focus of this chapter. In the first section the data is grouped according to regions, growth stages and yield levels. As the categorization can only unsatisfactory group farmers according to intensity levels, the second section introduces the cluster analysis as a grouping methodology, categorizing the data according to intensity of input use for the determination of different strategy groups. The third section discusses the results of the cluster analysis with regard to differences of the management strategies. A special focus is given to differences in pesticide use and their reasons. The section concludes with a categorization of the cluster groups. In the last part of the chapter a categorical data analysis is introduced determining major selection criteria for pesticides and quantifying their impact. Section five summarizes the results and draws conclusions.

6.1 Selection of Grouping Criteria

Regions, growth stages and yield levels have been selected as introductory grouping criteria. The target is to analyze if these variables are important for the clustering process and which of these criteria can be additionally used to further differentiate cluster groups. The variables for which these criteria are discussed are costs of pesticide use, fertilizer costs, costs of replanting, labor costs, total variable costs and gross margins. These variables are selected as indicators for differences among farms as they inform about the intensity of the groups as well as about the overall performance of the farm. To test the validity and explanatory use of the grouping factors multiple comparison tests have been conducted. These tests allow to determine which group means are responsible for the existing differences[69].

Regions have been selected as the first means of grouping to conclude whether regional influences exist. As Pathum Thani is the region where tangerine is grown longest and Nakhon Nayok has the highest share of farms

---

[69] Tukey's multiple comparison method and Duncan's multiple range test have been used to determine group differences. The first is a pairwise comparison test based on the studentized range. It determines a critical number such that if any pair of sample means has a difference greater than this critical number, it is concluded that the pair's two corresponding population means are different. The second method offers the possibility of simultaneous testing. The homogeneity of all means is tested at a certain level. Multiple range tests can be used with unequal cell sizes, but may, however, result in undesirable operating characteristics if cell size differences are large (SAS/STAT VOL.2, 1992). Both test come to the same results for the survey data.

with young plantations, differences in crop management can be hypothesized. The hypothesis for the criteria growth stages and yield levels is that the variables differ in relation to the plantation age (growth stage) or production levels (yield level) of tangerine over time. Growth stages can be regarded as a differentiating factor due to the perennial nature of tangerine and a time dependent yield development. That differences in management systems are determined by varying output levels is hypothesized for yield level classification. Growth stages have been differentiated in five year periods resulting in four growth stages; yields have been classified in five similar yield groups (1,000 kg range). Table 6.1 shows the differences of the means for the selected variables for the three grouping criteria[70]. The provinces Pathum Thani (PT) and Sara Buri (S) show no significant group differences for the variables. However, for pesticide and fertilizer costs and for total variable costs, means are significantly higher than in Nakhon Nayok (NN). Gross margin values are lower in Nakhon Nayok due to lower average plantation ages. Labor costs are higher in Pathum Thani, while no significant differences exist for replanting costs.

---

[70] When multiple comparisons are interpreted, it has to be remembered that failure to reject the hypothesis that two or more means are equal should not lead to the conclusion that the two means are in fact equal. Failure in rejecting the null hypothesis implies only that the difference between population means is not large enough to be detected with the given sample size (SAS/STAT VOL.2, 1992).

Table 6.1: Group Differences for Selected Variables and Grouping Criteria

			Variables											
Grouping Criteria		N	Pesticide Costs		Fertilizer Costs		Replanting Costs		Labor Costs		TVC		Gross Margin	
Region	PT	103	4,225	A	2,192	A	62.5	A	3,388	A	23,294	A	16,090	A
	SB	66	3,983	A	2,112	A	51.1	A	2,672	B	6,818	A	13,834	A
	NN	36	2,974	B	1,562	B	53,3	A	2,596	B	5,156	B	4,723	B
Growth Stages[a]	I	76	2,788	B	1,838	A	46,0	A	2,519	C	5,326	B	-198	B
	II	60	4,729	A	2,108	A	73,4	A	3,316	A/B	7,697	A	17,466	A
	III	43	4,403	A	2,305	A	56.1	A	3,578	A	7,351	A	26,925	A
	IV	26	4,618	A	2,157	A	54,6	A	2,863	A/B	7,499	A	21,140	A
Yield Levels[b]	I	49	2,767	D	1,639	B	51.4	A	2,455	B	4,961	C	-4,961	E
	II	51	4,167	B/C	2,315	A	60.3	A	2,976	A/B	7,398	B	-14	D
	III	45	4,492	A/B	1,808	B	60.4	A	2,969	A/B	6,981	B	13,404	C
	IV	35	3,675	C	2,273	A	66.5	A	3,546	A	6,717	B	29,550	B
	V	25	5,049	A	2,485	A	43.8	A	3,648	A	8,321	A	53,270	A

* = Means with the same letter are not significantly different at the 0.05 % level; 'A' indicates the highest mean value of all groups for the respective variable

[a] = Growth Stages:
I 0 - 4 years
II 5 - 9 years
III 10 - 14 years
IV 15 - 20 years

[b] = Yield Levels:
I no harvest
II 1 - 999 kg/rai
III 1,000 – 1,999 kg/rai
IV 2,000 – 2,999 kg/rai
V ≥ 3,000 kg/rai

Source: Author's Calculations

Comparing the second grouping criteria, the four growth stages[71], gives a slightly different picture. Young orchards have lower pesticide costs, lower total variable costs and lower gross margins which is due to the fact that less than half of the orchards in this stage have no harvest yet. Labor costs are lower in the early and the late stage and significantly higher between the years 10 - 15, which is the period where production is highest. The analysis of variance shows that not all variables show significant differences. The differentiation by growth stages cannot sufficiently picture the differences between all variables as overlapping between yield and group effects still exist.

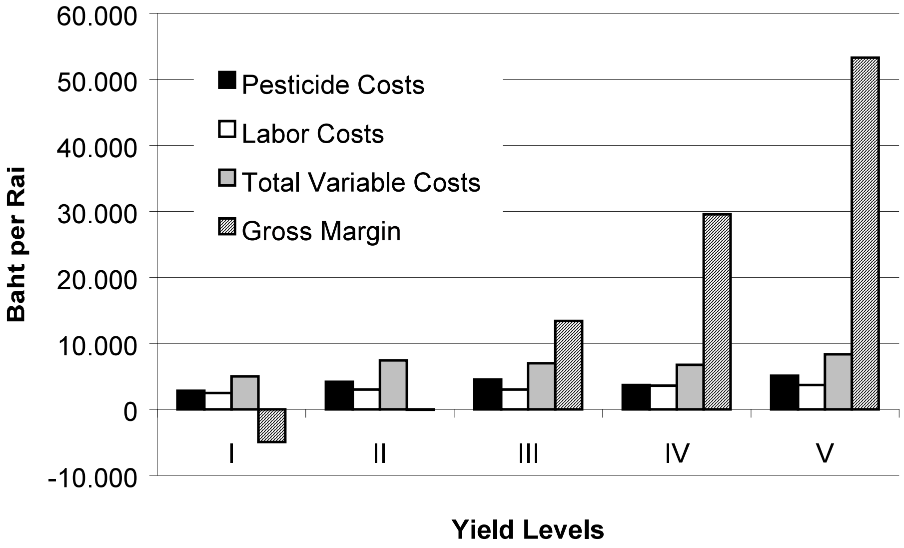
Therefore, a grouping by yield level seems to be more appropriate especially for the determination of output differences. At all levels significant differences between group means exist for gross margin values. On the costs side the orchards without harvest have lower total variable costs and lower pesticide costs. Orchards with the highest yields are also orchards with the highest pesticide cost. Fertilizer costs appear to be almost unrelated to yield levels. This also applies to the replanting costs. Labor costs are lowest in the first yield level.

Figure 6.1 pictures costs and returns by yield levels. The large share of pesticide costs of total variable costs over all yield levels becomes obvious. While the costs items stay almost the same over all yield levels, gross margins differ substantially. It can be seen that outputs differ largely for the respective yield levels while input and total variable costs show no large differences.

---

[71] For the definition of the growth stages and the yield levels refer to Table 6.1.

Figure 6.1: Development of Costs and Returns by Yield Levels (Total sample)



Source: Author's Calculations

The complex input-output relationship in tangerine production requires production factors to be analyzed in terms of management packages. Therefore a typology of management strategies will be identified using the method of cluster analysis. The classification of yield levels, regarded as a useful grouping criterion will be used in the further analysis to sub-group the management systems to be identified in the next section.

6.2 Categorization of Survey Data

Previous analyses indicate a large variability in input use. The question arises whether there are systematic differences in the production process between groups of farmers. In other words do farmers who are using similar levels of pesticides also have other indicators of the production system in common?

The target of the data categorization is to structure and group the survey data. Therefore, groups shall be identified differing significantly in their input intensities. The data categorization can determine in which of the factors influencing the production process interclass differences exist. It is expected that the categorization will help to explain causes for different management systems. Cluster analysis is used for the data categorization. The first sub-section discusses the methodology of cluster analysis while the second sub-section concentrates on the data categorization.

6.2.1 Methodological Concept of Cluster Analysis

In contrast to other grouping processes, an important characteristic of cluster analysis is the simultaneous analysis of several criteria within the grouping process. The structure of the total sample is pictured in the similarities and dissimilarities of objects. Using these similarities, objects can be classified and the hypothesis tested. The clustered groups should be homogenous as possible while little similarity should exist between the cluster groups[72].

The purpose of the analysis can be defined as the identification of homogenous groups within a heterogeneous sample of objects. Criteria for classical classification methods are that each object can only belong to one specific group, each group should be as homogenous as possible, formed groups should be significantly different from each other, only few clusters should be selected and clusters should comprise a sufficient number of objects (MÄRZ, 1990).

Five steps of analyzing can be summarized for the clustering procedure (BACKHAUS, 1994):

- the selection of parameters for classification,
- the choice of similarity measures,
- the selection of a clustering algorithm,
- the determination of a sufficient number of clusters and
- the analysis and interpretation of results.

6.2.1.1 Selection of Classification Parameters

The initial choice of the particular set of measurements used to describe each object to be clustered reflects the investigator's judgment of relevance for the purpose of classification (EVERITT, 1993). In this sense, only those parameters should be selected which are relevant for the classification process according to a hypothesis in relation to the classification target. Variables with high variations should be used while variables showing high correlation should be omitted[73]. The latter may distort the clustering procedure.

---

[72] For a discussion on clustering techniques and algorithms refer to Appendix VII.

[73] In this context a correlation can be considered as 'high' if the correlation coefficient exceeds a value of 0.9 (BACKHAUS et al., 1994).

In many applications the variables describing the objects to be clustered may not be measured in the same units. Therefore, each cluster variable has been standardized to unit variance prior to the analysis using the standard deviations calculated from the complete set of objects to be clustered (EVERITT, 1993)[74].

6.2.1.2 Cluster Solutions and Comparisons

Two questions need to be answered after the cluster groups have been found. Firstly, what is the appropriate number of clusters, and secondly how do the clusters differ from each other.

There is no satisfactory method for determining the optimal number of clusters for any type of cluster analysis (SAS, 1989). Formal approaches to the number of cluster problem have been suggested by several authors[75]. BACKHAUS et al. (1994) proposes to compare the error sum of squares (ESS) with the respective number of clusters. The number of clusters within the partition procedure where the ESS changes largest is defined as the optimal number of clusters (Elbow criterion).

Once the objects have been clustered, there is a need to compare the various clusters to observe how they differ[76]. BACKHAUS et al. (1994) uses the F-value as a criterion for the homogeneity of the clusters. The F value for each variable within the cluster computes as follows:

$$F = \frac{V(J,G)}{V(J)}$$

with $V(J,G)$ = Variance of variable J in group G

$V(J)$ = Variance of variable J in the total sample

The lower the F-value the smaller is the variance of the respective parameter in the cluster in comparison to the total sample. The F-values have to be calculated for all clustering parameters. A cluster can be considered as homogenous if all F-values do not exceed one. Another criterion for the interpretation of the clusters is the T-value:

---

[74] However, a purely objective solution of the selection process is not possible since the selected parameters influence the group formation. Classification, therefore, remains subjective and highly dependent on the criteria chosen and should always be interpreted with respect to the grouping purpose.

[75] Refer to EVERITT (1993), DILLON (1984) for more details on these approaches.

[76] Validating the quality of a cluster solution is a difficult issue (DILLON, 1984). Ordinary significance tests, such as the F-test are not valid for testing differences between clusters since the assumptions of the usual significance tests are violated as the clustering methods attempt to maximize the separation between clusters (SAS, 1989).

$$T = \frac{\overline{X}(J,G) - \overline{X}(J)}{S(J)}$$

with
$\overline{X}(J,G)$ = Mean of variable J in group G
$\overline{X}(J)$ = Mean of variable J in total sample
$S(J)$ = Standard deviation of variable J in total sample

Negative T-values indicate that the parameter in the respective group is underrepresented compared to the total sample and vice versa.

6.2.2 Categorization of Survey Data

The data categorization is carried out to group those farms which are relatively similar in their input uses but still heterogeneous in other variables e.g. the age of the plantation, farm size, social indicators.

6.2.2.1 The Selection of Cluster Parameters

As the objective is to categorize the data according to different intensity levels, a first step has to answer the question which variables determine the intensity of production. As described in chapter four climatic and soil conditions as well as machine costs do not vary greatly in the study area. As cluster analysis focus on heterogeneous factors, these factors can be excluded.

Three variables have been used to categorize the data, namely the costs of pesticide inputs per rai, the costs of fertilizer inputs per rai and pesticide costs in per cent of total variable costs[77]. Reasons for the selection of these three parameters are the following:

- Pesticide and fertilizer costs contribute most to the variability of intensity levels of survey data.
- Farms with low pesticide inputs may have high fertilizer inputs and vice versa. Therefore, fertilizer costs can contribute to a more specific clustering.
- Pesticide costs in per cent of total variable costs can additionally serve as an indicator for the input intensity. Pesticide costs may be low, but their percentage of total costs can still be relatively high, if other costs are relatively low.

---

[77] The clustering procedure has been conducted various times using different variables as well as different numbers and combinations of variables. The three variables discussed above resulted in the most homogenic cluster groups.

It is assumed that the selection of these variables is able to find 'good' clusters with significant differences in their intensity levels. The cluster parameters have been standardized before conducting the cluster analysis[78]. The correlation of the cluster variables has been estimated in Table 6.2. Results suggest that the three parameters can be used for the cluster procedure. The highest correlation exists between pesticide costs and the percentage of total costs.

Table 6.2: Correlation Analysis of Cluster Parameters

	Pesticide Costs	Fertilizer Costs	Pesticide Costs in % of TVC
Pesticide Costs	1.000 (0.0)*	0.31483 (0.0001)	0.80569 (0.0001)
Fertilizer Costs		1.000 (0.0)	- 0.03390 (0.6294)
Pesticide Costs in % of TVC			1.000 (0.0)

* values in brackets are significance probabilities

Source: Author's Calculations

6.2.2.2 The Choice of the Cluster Algorithm

The Ward Error Sum of Square Method has been chosen for the data categorization. According to BACKHAUS et al. (1994) this method is able to find the 'real cluster' and forms cluster of similar sizes[79]. As this method is susceptible to outliers, these were eliminated in the clustering procedure.

The eliminating of outliers was conducted within the clustering procedure using available options within the statistical package.

---

[78] $Z_{ij} = \frac{x_{ij} - \bar{x}_i}{s_i}$, where $\bar{x}_i = \frac{\sum_{j=1}^{t} x_{ij}}{t}$ and $s_i = \left(\frac{\sum_{j=1}^{t} \left(x_{ij} - \bar{x}_i \right)^2}{t-1} \right)^{1/2}$

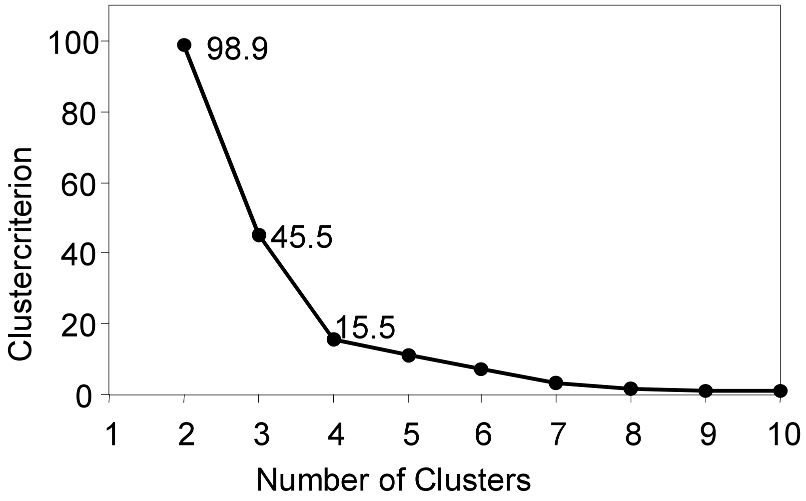
In words, the standardized value Z_{ij} for any i th attribute and j th object is calculated (ROMESBURG, 1990).

[79] Other clustering techniques (single, average linkage) have been tested. But the result formed no satisfying and realistic clusters.

6.2.2.3 The Determination of the Number of Clusters

As outlined in section 6.2.1.2 there exists little options to determine the optimal number of clusters. The Elbow criterion compares the sum of squares within the formed groups with the respective number of clusters within the grouping process. The error sum of squares changes largest reaching three clusters in the partition process as is shown in Figure 6.2. Therefore, the three cluster solution has been chosen and will form the basis for the following analyses.

Figure 6.2: Determination of the Optimal Number of Clusters



Source: Author's Calculations

The F- and T-value can be used to determine the homogeneity of clusters and their representation in the total sample respectively[80].

Table 6.3 has the F- and T-values. A cluster can be considered as homogenous if the F-value is not exceeding one for all cluster parameters. For the conducted cluster analysis all values are lower than one and, therefore, represent another prove of the goodness of clusters. The T-value indicates the over- or under-representation of the respective cluster compared to the total sample. As expected, the T-value is negative for most of the parameters in cluster 1 and cluster 2 and positive in cluster 3.

Table 6.3: F- and T-Values for Cluster Parameters

---

[80] Refer to section 6.2.1.2 for the calculation of the F- and T-values.

Variable	Cluster 1 *low intensive*		Cluster 2 *medium intensive*		Cluster 3 *high intensive*	
	F Value	T Value	F Value	T Value	F Value	T Value
Pesticide Costs	0.0645	-1.0467	0.1886	-0.4639	0.5082	0.9536
Fertilizer Costs	0.8406	-0.1578	0.3925	-0.6043	0.9343	0.5974
Pesticide Costs in % of TVC	0.1613	-1.3513	0.4049	0.0377	0.4994	0.6908

Source: Author's Calculations

6.3 Statistical Analysis of Interclass Differences in Farm Characteristics

In this section the three groups resulting from the cluster analysis are analyzed. The target is to find out what determines the different management strategies in terms of their socio-economic status and their crop characteristics and to analyze the management strategies related to differences in pesticide use. The first section concentrates on the analysis of differences in crop characteristics. In the second part an analysis of variance of selected farm criteria is conducted and group differences identified. Reasons for differences in pesticide use are focus of the third section. The final section summarizes farm budgets for the different clusters and characterizes the groups.

6.3.1 Variable Costs and Productivity

Figure 6.3 shows the ratio of mean values of the respective cluster to total mean value for selected variables in graphical form[81]. The ratio helps to point out cluster group differences. It is obvious that cluster 3 is the most intensive indicating the highest production costs per rai for most factors (e.g. plantation age, numbers of application, replanting costs, gross margin)[82]. As standard deviation for some variables is high further analysis of the variables and their behavior is conducted in the following section[83].

While cluster 3 farmers are exceeding the average level for most variables, cluster 2 and cluster 1 farmers are below. For the percentage of pesticide costs of total variable costs cluster 2 farmers are above the total mean.

---

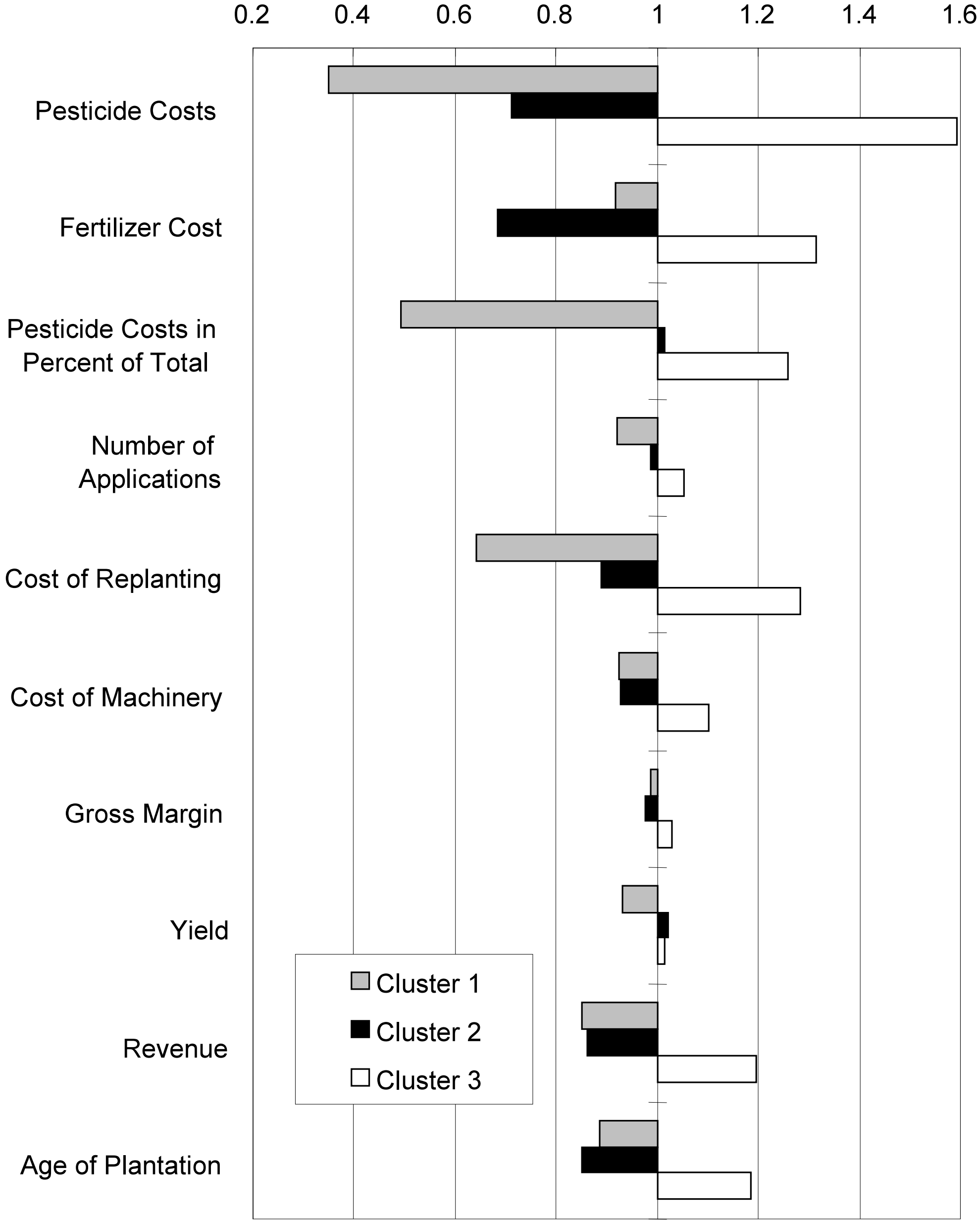
[81] Table V.3 in the Appendix shows the three management strategies (clusters), the number of farmers included, means and standard deviations. The arrow indicates increasing values.

[82] A correlation analysis of selected variables of the clusters is shown in the Appendix, Table V.5-V.7.

[83] Figure V.1 in the Appendix shows the distribution of farmers by cluster for selected classification variables.

Cluster 1 farmers show by far the lowest share of pesticide costs of total variable costs.

Figure 6.3: **Mean Differences between Clusters for Selected Variables** (Ratio: Cluster/Total)



Source: Author's Calculations

The number of replanted trees can be regarded as an indicator of the health status of the orchard. A high number of replanted trees during the productive period of the orchard can be taken a disease and overproduction indicator[84]. Difference can be determined in the number of applications among the clusters. As the cluster groups with higher pesticide costs are also the groups with higher application rates, it can be concluded that higher pesticide costs and more frequent applications are positively related[85].

Although there exist considerable differences in revenues (yields), gross margins differ only slightly because of higher production costs in the high intensity cluster. Overall gross margins are only slightly higher in cluster 3. However, the gross margin calculation does not yet differentiate orchards in their most productive years from orchards in years of lower productivity[86]. This is taken into account in the following section.

As labor costs itself are not a sufficient indicator to discuss farm differences in relation to work schedules, labor costs are further divided by cluster into the average labor costs according to the various farm activities (Table 6.4).

Table 6.4: Average Labor Costs by Cluster (in Baht per rai per year)

Labor	Cluster 1	Cluster 2	Cluster 3
Pesticide application	348.50	354.72	422.36
Fertilizer application	48.75	66.25	54.57
Irrigation	968.40	649.65	626.77
Weeding	719.07	436.66	424.13
Application of organic manure	150.74	81.56	114.97
Supporting sticks	351.61	315.72	507.90
Pruning	147.03	158.91	287.80
Cleaning of canals	293.96	214.60	301.90
Harvesting	404.49	318.94	490.77

Source: Author's Calculations

Labor costs are lowest in cluster 2. Cluster 1 has higher costs for irrigation, weeding and application of organic material. That the third cluster has the highest costs for pesticide applications derives from the fact that they are the group with the highest pesticide costs and number of applications. However, cluster 3 has the highest labor costs for pruning and the establishment of

---

[84] Refer to discussion on replanting in section 4.2.2.

[85] Refer to correlation results in Appendix V.5-V.7.

[86] Refer to the discussion on age-yield relationship in 3.5.1.

supporting sticks. This measures can be regarded as supportive for a healthy orchard environment. This is a first indicator that higher pesticide use is not accompanied by less non-chemical methods.

6.3.2 Analysis of Variances between Groups

As it became obvious in the previous section, the group means of the clusters are not sufficient to analyze group differences because of relatively high variation within the groups. Therefore, an analysis of variances is conducted to test if the means of the clusters are significantly different. As the formal analysis of variance procedure tests only the hypothesis whether groups means differ but not whether all group means are significantly different from each other, multiple comparison tests have been applied[87]. Table 6.5 summarizes the results of the multiple comparison test for the clusters.

---

[87] The analysis of variance allows to compare two or more populations in terms of their population means. The analysis of variance techniques analyze the sample variance in order to test and estimate the means (Keller et al., 1994). The problem objective in this case is to compare three populations.

The following two hypothesis were tested: H_0: $\mu1 = \mu2 = \mu3$
H_1: at least two means differ

The test statistic computed is the ANOVA F-test. The test tells if the means are significantly different from each other but it does not tell which means differ from which other mean. Here multiple comparison tests give more detailed information about differences among the groups. The calculations have been conducted using SAS software procedures for unbalanced ANOVA.

Table 6.5: Multiple Range Test for Farm Criteria by Cluster

	Variable	Grouping*	Mean	Cluster[+]
Socioeconomic indicators	Age of Farmer (years)	A	45.9	1
		B/A	43.1	2
		B	40.7	3
	Level of Education	A	2.6	3
		B/A	2.4	2
		B	2.2	1
Pest management	Pesticide Costs (Baht per rai)	A	6,254.8	3
		B	2,795.0	2
		C	1,372.7	1
	Pesticide Costs (% of TVC)	A	48.0	3
		B	38.7	2
		C	18.8	1
Other inputs	Fertilizer Cost (Baht per rai)	A	2,699.8	3
		B	1,885.7	1
		C	1,404.5	2
	Cost of Replanting (Baht per rai)	A	73.5	3
		B/A	50.9	2
		B	36.7	1
	Labor Costs (Baht per rai)	A	3,432.6	1
		A	3,231.2	3
		B	2,536.7	2
	Cost of Machinery (Baht per rai)	A	2,429.7	3
		B	2,042	2
		B	2,040.8	1
	Costs of Credits (annuity per rai and year)	A	9,568	3
		B/A	8,021	2
		B	6,068	1
	Total Variable Costs (Baht per rai)	A	9,851.1	3
		B	4,770.4	2
		C	3,961	1
Output	Yield (kg/rai)	A	1,550.9	3
		B	1,119.8	2
		B	1,104.1	1
	Revenue (Baht per rai)	A	23,930.6	3
		B	17,279.1	2
		B	17,035.8	1
	Gross Margin (Baht per rai)	A	10,257.3	3
		A	9,685.8	2
		A	9,377.2	1

[*] Different letters indicate significant group mean differences at the 0.05 significance level.

[+] CL 1 = 46 farmer, CL 2 = 73 farmer, CL 3 = 86 farmer, for credits: CL 1 = 30 farmer, CL 2 = 52 farmer, CL 3 = 51 farmer

Source: Author's Calculations

Regarding the age of the farmer and the educational level significant differences exist only between cluster 1 and cluster 3. Farmers age in cluster 3 is on average five years below the age of cluster 1 farmers. Farmers in cluster 3 are on average better educated then other farmers. This suggests that younger farmers with a higher educational level are more likely to produce on a high intensive level. Replanting costs, costs of organic manure and machine costs of cluster 3 are higher than the other two clusters indicating that a high intensity of pesticide use goes along with a high intensity of the levels of other inputs. Therefore, cluster 3 farmers can be regarded as the farmers producing with the most intensive management system. Cluster 2 has significantly lower average labor costs. Mean yields are highest in cluster 3. This stands in relation to a higher mean age of the plantation resulting in a higher share of farms in the most productive years.

To take account of the biological age-yield relationship and differences in productivity, the clusters are further split into yield levels in a second step. It is expected that this method reduces the variability within the sub-groups[88]. The five yield levels, introduced in Table 6.1, are used for the differentiation. Table 6.6 shows the distribution of the survey farmers by cluster and yield level. Cluster 3 has a higher share in the higher yield levels while cluster 1 has a majority of farmers in the lower yield levels.

Table 6.6: Number of Farmers in Cluster Groups by Yield Level

Cluster	Yield Level I	Yield Level II	Yield Level III	Yield Level IV	Yield Level V
Cluster 1	14	15	5	8	4
Cluster 2	26	9	20	14	5
Cluster 3	9	27	20	13	16

Source: Survey Data

Results of the multiple range tests by yield levels are shown in Table 6.7. The third cluster group remains the most intensive cluster over all yield levels. Pesticide costs vary between clusters on all yield levels but do not vary largely between yield levels within clusters. This indicates that farmers in cluster 3 independently of the yield level use more pesticides. On average cluster 3 farmers have three times higher pesticide costs than cluster 1 farmers

---

[88] For a complete set of variables analyzed regarding group comparisons refer to the Appendix, Table V.8-V.10. Differentiation is made between clusters, between yield levels and between clusters by yield level.

although they do not produce more output. The analysis reveals that differences between the mean pesticide costs by cluster stay the same regardless of the yield potential.

The analysis shows that there is high variance between clusters but low variance between orchards of different yield levels belonging to one cluster. This constant level of intensity results in total variable costs in cluster 3 which are on average two to three times higher than in cluster 1. Cluster 2 farmers remain with their cost level always between the other two clusters except for labor costs which are lowest in cluster 2. However, the data do not suggest that cluster 1 farmers compensate the lower pesticide use with increased labor use and other non-chemical inputs.

It is concluded that significant differences exist between the clusters. If they are not completely obvious by cluster group comparison, they become apparent if the clusters are further divided into yield levels. The analysis shows that the three clusters represent management systems with varying levels of intensity. The subsequent analyses will concentrate on finding reasons for such different behavior of farmers.

Table 6.7: Multiple Range Test between Clusters by Yield Levels

Variable	Yield Level I			Yield Level II			Yield Level III			Yield Level IV			Yield Level V		
	G*	Mean	CL	G	Mean	CL	G	Mean	CL	G	Mean	CL	G	Mean	CL
Pesticide Costs	A	6,609.0	3	A	6,093.5	3	A	6,608.8	3	A	5,420.5	3	A	6,615.3	3
	B	2,346.7	2	B	2,820.0	2	B	3,163.2	2	B	3,063.5	2	B	2,910.5	2
	C	1,078.5	1	C	1,505.8	1	C	1,340.1	1	C	1,615.8	1	B	1,457.9	1
Fertilizer Costs	A	2,703.4	3	A	3,007.5	3	A	2,215.1	3	A	2,897.2	3	A	2,611.6	3
	B	1,678.6	1	B	1,807.2	1	B	1,506.6	2	A	2,345.2	1	A	2,611.0	1
	B	1,249.5	2	B	1,084.8	2	B	1,385.9	1	B	1,557.3	2	A	1,980.3	2
Cost of Replanting	A	74.5	3	A	74.1	3	A	75.3	3	A	97.0	3	A	49.2	3
	A	50.4	2	A	51.9	2	A	53.5	2	B/A	57.6	2	A	46.2	1
	A	38.4	1	A	40.4	1	A	28.0	1	B	27.7	1	A	24.6	2
Labor Costs	A	3,199.7	1	A	3,273.1	1	A	3,103.8	2	A	4,316.9	1	A	4,172.0	3
	B/A	2,478.2	3	A	3,177.7	3	A	2,869.9	3	A	3,381.3	2	B/A	3,836.0	1
	B	2,045.5	2	B	1,873.8	2	A	2,825.9	1	A	3,258.9	3	B	1,820.0	2
TVC	A	10,145.5	3	A	10,201.3	3	A	9,566.3	3	A	9,174.3	3	A	10,043.0	3
	B	4,064.3	2	B	4,456.1	2	B	5,260.0	2	B	5,291.9	2	B	5,693.3	2
	B	3,292.5	1	B	4,116.6	1	C	3,520.5	1	B	4,734.5	1	B	4,720.5	1
Gross Margin	A	-3,292.5	1	A	2,572.0	2	A	18,549.0	1	A	31,797.0	1	A	65,679.0	1
	A	-4,064.3	2	A	2,514.0	1	B/A	15,042.0	2	A	31,741.0	2	B/A	56,438.0	2
	B	-10,145.5	3	B	-2,280.0	3	B	10,481.0	3	B	26,232.0	3	B	49,178.0	3

G = Grouping Results, CL = Cluster
* = Means with the same letter are not significantly different at the 0.05 level.

Source: Author's Calculations

6.3.3 Differences in Pesticide Use Patterns

This section analyzes the difference in pesticide use between the clusters. In the survey data were collected which allow to differentiate pesticide use according to the development stage of the fruit. Also, trade names and the quantity per application was asked from the respondents.

6.3.3.1 Differentiation According to Fruit Stage

Pesticide use is analyzed in relation to the fruit stage because as discussed in chapter 4 pesticide application in some fruit stages. Hence this analysis can provide some indication about the technical efficiency of pest control.

For the purpose of the analyses the production cycle within the year has been divided into five stages, i.e. young shoot, flowering, young fruit, premature fruit and mature fruit stage[89].

Figure 6.4 compares costs of pesticides by fruit stage cluster[90]. The highest costs can be observed in the young shoot stage. As the fruit develops the farmers spray less. From a technical point of view this generally makes sense. The young shoot stage is the stage where insects can do most harm which explains the higher pesticide costs spend. However, in the flowering stage it is not recommended to spray in order not to hinder fruit setting. Although farmers stop spraying during this stage the majority ignores the recommendations of the extension service. In stage 3 spraying is conducted mainly to control thrips.

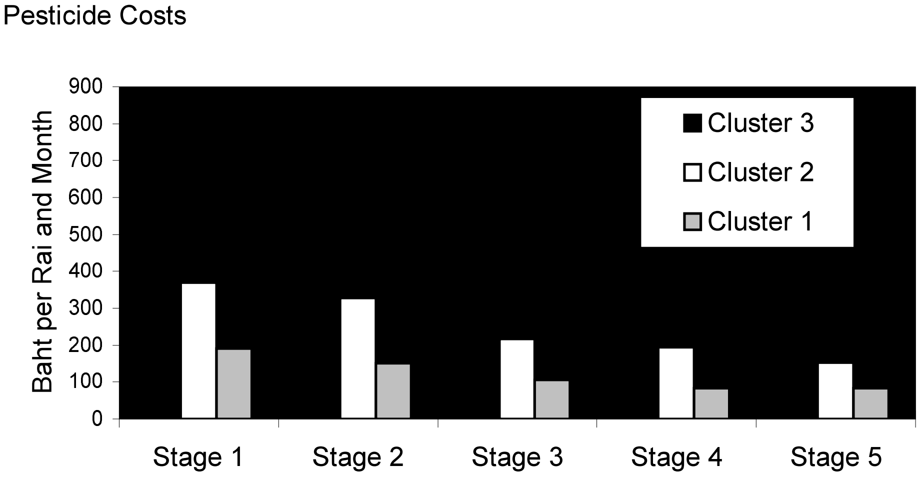
Comparing pesticide use across clusters shows that there is no difference in the tendency of use by growth stage but the level of use differs. The mean value of pesticides used of cluster 3 in the young shoot stage is around four times the one used of cluster 1. On the other hand the relative decrease in pesticide costs is most pronounced for cluster 3.

---

[89] For the design of the question refer to the questionnaire in Appendix VIII.

[90] Respective quantities result in a Figure of similar shape.

Figure 6.4: Mean Values of Pesticide Costs by Fruit Stages



Stage 1: Young shoot
Stage 2: Flowering
Stage 3: Young fruit, mature leaf
Stage 4: Premature fruit
Stage 5: Mature fruit

Source: Author's Calculations

To analyze these differences statistically an analysis of variance combined with multiple comparison tests has been conducted. The following variables were included in the analyses: pesticide costs, quantities by fruit stage, total quantities, yield in relation to pesticide quantities, yield in relation to pesticide costs. Results can be summarized as follows: In stage 1 quantities and costs are significantly different, in stage 2 costs are significantly different and quantities are significantly between CL3 and CL1, CL2. In stage 3, stage 4, stage 5 the same result as stage 2 were obtained. This analysis supports the interpretation of Figure 6.4. The amount of pesticides applied decreases over the fruit stages for all three clusters although there are differences in the level of pesticide quantity.

In order to draw some conclusions with regard to pesticide productivity, a comparison is made by yield level and the ratio of yield to pesticide (Table 6.8)[91]. It is shown that cluster 1 has a significantly higher ratio on all but for yield level V. Hence it appears that cluster 1 produces more per unit of pesticide.

---

[91] For the classification of yield levels refer to the explanation in Table 6.1.

Table 6.8: Relation of Yields to Pesticide Costs and Quantities

	Yield Level II+	G*	Yield Level III	G	Yield Level IV	G	Yield Level V	G
*Yield/Pesticide Costs***								
Cluster 1	0.45	A	1.15	A	1.84	A	4.41	A
Cluster 2	0.16	B	0.64	B	1.08	B	6.76	B
Cluster 3	0.09	B	0.34	B	0.57	B	1.14	B

\+ Yield level I is not considered as orchards are not yet in production; yield is expressed in kg per rai

* G = Duncan grouping; means with the same letter are not significantly different at the 0.05 level

** kg per Baht

Source: Author's Calculations

This was also shown in the previous analysis where pesticide costs stay almost equal over the yield levels for every cluster[92].

6.3.3.2 Differentiation According to Type of Pesticide

As a further step to analyze possible technical inefficiency of pesticide use in citrus the types of pesticides used, pesticide costs and quantities as well as the number of applications are compared (Table 6.9).

---

[92] Refer to Table 6.7.

Table 6.9: Average Quantity, Costs and Number of Applications Split into Pesticide Categories

		Insecticide	Fungicide	Herbicide	Others*
Cluster 1	Quantity (l/rai)	5.00	4.76	0.74	1.11
	Costs (Baht/rai)	880.9	445.7	82.8	154.5
	Applications/year	20.5	11.4	1.7	5.1
	% of Farmers Using	*100*	*72.7*	*6.5*	*34.8*
Cluster 2	Quantity (l/rai)	9.9	7.1	0.6	3.6
	Costs (Baht/rai)	2,053.9	792.9	87.4	555.5
	Applications/year	21.0	10.1	2.4	5.8
	% of Farmers Using	*100*	*78.1*	*9.6*	*49.3*
Cluster 3	Quantity (l/rai)	17.0	14.7	2.3	7.0
	Costs (Baht/rai)	3,548.8	1,738.6	351.7	1,198.9
	Applications/year	22.8	11.0	2.3	7.0
	% of Farmers Using	*100*	*93.0*	*16.3*	*45.4*

* The group of other pesticides summarizes plant growth regulators, adjuvants, trace elements and vitamins

Source: Author's Calculations

It is shown that insecticides dominate all other types of pesticides in terms of quantity used, number of applications, costs and percent farmers using. As mentioned earlier, the quantity used increases by cluster. However the rate of applications is rather similar with over 20 insecticide applications per year. Consequently there are huge differences in the application rate which might be linked to the possibility of resistance to pesticides. Fungicides are used by most farmers in cluster 3. While the quantity and the costs increase by cluster the number of applications is similar. This again indicates differences in the dosage. Herbicides are used by only few farmers but again more in cluster 3. Other chemicals of which plant growth regulators are dominant are used by about one third (cluster 1) to one half (cluster 3) of the farmers.

Comparing these pesticide use levels to international standards in fruit tree production it becomes clear that the amount of active ingredients applied especially by farmers belonging to cluster 3 pesticides are on the upper end of the spectrum. Assuming an average content of active ingredients of 35 % results in 38,7 kg for insecticides alone in cluster 3. For example, for fruits in the Netherlands an average of 20,7 kg/ha and for Italy 14,9 kg/ha was reported (OSKAM et al. 1992). In the US 5 and 17 liters of insecticide volumes (not active ingredient) were reported for California and Florida respectively (USDA 1996).

6.3.4 Farm Budgets

The analyses on the determination of cluster differences will be concluded by a comparison of farm budget calculations of the clusters. The calculation provides an overview of differences in production as well as output.

Table 6.10 shows farm budget calculations for the clusters as well as for the total sample. Value terms are expressed as mean values of groups. Gross margin values are expressed in value per area (rai) and in value per working hour. Revenues are calculated on the basis of the average tangerine price (15.43 Baht/kg) and individual yields. Revenues and gross margins have been further differentiated according to yield levels to reduce variances originating from different growth and yield levels.

Differences become obvious when comparing the production costs and outputs. Almost all costs items have increasing values from cluster 1 to cluster 3.

Considering the overall revenues of the clusters, cluster 3 has the highest average revenues. This picture changes when the revenues are split into yield levels. Cluster 1 and cluster 2 have revenues above the total average while cluster 3 is below the average for all yield levels. The differentiation of revenues by yield levels points out that the higher production intensity especially of cluster 3 does not result in higher revenues. In fact, it is vice versa revenues are lower. This result makes the higher input use of cluster 2 and cluster 3 questionable. One could hypothesize that the constant higher input use of these cluster resulted in the necessity to produce with higher intensities due to increasing production problems. If the hypothesis is true cluster 3 farmers have to use higher intensities to be able to reach targeted yields.

Table 6.10: Farm Budget Calculation by Cluster (in Baht per Rai)

	Cluster 1	Cluster 2	Cluster 3	Total
Orchard Size (rai)	82.07	87.29	97.19	86.48
Average Orchard Age (years)	6.60	6.34	8.84	7.44
Number of Trees per rai	51.03	50.60	50.33	50.58
Yield (kg per rai)	1,104.07	1,119.84	1,550.91	1,297.14
Revenue	**17,035.84**	**17,279.08**	**23,930.59**	**20,014.89**
Revenue per rai:				
Yield Level I	-	-	-	-
Yield Level II	6,630	7,028	7,921	7,383.87
Yield Level III	22,070	20,302	20,047	20,385.04
Yield Level IV	36,531	37,033	35,406	36,267.35
Yield Level V	70,399	62,131	59,221	61,591.61
Costs of Pesticide Use	1,372.70	2,795.04	6,254.79	3,972.29
Costs of Fertilizer Use	1,885.73	1,404.47	2,699.77	2,055.85
Costs of Organic Manure	665.80	519.89	823.06	679.82
Costs of Replanting Material	36.74	50.96	73.51	57.23
Total Variable Costs	**3,960.98**	**4,770.36**	**9,851.13**	**6,720.19**
Total Variable Costs:				
Yield Level I	3,292	4,064	10,145	4,961
Yield Level II	4,116	4,456	10,201	7,398
Yield Level III	3,520	5,259	9,566	6,981
Yield Level IV	4,734	5,291	9,174	6,717
Yield Level V	4,720	5,693	10,043	8,321
Labor Costs	3,432.57	2,536.72	3,231.16	3,029.07
Interest of Current Assets	239.21	286.22	591.06	403.56
Gross Margin	**9,377.25**	**9,685.78**	**10,257.23**	**9,856.28**
Gross Margin :				
Yield Level I	- 6,779.72	- 6,353.61	- 13,232.39	-7,738.80
Yield Level II	- 1,006.55	431.19	- 6,069.94	-3,433.45
Yield Level III	15,511.92	11,622.44	7,037.00	10,016.63
Yield Level IV	27,196.01	28,041.80	22,422.31	25,600.68
Yield Level V	61,560.06	54,276.51	44,403.07	49,122.89
Gross Margin per Labor Hour	14.74	20.48	17.91	18.11

Source: Author's Calculations

Due to differences in production costs, gross margin differences are high. Cluster 3 farmers are producing with a loss twice as high as in the other clusters in the first yield level. While cluster 2 already has on average positive values in the second yield level, cluster 3 farmers have to cope with losses to an extent the other clusters experienced in the first stage. Again, cluster 3's performance is below total average gross margin values for all yield levels while cluster 2 and cluster 1 are above. Due to a quicker increase in average yields cluster 2 performs better in yield level II and is the only cluster with positive values in this stage[93]. While differences in revenues are existent but relatively small, differences in gross margins are considerably high. As revenues have been calculated with a constant tangerine price the increase of difference between clusters can be mostly related to varying production costs[94].

Considering overall gross margin values, reasons for the higher average gross margin of cluster 3 can be seen in the larger share of farmers in higher yield levels and with older plantations[95]. This also applies to overall revenues. The gross margin value per labor hour draws a different picture. As cluster 1 uses more labor it has the lowest gross margin value per labor hour. Cluster 2 has the highest gross margin values due the lowest labor costs. The gross margin calculation underlines the earlier observation that high external inputs do not result in higher gross margins and higher outputs.

6.3.5 Differences in Management Systems - Conclusions

It should be recalled that farmers use basically the same pre-planting strategies, growing methods, irrigation technology but vary considerably with regards to the expenditures on pesticides and the quantities used. Given the very limited differences in the production systems and technology, pesticide productivity varies considerably among the clusters indicating either technical inefficiency or large variation in pest populations.

Cluster 1 farmers can be characterized as farmers managing their farm with less intensive input use with regard to the timing of harvest and use of organic materials. Being slightly older on average, cluster 1 farmers spend less time in tangerine growing and produce on younger orchards. They produce tangerine with the low input intensity. However, their gross margins are comparably high.

---

[93] For a discussion on the relation between age and yield refer to section 6.1.

[94] Refer also to Table 6.7.

[95] 63% of CL 1, 48% of CL 2 and 42% of CL 3 belong to yield level I and level II.

Cluster 2 farmers produce less intensively in terms of the number of harvests per year, but with higher pesticide use, while fertilizer and organic materials are used less intensively than in the other clusters. Cluster 2 farmers seem to aim at maximizing the service life of their orchards rather than on the intensification of annual outputs. Cluster 2 farmers use higher quantities of pesticides, are more likely to use all types of pesticides and are using the more expensive ones. In cluster 1 input levels of other input factors and labor inputs are lower.

In cluster 3 the use of pesticides and other inputs is highest. However, input factors which can be regarded as substitutes for pesticide use i.e. replanting and organic materials are also used on high levels. The number of farmers with three harvest is high with extremely high input use. Pesticide application quantities are three times higher on average than in cluster 1. Farmers in cluster 3 tend to be younger, but they produce on older orchards, the majority being in their most productive growth stages. Gross margin values are lower than in the other clusters if split into yield levels. Cluster 3 farmers produce with the highest input intensities, also pictured in higher pesticide application rates and a broader spectrum of pesticide used. However, the input intensive production does not result in higher yields and returns. This suggests that the level of optimal input use is exceeded.

6.4 Factor Analysis of Farmers Criteria for the Selection of Pesticides

In this context factor analysis is used to analyze farmers behavior regarding pesticide purchases. With the help of factor analysis a set of variables is expressed in terms of a smaller number of hypothetical factors and aims to discover the relation between independent variables is discovered. It is aimed to extract major factors which are believed to have an influence on the selection of pesticides. The target is to answer the question which factors are relevant and whether the price of the pesticide plays a major role for the decision which pesticide is bought.

It is expected that the factor analysis can contribute to the explanation of cluster differences of the previous section. Furthermore, factor analysis can indicate possible intervention strategies for the reduction of chemical pesticides by farmers[96]. In the farm survey a list of twelve possible aspects of

---

[96] For an introduction to the methodological concept of factor analysis refer to Appendix VII.

the individual pesticide purchase decision have been presented to the farmers (Table 6.11).

Table 6.11: Aspects of Pesticide Purchase Decisions

I	product neighbors or friends are using
II	farmers' knowledge about pesticide efficacy
III	pest occurrence in former years
IV	crop loss assessment
V	management system successful over long time
VI	pesticide price
VII	promotion of chemical industry
VIII	recommendation from extension worker
IX	other people (government or NGO)
X	knowledge about hazardousness of pesticide chosen
XI	information of other sources like radio, newspaper, magazines etc.
XII	tangerine price

Source: Own Survey

The aspects were determined as relevant for purchase decisions in the preliminary surveys and group discussions conducted for the questionnaire. The list was explained to the farmers and they were asked to rank the aspects according to their relevance in their individual decision making.

The factor analysis has been conducted with the SAS statistical package using the principal factor method. Kaiser's measure of sampling adequacy (MSA) resulted in an overall MSA of 0.664[97]. The principal factor analysis allows the reduction to two factors according to the proportion criterion[98]. The varimax rotation results in an analysis of the principal components of the two factors. The variance explained by the first factor is 1.462, while the one for the second factor is 0.988. A second rotation according to the promax method is increasing the loadings. Inter-factor correlation between factor 1 and factor 2 is 0.316. The analysis results in a simple structure of the factor loading matrix.

---

[97] Kaiser's MSA gives a summary for each variable and for all variables of how much smaller the partial correlation are compared to the original ones. Values of 0.8 or higher are considered as good, while a MSA below 0.5 is considered unacceptable (BACKHAUS, 1994). Therefore, the analysis lies in the acceptable range.

[98] The proportion criterion specifies the proportion of common variance to be accounted for by the retained factors using the prior communality estimates (SAS/STAT Vol.1, 1990).

Variables only load high in one factor and have low values for the other factor. Variables with factor loadings higher than 0.3 are[99]:

- Factor 1: I, II, V, X
- Factor 2: VI, VII, VIII, IX, XI, XII

Factor 1 has the highest loadings for variables I, II and X (products neighbors using, efficacy, hazardousness), factor 2 for variable XI (information from radio, magazines,...).

Table 6.12 presents schematically factor loadings. '+' indicates positive loadings, while '-' indicates negative correlation in relation to the respective factor. The negative prefix of variables I and V in factor 1 can be interpreted as a negative correlation between the variables 'efficacy' and 'hazardousness' and a successful management over time, respectively the products friends and neighbors are using.

Table 6.12: Schematic Presentation of Rotated Factor Loadings

Variable		*Factor 1* Individual Perceptions	*Factor 2* Prices and Recommendations
Products of neighbors and friends	I	-	
Knowledge on efficacy	II	+	
Management system successful	V	-	
Pesticide price	VI		+
Promotion of chemical industry	VII		+
Recommendation from extension	VIII		+
Recommendation from others	IX		+
Knowledge on hazardousness	X	+	
Information from radio, magazines	XI		+
Tangerine price	XII		+

Source: Author's Calculations

The neglect of the variable 'pest occurrence in former years' implies that farmers do not base their current pest management decisions on previous

---

[99] Only these factors will be considered in the following. The factors 'crop loss assessment' (factor IV) and 'pest occurrence in former years' (factor III) will therefore not be considered further.

years experience. The influence of other sources than personal production experiences seem to have a much higher influence.

Two factors are identified as the main factors for the decision which pesticide is bought. These factors can be titled with 'individual perceptions' and 'prices and recommendations'. The first factor covers personal perceptions as well as the common production practice in the area. The second factor concentrates on price aspects and recommendations from other sources, including the chemical industry. The first factor has by far more importance than the second one. However, considering that the sales agents from the chemical industry are strongly promoting their products in the area one might hypothesize that effects of the products friends and neighbors are using overlaps with recommendations from the industry and influence perceptions. Pesticide prices cannot be identified as one of the most important decision making factors.

To analyze whether differences between the clusters exist the factor analysis is conducted by cluster (Table 6.13). Differences occur between clusters regarding the structure of the two factors. In cluster 1 farmers seem to consider crop loss estimations and previous years pest pressure in their decision. This might explain why cluster 1 farmers are using less pesticides than the other clusters. They rely in their decision on previous years experience and are therefore better able to reflect their pest management. Factor 2's structure has the highest loadings on 'recommendations of extension service' (factor VIII).

Table 6.13: Rotated Factor Loadings by Cluster*

	Cluster 1		Cluster 2		Cluster 3	
Variable	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
I	-0.53		0.69		0.66	
II	0.68		-0.61		-0.53	
III	0.48					
IV	0.56					0.48
V	-0.41		0.62			
VI			-0.32	0.36		0.37
VII		0.38		0.38		
VIII		0.63	-0.44			0.63
IX		0.50				0.31
X	0.60		-0.48		-0.45	0.34
XI	0.31	0.35		0.65		0.64
XII		0.38		0.55		

* Only loadings > 0.3 are considered.

Source: Author's Calculations

Cluster 2 loads highest on variable I, II, and V for factor 1 and on variables XI and XII for factor 2. 'Products friends and neighbors are using' are as important as the trust in the 'currently used management system'. Factor 2 is mainly influenced of pesticide price and industry's promotion. With the exception of variable I and V cluster 2 shows negative loadings for the first factor. This implies that the aspects 'prices of tangerine' and 'of pesticides' as well as 'extension recommendations' are negatively correlated to 'products friends and neighbors are using' as well as 'own management system'.

Cluster 3 has high loadings for variables I and II on factor 1, whereas factor 2 has highest loadings for variables VIII and XI. In contrast to the other clusters variable IV (crop loss assessment) is loading on factor 2. The products friends and neighbors are using are one of the most important variables in cluster 3. As stated above, the perceptions of friend and neighbors can be assumed to be biased through strong chemical industry promotion of their products. Therefore, cluster 3 farmers can be regarded as most susceptible for those strategies.

The dependence on methods of friends and neighbors is considered to play an important role in the decision making process. Therefore, one might ask whether the location of the orchard is correlated with WHO classes and pesticide categories. If neighbors' recommendations would be that important it should be possible to identify a relation. The data grouping according to regions resulted in almost no differences of these variables between the regions. Therefore, an regional influence cannot be hypothesized[100].

The factor analysis reveals that the decision making factors for pesticide purchases of the clusters differ in terms of their loadings. Cluster 1 can be described to take crop loss assessment aspects and pest pressures in former years into consideration while also considering extension recommendations. Cluster 2 farmers concentrate on products which they have been using for several years as well as neighbors and friends are using. Cluster 2 farmers also consider the price of tangerine as a decision making factor. Cluster 3 farmers rely on neighbors and friends performance and on their own perception of pesticide efficacy for pesticide use decisions. Furthermore, newspaper, magazine and extension recommendations and crop loss assessment are considered. Cluster 3 farmers have the priority on factor 2 while the other cluster groups concentrate on factor 1.

The factor analysis can contribute to the explanation of different intensification levels. Cluster 1 farmers rely more on their own experience and consider previous years pest development in their decision making process allowing a more situation based use of pesticides. Cluster 2 farmers rely on ‘what they have always done’ and are influenced by friends, neighbors and implicitly the industry through their salesmen. Cluster 3 farmers are more relying on recommendations from outside. They are therefore most likely to produce more intensively being told that high amounts of pesticides are needed to limit crop losses.

6.5 Discussion

The cluster analysis of pesticide use revealed that there are differences in terms of pesticide costs, quantities and the spectrum of pesticides used. The differences in costs indicate higher application rates as well as the use of more expensive pesticides. No difference exists regarding the timing of pesticide use within the fruit stage.

The farm budget analysis shows that higher external input use does not go along with higher outputs if the groups are differentiated by yield levels. Also

---

[100] For results of the analysis on WHO-classification and pesticide categories split into regions refer to the Appendix, Table V.10, V.11.

higher pesticide use levels do not imply the use of fewer non-chemical methods.

The cluster analysis allows to draw some conclusions on the type of farmers that belong to these clusters. Cluster 1 farmers, in contrast, grow tangerine by trying to maximize their annual returns. They rely on their personal experience regarding pesticide efficacy and pest pressures in previous years. They might, therefore, be able to judge pesticide use levels more situation dependent.

Cluster 2 farmers, although using higher inputs than cluster 1 farmers, may be defined as farmers trying to maximize the life production period of the orchard.

The factor analysis revealed that cluster 3 farmers are relying largely on recommendations from sources that can be regarded as being in favor of pesticides relative to non-chemical methods.

Although differences exist in management practices, there are also similarities. Therefore one can argue that farmers have started of their production using similar management practices. Cluster 1 farmers produce with lower levels of inputs but rely on chemical pesticides in crop protection. Here the percentage of farmers producing three harvest per year is highest, a measure for the intensity of production. On the other hand, in cluster 3 a similar percentage of farmers have three harvests, but at a higher level of input use and a wider range of chemicals used. Cluster 2 farmers tend to have less harvests per year, lower labor inputs, but higher pesticide use than in cluster 1. The ratio of yield to variable costs is highest in cluster 1. Also cluster 1 farmers have the lowest replanting costs. This can be regarded as an indicator for a healthy orchard.

Considering, that cluster 3 farmers on average have the older orchards, the question arises whether pesticide intensity levels are increasing over time. Apart from different perceptions, different sources of information on pesticides, possible different loss attitudes, different decision making factors and different pesticides used, this might give an explanation for the large variation in intensity levels.

The relation between input use and output are investigated in the next chapter. The question of efficient production is addressed, under a different angle, i.e. investigating age-yield relations, production functions and the possibility of the existence of path-dependency.

7 Pesticide Use and Tangerine Productivity under Different Management Regimes

This chapter discusses aspects of tangerine productivity, yield development over the tangerine production cycle, the influence of pesticide use on the productivity and on the development of pesticide use over time. The relation between age and yield is discussed in the first section. The second section analyses the effect of pesticides on the productivity of tangerine. The third section investigates the possible existence of path-dependency of pesticide use in the survey area.

7.1 Management Systems and their Influence on Yields - The Relation between Age and Yield

The objective of the analysis is to obtain production-related yield-age functions rather than biological growth functions. The functions derived from the survey data reflect the yield-age relationship for the region and the orchards at the time of the survey. As the survey data is of cross sectional origin, an analysis of age and yields is confronted with the variability existing due to time and technological changes. However, as described in chapter 5, production technology in the survey area has not changed largely over time. Some effects on production through the use of improved fertilizers and pesticides can be assumed. Therefore, technological changes are considered as being of little relevance for the yield-age relation in the survey area.

To analyze the relation between yield and age in fruit trees, six functions have been tested by HAWORTH and VINCENT (1977)[101]. They concluded that 'Hoerl's Special Function' can most ideally picture the yield development of fruit trees over time[102]. The function has the following form:

---

[101] Refer also to the discussion on productivity aspects in perennial crops in section 3.5.2.

[102] The other functions tested are:

- quadratic: $y = a + bx + cx^2$
- log quadratic: $\ln y = Ae^{bx+cx^2}$
- log reciprocal: $y = Ae^{b/x}$
- modified Gompertz: $y = Ae^{-be^{-cx}}e^{dx}$
- generalized logistic: $y = \dfrac{A}{(1+\phi\, e^{-b-cx})^{1/\phi}}$

(7.1) $y = Ax^b e^{cx}$

where $y =$ yield in kg per area and $x =$ age of tree crop in years, and can be expressed in a semi-log-linear form as follows:

(7.2) $\ln y = a + b \ln x + cx$

The function is intrinsically linear in the parameters and can be fitted using ordinary least squares with the appropriate assumptions about the residual variance. The 'Hoerl Function' has been used to estimate the yield-age relationship of tangerine in the survey area. The whole data set has been used for the calculation. It might be tempting to simplify curve fitting by finding average yields for each age of orchard and then fit a curve through the means. HAWORTH and VINCENT (1977) argue that the generally different number of observations at each age should be accounted for if a biased curve fit is to be avoided. This can be considered for by using ordinary least square estimation applied to all raw data where differing numbers of replicate values are taken into account.

The log transformation takes account of heteroscedasticity[103]. Outliers which were identified in a scatter diagram for the respective clusters were excluded. Only orchards in production have been included in the calculation. Thus, one hundred fifty observations have been considered in the analysis. The regression has been conducted analyzing the total sample as well as differentiated by the three cluster groups. Table 7.1 shows the regression results. All parameter estimates are significant at the 0.5% level, except for two cases. The regression of cluster 1 has the highest R-square resulting from the smallest variances in yields at specific years.

---

[103] Heteroskedasticity is often due to the skewness in the distribution of the variables under study. As a result a suitable transformation can make heteroskedasticity disappear while making the relationship linear at the same time (MUKHERJEE et al., 1998)

Table 7.1: Regression Results of Age-Yield Relationship

	Parameter	Value	Std. Error	Prob > ∣T∣	R-Square	Adjusted R-SQ
Total Sample	a	3.4406	0.5245	0.001		
	b	2.8212	0.4933	0.001	0.3144	0.3051
	c	-0.2408	0.0576	0.001		
Cluster 1	a	2.1190	1.1608	0.079		
	b	3.6472	1.1644	0.004	0.4765	0.4392
	c	-0.3009	0.1433	0.045		
Cluster 2	a	4.6604	0.9739	0.001		
	b	2.1066	0.9153	0.027	0.1698	0.1293
	c	-0.1974	0.1052	0.068		
Cluster 3	a	3.7102	0.7344	0.001		
	b	2.5044	0.6714	0.001	0.3076	0.2883
	c	-0.2000	0.0769	0.011		

Prob > ∣T∣ = probability value for *t-test* statistic

Source: Author's Calculations

The functions estimated for tangerine are:

(7.3) $\ln y = 3.44 + 2.82 \ln x - 0.24x$ for the total sample

(7.4) $\ln y = 2.12 + 3.65 \ln x - 0.3x$ for Cluster 1

(7.5) $\ln y = 4.66 + 2.10 \ln x - 0.2x$ for Cluster 2

(7.6) $\ln y = 3.71 + 2.51 \ln x - 0.2x$ for Cluster 3

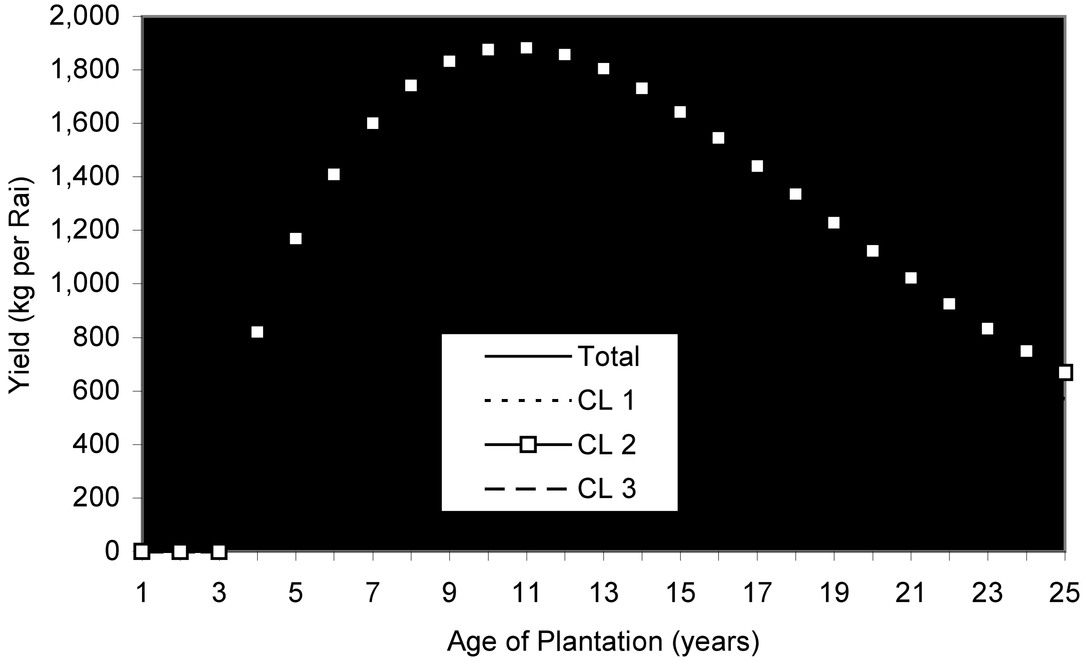
Figure 7.1 depicts the functions in graphical form (for x = Min (0; 4...25)). A production period of twenty-five years is considered. Maximum yields for the total sample are reached around year 12 and decline steadily afterwards. The yield-age function of cluster 2 increases more quickly compared to cluster 1. Maximum yield is reached in year 10 and 12 respectively, with cluster 1 having a slightly higher maximum yield. Cluster 3 has the lowest yields most of the time, performing slightly better towards the later stages.

From the curve fitting it can be expected that a long lifespan of the orchard can contribute to increase orchard returns over the cultivation period. The estimated maximum yields are around 1,900 kg per rai. Considering that potential yields in the high yielding period of around 5,000 kg per rai could be expected[104], the estimation reveals much lower yield levels.

---

[104] Refer to section 4.2.1.

Figure 7.1: Age-Yield Relationship of Tangerine in the Study Area



Source: Author's Calculations

Before starting to analyze differences in yield-age relationship amongst clusters, one needs to determine whether regressions of each cluster are significantly different in their structure. Thus, a test of structural stability of the regression models has been conducted (MUKHERJEE et al., 1998). The Chow Test[105] sets the residual sum of squares of the total group in relation to that of the sub-groups (DOUGHERTY, 1992). The test has been conducted in pairs (Table 7.2). The results allow the rejection of the H_0-hypothesis for the functions of cluster 1 and 2 at the 0.05 significance level. Therefore, these functions can be regarded as significantly different. H_0 cannot be rejected for the other comparisons[106].

---

[105] $$Chow\ Test = \frac{(RSS - RSS_1 - RSS_2) / k}{(RSS_1 + RSS_2) / (n_1 + n_2 - 2k)}$$

where RSS = Residual Sum of Squares, k = number of parameters estimated, n = total population, $n = n_1 + n_2$, n_1, n_2 = sub-populations (GUJARATI, 1995).

H_0-hypothesis= functions of sub-populations are the same

[106] The other pairs are only significantly different at the 0.25 level.

Table 7.2: Chow Test Results for the Yield-Age Relation

	RSS 1	RSS 2	RSS	N	Chow Test
Cluster 1+2	24.180	20.566	50.020	74	4.12
Cluster 2+3	20.566	42.140	64.579	118	1.70
Cluster 1+3	24.18009	42.14002	68.041	105	1.31

Source: Author's Calculations

It is worthwhile noting that the regression coefficient is much larger for the cluster 1 regression. To recall, the first cluster represents the low input case scenario with lower number of annual harvests and slightly younger orchards on average. Cluster 2 has medium to high input usage and focuses on a maximization of annual harvests. Cluster 3 farmers are the by far highest input users with on average slightly older orchards and lower yields.

It can be concluded that the plantation age contributes much more to the explanation of yields in cluster 1 than it does in the other clusters. Cluster 1 farmers are able to obtain similar yields as farmers from the other clusters with a much higher influence of the age-yield relation. One can assume that cluster 2 and cluster 3 farmers either use inputs inefficiently which may negatively influences the effect of plantation age leading to a less favorable yield age relation.

The Chow test revealed that differences in the yield-age relationship are mostly significant between cluster 1 and cluster 2. The analysis showed that the estimated functions result in production levels which are below potential yields indicated by experts. Hence, one can conclude that the majority of farmers in the region are not reaching potential yields under the currently applied management systems. The yield-age relation will be further taken into consideration in the following section on production functions in the survey area.

7.2 The Production Function of Tangerine

This section discusses the production situation of tangerine production in the survey area. A set of variables hypothesized to be of relevance for tangerine production is developed on the basis of the previous analyses. The specification of the production function and its implications are discussed. The target of this section is the determination of important parameters in the production function. It is expected that the multiple regression analysis allows stronger conclusions about cluster differences and farmers input behavior.

7.2.1 Criteria for the Selection of Variables and the Functional Form

For the regression analysis explanatory variables need to be selected according to production function theory and their relevance. Generally the explanatory variables cover input factors, location factors, status factors and indicators for the special farm situation. Table 7.3 gives an overview on the variables assumed to have an influence on production, discusses their relevance and indicates in what form the variables have been included in the regression.

Location dependent factors (like natural conditions, climate, rainfall) can be regarded as homogenous for the whole sampling area. Thus, they are not included in the regression. Among the input variables are the use of pesticides, fertilizers and organic manure as well as costs for machinery and labor. The relevance of the plantation age for output has been shown in the previous section and is one of the important determining factors for perennial crops. The orchard size might have an influence on output and is therefore considered. Finally, dummy variables are chosen to describe the educational level, the land status (own or rented), the number of harvests, the replanting of trees and other aspects believed to be of relevance in tangerine production.

Table 7.3: Explanatory Variables of the Production Function

Explanatory Variables	Relevance/Assumptions	Measurement Criteria
Pesticide use	Influence on yield development	Costs of individual pesticides categories per year
Fertilizer use	Direct/indirect influence on yield	Costs of fertilizers used per year
Use of organic manure	Direct/indirect influence on yield	Costs of organic manure used per year
Replanting	Direct influence on yield	Costs of replanted trees per year
Labor	Labor input in management system	Labor Costs per year
Plantation age	Yield changes with age of trees	Age of plantation in years
Orchard size	Scale effects might be applicable in larger orchards and might imply different strategies	Size of orchard in rai
Level of education	Possible influence on yield through information advantage	Dummy for educational level
Experience of farmer in tangerine growing	Possible influence on yield through learning effects	Dummies for over five years experiences in tangerine farming
Number of harvest per year	Possible relation of number of harvest to amount harvested (higher yield with three harvests)	Dummy for three harvests
Land status	Possible production differences on rented or own land	Dummy for land status
Management systems	Different intensity levels will produce varying output levels	Dummy for cluster belonging

Source: Author's Compilation

In accordance with HEADLEY (1968) that farmers are price takers and therefore values of output and input can be taken instead of weighing quantities against quantities, the variables included in the regression are in value terms. The output is weighted by the average price of tangerine obtained by all farmers.

Using value terms instead of pesticide quantities is suggested by the technical heterogeneity of pesticides as an input factor. Choosing pesticide quantities or amounts of active ingredients as a variable would underestimate the impact of newer, low quantity pesticides. Pesticide prices instead have the opposite effect. Old, more hazardous but cheap pesticides are not sufficiently taken account of. Despite of the problems which arise with the incorporation of pesticides as a variable, BURROWS (1983) argues that pesticides expressed in value terms per area are still the most appropriate measure, since it is a composite best reflecting chemical formulations, toxicity and quantities. In addition, the costs can capture the heavy use of inexpensive materials and the use of expensive compounds avoiding spurious quantity-price relations across individual farmers.

The production function is proposed as follows:

$$(6.7) \quad PF = f\ (OS, A, P_i, P_f, P_o, F, O, L, M, R, CL, D_{rent}, D_{harv}, D_{edu})$$

where PF denotes output, OS = orchard size (in rai), A = age of plantation (in years), P_i, P_f, P_o = pesticides (insecticides, fungicides, other pesticides in Baht per rai and year), F = fertilizers (in Baht per rai and year), O = organic manure (in Baht per rai and year), L = labor (in Baht per rai and year), M = machinery (in Baht per rai and year), R = replanting (in Baht per rai and year), CL = cluster belonging, D_{rent} = dummy for rented land (own land = 1), D_{harv} = dummy for three harvests per year (three harvests = 1), D_{edu} = educational status (above secondary school = 1)[107].

A Cobb-Douglas function, frequently used in economic analysis, has been chosen as the production function specification. Under the assumption of competitive factor markets, the parameter estimates can be interpreted as being the predicted shares of output earned by the respective input. The factor shares are equal to the marginal product of the respective inputs (DOUGHERTY, 1992).

According to CARPENTIER and WEAVER (1997), the Cobb-Douglas specification allows jointness in pest treatment and private input behavior. They argue that a separability specification as proposed by LICHTENBERG and ZILBERMANN (1986) might be inappropriate in a multi-pest environment with probably joint process of damage abatement and productivity aspects. This multi pest environment prevails in the survey area. Pest pressure continues throughout the year on a similar level as does the production process and the pesticide input across the survey area[108]. As beneficials are almost non existent (refer to section 5.2), it is likely that pest outbreaks occur in large areas at the same time. Damage abatement through pesticides can be assumed to have rather

---

[107] Risk and information factors have not been incorporated in the function. Refer to sections 3.2.3 and 3.2.4.

[108] PARADORNUWAT (1995a) states that the practice of three harvests per year together with high temperatures and humidity create problems of pest damage all year round.

uniform effects in the survey area. Therefore, the incorporation of a damage abatement function in the production function as suggested by LICHTENBERG and ZILBERMAN (1986) has not been conducted. In the absence of data on the actual damage abatement effects in the area, the treatment of pesticides in the framework of a conventional production function is assumed to be a feasible approach for a perennial crop with homogenous planting conditions and the permanent prevalence of high levels of pest occurrence.

The cross sectional nature of the data cannot take account of temporal variations (CARPENTIER and WEAVER, 1997) which, in the case of tangerine, can be regarded to be of minor importance due to large homogeneity in the production area and the production process. However, the cross sectional data base can take account of farm specific effects which have been argued to be the major determinants of variations in the tangerine production area.

In accordance to the previous analysis of the relation between age and yield (refer to section 7.1), where age has a linear and an exponential relation to yield, the production function also assumes this relation. Only farms in production are included in the analysis. The production function specified is a modified Cobb-Douglas function with an additional exponential relation in plantation age to take account of decreasing output in the late growing stages.

The general form of the function can be written as follows:

$$(6.8) \quad Y_k = Ge^{\alpha_1 P} \prod_{i=2}^{n} X_{i,k}^{\alpha_i} \ , \quad i = 2 \ldots n, k = 1 \ldots m$$

where Y_k denotes the value of output of farm k, P denotes the plantation age, $X_{i,k}$ is the value of farm k's input factor i, and G is a constant. Function (6.8) can be log linearized to give:

$$(6.9) \quad y_k = \gamma + \alpha_1 P + \sum_{i=2}^{n} \alpha_i x_{i,k} + u_k \ ,$$

where y_k is the natural logarithm of weighted output, P denotes the plantation age, $x_{i,k}$ are the natural logarithms of farm k's input factor i and u_k is the random disturbance. The function also incorporates Dummies for the cluster belonging, the land status, educational status and the number of harvests. The data used to fit equation (6.9) are derived from the survey. The variables entering equation (6.9) are explained in Table 7.3.

7.2.2 Regression Results

It has been tested if the data follows the statistically required conditions of multiple regression analysis. The error variable of the regression analysis is normally distributed. The analysis of studentized residuals reveals no outliers. As discussed in the previous section, the problem of heteroscedasticity is dealt with by the logarithmic transformation of the Cobb-Douglas function. To test whether multicollinearity exists between the regression variables, a correlation analysis has been conducted. Results show that the highest correlation coefficients are around 0.5. Therefore, the regression variables can be regarded as free from multicollinearity.

The regression has been conducted using ordinary least square estimation. All observations with orchards in production have been included in the analysis. To be able to estimate all pesticide categories over all farms, farmers not using fungicides have been excluded (22 orchards in production). Therefore, 132 orchards are used in the regression analysis. Some parameters, hypothesized earlier to be of relevance, have been excluded because of very small parameter estimates, no significant t-value and no increase in R-square through their incorporation. These variables are the time of tangerine growing and the dummy for organic manure use. The variable describing the use of herbicides has not been considered as only a very small share of farmers use herbicides.

The regression has first been conducted with the total sample leaving the clusters out of consideration[109]. The analysis results in negative marginal productivity for the three pesticide variables (insecticides, fungicides, other pesticides). Furthermore, results for the age of plantation (linear and exponential), the orchard size, labor and own land conclude to a positive marginal productivity of these variables. This analysis has been further specified to analyze the impact of the three clusters. Dummy variables for the cluster belonging introduce the influence of the respective management group.

Table 7.4 shows the regression results of regression (6.9) including the cluster belonging. The parameters are the logarithmic values and therefore represent the production elasticities. No significant result could be obtained for fertilizer input allowing the conclusion that fertilizer use occurs more or less independent from output levels.

---

[109] Refer to Table VI.1 in the Appendix. A regression only considering clusters without incorporating pesticide costs result in mostly not significant parameters.

Table 7.4: Parameter Estimates for the Production Function Specification (N = 132)

Parameter	Variable (in logarithmic form)	Parameter Estimate	t-ratio
γ	Intercept	1.9509	1.054
α_1	Age of Plantation (linear)	1.5594	3.070 ***
α_2	Age of Plantation (exponential)	-0.1234	2.159 **
α_3	Orchard Size	0.1878	2.287 **
α_4	Fungicides	-0.1231	2.235 **
α_5	Insecticides	-0.2198	2.399 **
α_6	Other Pesticides	-0.0193	2.569 **
α_7	Fertilizer	0.1121	0.915
α_8	Organic Manure	0.0230	0.235
α_9	Replanting	0.0668	1.063
α_{10}	Labor	0.4939	3.509 ***
α_{11}	Machinery	0.1883	1.294
D_1	Cluster 2	0.7416	3.532 ***
D_2	Cluster 3	0.5001	2.075 **
D_3	Own Land	0.2909	1.841 *
D_4	Education	0.1849	1.366
D_5	Three Harvests	0.2051	1.242
	R-square	0.4442	
	Adjusted R-square	0.3669	
	F-value	5.744 ***	

*** significance level < 0.01; ** significance level < 0.05, * significance level < 0.1

Source: Author's Calculations

Naturally, the age of the plantation has a high influence on the output. The negative prefix on the exponential component of the plantation age explains decreasing outputs in later years. The regression analysis reveals further that the orchard size has a positive influence on output. The output is also positively influenced by labor inputs. One unit of increased labor input increases the output by 0.5. The variable for machinery costs has no significant parameter estimate.

The land status has some influence on the output meaning that farms operating on own land perform better than the ones on rented land. The conclusion that rented land is treated differently from own land can therefore not be rejected. The parameter suggests better yields from own land by an parameter of 0.29 which would be in line with assumptions drawn from group discussions in the field. Farmers report different behavior on rented land.

The regression parameters of insecticide and fungicide costs are significant. The regression parameter suggests a negative production elasticity. Among all pesticide categories, insecticide costs have the highest negative estimate followed by fungicide costs, whereas the costs of other pesticides show little effect on output. This estimators cannot necessarily be interpreted that high pesticide use has a direct negative effect on output. In fact, it shows that for a majority of farmers current pesticide costs are negatively correlated to output. The supports findings from the previous chapter that farmers producing more intensive are not necessarily the farmers with highest outputs. However, the cluster belonging per se has a positive production elasticity concluding to higher outputs in cluster 2 and cluster 3. A positive marginal relation between the educational level and the output has no significant parameter estimates as it is the case with the number of harvests and replanting costs.

The most striking result obtained from the regression analysis is the negative marginal productivity of pesticide inputs. This stands in contrast to production functions estimated in other studies as discussed in section 2.1. This result suggests that the current level of pesticides in tangerine production in terms of pesticide costs is inefficient.

7.3 Sustainable Production and Existing Management Systems

Suboptimal pesticide use raises the question of sustainability of current citrus pest management strategies. It also indicates a possibility of the existence of path-dependency, i.e. the system may have entered the pesticide treadmill. In the first sub-section indicators of inefficient pesticide use are discussed. As inefficient pesticide use level itself is not a sufficient indicator for the existence of path-dependency, it has to be analyzed whether a locked-in situation exists (refer to section 3.4). Possible aspects of a locked-in situation are discussed in the second section. The third section concentrates on the survey and the existence of indicators of path-dependency.

CARLSON (1977) argued that the development of pest resistance implies decreasing marginal pesticide productivity over time and that the demand should fall for those pesticides which have developed resistance. The standard characterization of this phenomenon is that farmers' typical short-run response to the development of resistance is to increase usage levels as compensation for the decrease in pesticide productivity. The use of the respective pesticide will only decrease when its effectiveness is lower than that of an alternative pesticide (LICHTENBERG and ZILBERMAN, 1986). Existing management strategies can be considered as a result of previous decisions. Unfortunately, in the absence of a reference system, it cannot be concluded how far the existing production systems are diverging from a sustainable path. DOSI (1997) argues that there is the methodological problem of how to recognize path-dependency when you see it. One just observes one sample path which actually occurred in history. He argues that in order to know whether the occurrence of the current situation is path-dependent or not, one ought to be able to 're-run' history. In the context of pesticide use one must prove that suboptimal use levels led to a locked-in situation. Intensive use of pesticides will be continued as long as the shift to another management strategy is regarded as too costly. To what degree this is applicable to the survey area is discussed in the following.

7.3.1 A Locked-In Situation?

The production function analysis in the previous section showed that pesticide overuse exists and that the marginal product of pesticides may well be negative. The analysis on the age-yield relation revealed that yields for the respective cluster differ over time. However, in the absence of a reference system, it cannot be determined who is performing best. Conclusion can only be drawn in so far as all analyses revealed inefficient pesticide use levels.

As discussed in economic literature, there are three conditions for path dependency: sunk costs, increasing returns to scale and network externalities[110]. The aim of this section is, therefore, to determine if these theoretically derived indicators are relevant in tangerine production in the survey area. It also has to be investigated how a management system change could look like and what the costs for such a change would be as a locked-in situation remains basically due to high costs of a technology change.

7.3.1.1 Sunk Costs in Tangerine Production

Sunk costs related to pesticide use refer, among others, to the research efforts for new varieties, for new pesticides and fertilizers and their promotion programs. For many years governmental policy of Thailand has been focusing on the promotion and support of high yielding varieties and the use of chemical crop protection. This is justified by the common opinion that chemical crop

---

[110] Refer to section 3.4.1.2

protection is part of an inseparable production package. Also in tangerine production there are promotions of chemical crop protection. The costs of this promotion as well as to produce new pesticides, not yet confronted with resistance effects, can be regarded as sunk costs.

The equipment purchased for chemical crop protection can also be classified as sunk costs. For the tangerine farmers this covers the boats equipped with sprayers and knapsack sprayers. Once bought, practically there is no other use than for spraying pesticides. This tends to discourage the organization of additional information for alternatives. Alternative methods cause information costs, i.e. how to obtain the necessary equipment and how to use it. Furthermore the presence of pesticide company's salesmen in the survey area influences the information environment in favor of chemical pesticides. Pesticide retail shops have the additional function of meeting points and discussion centers.

Another aspect of sunk costs relates to the investment in orchard establishment and the first years until production begins. These costs leave the farmer with little choice but to continue tangerine growing at least until he reaches the break-even point. With orchard establishment the decision on the planting material is made. This reduces management options in later years. The use of resistant rootstocks would allow a decrease in chemical crop protection. However, once planted, the trees will be kept at least until a change of the planting system would pay off. It can therefore be concluded that sunk costs prevail in tangerine production.

7.3.1.2 Relevance of Increasing Returns to Scale in Tangerine Production

The second aspect of the determination of path-dependency is the question whether increasing returns to scale exist. Three sources of increasing returns to scale in agricultural production are listed by REICHELFELDER (1981). First, the majority of costs are fixed costs. This is partly true for tangerine production. Considering that the costs for the orchard establishment are categorized as sunk costs, the percentage of additional fixed costs is relatively small compared to variable input costs. However, increasing returns to scale exist in the way that the costs per unit of output fall for boats, spraying equipment, water pumps etc. as orchard sizes increase.

The second aspect relates to the payoffs from gaining experience in the production process. The more experienced farmers are the better and the more accurate management decisions can be made, i.e. with regards to timing and on the method of crop protection.

Increasing returns to scale can be observed in two aspects in relation to pesticides. First, as explained in section 3.4, a time-dependence in the use of pesticide may exist. Due to the effect of pesticides on the ecosystem the need for pesticides might rise over time. Second, continuous improvement of chemical pesticide products increases the advantage of pesticide use. New products at least promise higher efficiency. Thus, once on the path of chemical pesticide use, the ongoing introduction of new products and product combinations opens the option of increased returns.

7.3.1.3 Network Externalities in Tangerine Production

The third factor, contributing to path dependency, are network externalities. Network externalities are describing the phenomenon that positive payoffs can occur through interaction (refer to section 3.4). Interactions are existing on several levels in tangerine production in the survey area. The agro-ecosystem is dominated by tangerine growing. Varieties used and production methods are similar. As chemical crop protection methods are closely related to production methods in the area, information and knowledge concerning crop protection issues is shared among farmers. Farmers who start to grow tangerine quickly get to know pesticides as an inseparable element of tangerine production. Thus their knowledge regarding pesticide use is high relative to other crop protection methods.

Retail shops serve as meeting points, training center and information source regarding relevant aspects of tangerine production. This is not necessarily limited to crop protection and fertilizer use. In fact, it seems to be part of the social discourse among farmers in the area. Thus, a farmer who shows a critical attitude towards using chemical pesticides is excluded from important information sources. A third aspect often pointed out by farmers in the area is the social pressure of retaining a pesticide intensive strategy. Farmers fear that if one farmer stops using chemical crop protection, this might negatively affect their orchards and thus increase pest pressure in their fields. One might describe this phenomenon as a negative network externality.

The promotion of chemical crop protection methods through government extension service and private companies further increases the information advantage of chemical crop protection. Hence the costs of obtaining information of alternatives to chemical crop protection are high [111].

---

[111] The reasons for such discrepancies between chemical crop protection and alternative or additional crop protection methods is discussed in chapter 3.

7.3.1.4 Costs of a Change in Crop Protection Technology

A locked-in situation is favored by high costs of technology change. Instead, all applicable measures are taken into account to enable a pest preventing environment.

In principle alternative methods of pest control are the use of resistant rootstocks and to stop using marcotted plants. This is expected to improve the health of trees and decrease their susceptibility to pests (ROISTACHER, 1995). The costs for introducing resistant rootstocks are high for several reasons. First, resistant rootstock supply is very limited. Production is not yet conducted on large scale due to an insufficient number and operation of nurseries and a government controlled promotion of nurseries. Secondly, the decision on which trees to plant is made at the beginning of orchard establishment. Thirdly, the information on the benefits of resistant rootstocks is uncertain. Also marcotting is a cheaper and simpler multiplication method which the farmer can do by himself.

A second component of the adjustment costs are costs for additional research on management systems alternatively. Current research priorities of the government concentrate mostly on chemical crop protection although IPM is part in the government's agricultural development plan [112].

Currently, the costs of information for a farmer willing to adopt non-chemical methods of control are extremely high. Information is difficult to obtain and the adaptability to the farmer's specific situation is uncertain. Another aspect, which can be classified into 'costs of change', is the establishment of marketing channels for higher priced products cultivated with less pesticide inputs as it is established in other countries. Some efforts have been made in a small scale (organic rice, Green Net, 'pesticide free village').

Another possibility is the change of the irrigation system. This could contribute to a healthier orchard environment. Such a change would imply to stop growing tangerines on dikes and the use of sprinklers for irrigation. However, this is a very costly change and is easier adopted on new developed orchards. In fact, there are already some farmers changing their irrigation system in newly developed orchard areas.

The above discussion suggests that the given information environment due to lack of incentives, lack of research and only weak promotion of alternative

---

[112] For some suggestions on IPM technologies refer to section 4.2.3 and Table IV.3 in the Appendix.

technologies is not supportive for change towards more non-chemical methods of control. The costs of a system change can be regarded as high and therefore hinder the introduction and dissemination of alternatives. This suggests that a locked-in situation does in fact exist.

7.3.2 Indicators of Path-Dependency in Tangerine Production

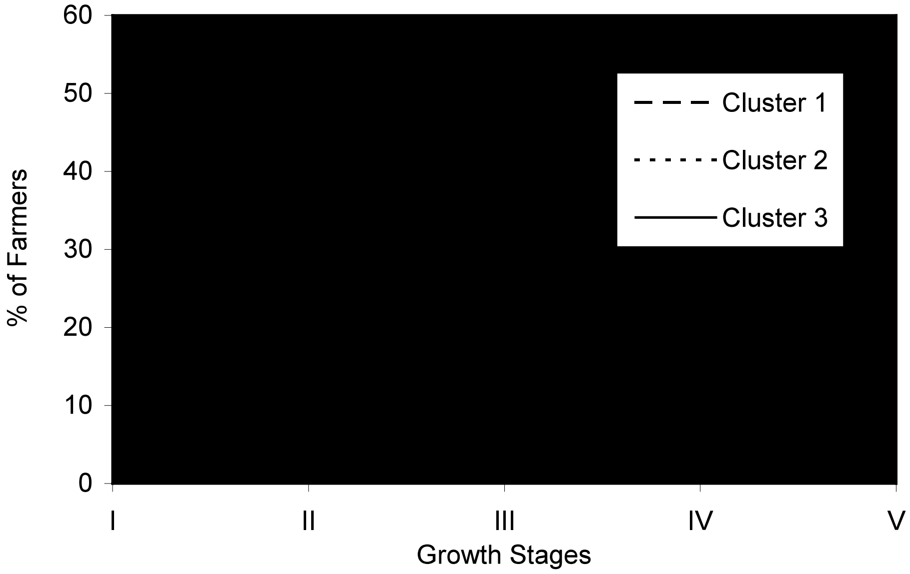
If time series data would be available, one could analyze the development path of a farmer and observe whether crop protection methods changed over time. BALMANN and HILBIG (1998) simulated structural change in agriculture and used cluster analysis to structure the data. They concluded that if the farmers stay in their cluster for a long period of time, path-dependency prevailed in the simulated agrarian structures. In the following, four options are discussed on how path-dependency can be identified using cross sectional data for the case of pesticides in cities. Using the survey data comparisons are made by plantation age, regional differences, impacts of the production function and distribution within the clusters.

One way to verify the hypothesis of a path-dependency is to observe whether farmers who start with tangerine production follow a different crop protection strategy as compared to farmers who are producing tangerine for many years. The hypothesis therefore is that farmers less experienced in tangerine growing are more frequently found in the low intensity cluster – but over time already follow the path of the more experienced orchard growers. Therefore, in the analysis orchards are considered as points in time according to their plantation age.

7.3.2.1 The Dependency by Plantation Age

To analyze whether these assumptions are true orchards are divided by age and clusters (Figure 7.2). Cluster 3 farmers are expected to have a higher percentage of older orchards compared to the other two clusters. In addition to orchard age (contrary to the analyses in the previous chapters), replanted orchards are taken into account. In the case of a renewed plantation on the same location, the growing period of the former (replanted) orchards has been considered in the calculation. This procedure has been chosen as it is assumed that orchards grown on replanted tangerine land might have an affect on the pest ecosystem; i.e. higher pest pressure must be expected.

Figure 7.2: The Development Path of Clusters by Growth Stages (in percent of farmers of each cluster)



Growth Stages: I = 0 - 5 years III = 10 - 15 years V > 20 years
II = 5 - 10 years IV = 15 - 20 years

Source: Author's Calculations

As shown in Figure 7.2, cluster 3 farmers have a higher percentage of orchards with older trees. The share of orchards in growth stage two and three and in the oldest growth stage is highest. Cluster 1 farmers have the highest percentage of orchards in the young stage and have a continuously declining share towards the older stages. Cluster 2 has a lower percentage in stage two and three and peaks in the young and the older stage. Older orchards generally produce on more intensive levels, i.e. the average plantation age of cluster 3 is significantly higher[113].

7.3.2.2 The Dependency by Region

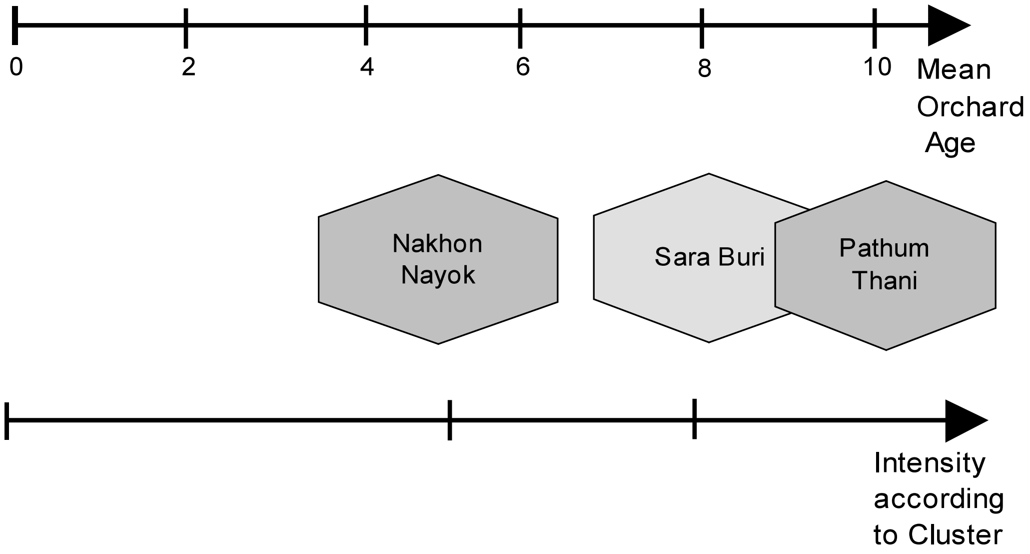
There are regional differences with regards to the duration of tangerine growing. Therefore it is hypothesized that the region with a long history of tangerine growing tangerine is also the area with a high level of intensity input use, i.e. more farmers of cluster 3 would be found in that region. Pathum Thani is the ‘oldest’ production region for tangerine in the survey area. From Pathum Thani, tangerine production spread to the provinces of Sara Buri and Nakhon Nayok.

---

[113] Refer to Table V.8 in the Appendix.

In Figure 7.3 the relation between production area (province) and the average age of plantations is drawn. As described above share of orchards in the less intensive clusters is higher than in the ‘younger’ production area while in Pathum Thani the majority of the farms are in cluster 3. The existence of path dependence would mean that the ‘younger’ region follow the path of the ‘older’ region. In Figure 7.3 the peaks of the hexagon are indicating the mean plantation age while the width indicates where the majority of cluster belongs. It is shown that all three provinces have farms from more than one cluster.

Figure 7.3: Possible Development of Path-Dependencies in Tangerine Production



Source: Author's Calculations

Table 7.5 shows that a larger share of farmers from Pathum Thani can be found in the third cluster whereas around three quarters of the farmers in Nakhon Nayok belong to cluster 1 and cluster 2 [114].

Table 7.5: Distribution of Clusters per Production Region (%)

	Pathum Thani	Sara Buri	Nakhon Nayok
Cluster 1	23.3	19.7	25.0
Cluster 2	27.2	39.4	52.8
Cluster 3	49.5	40.9	22.2
Total	50.2	32.2	17.6

Source: Survey Data

Considering that production conditions are the same for all three areas, the ‘younger’ production regions follow the development path of the ‘older’ areas. This suggests an increase of intensity over time. This could be an indicator for the existence of path-dependency in pesticide use.

7.3.2.3 Development of Pesticide Costs

As discussed in the previous sub-sections, there is some indication that the time farmers grow tangerine on the same piece of land affects the development of pesticide use over time.

Similar to the study of BALMANN and HILBIG (1998) who concluded that farmers belonging to a certain cluster of agrarian structure stay within the cluster in the course of structural development. One can hypothesize that path dependency in pesticide use may exist, if farmers stay in their cluster over time. This implies the assumption that the three clusters are in fact different management systems producing on different intensity levels[115].

Consequently, each cluster is defined according to the time tangerine is grown on the farm. Similar to the analysis of age-yield relation[116] the cross sectional

---

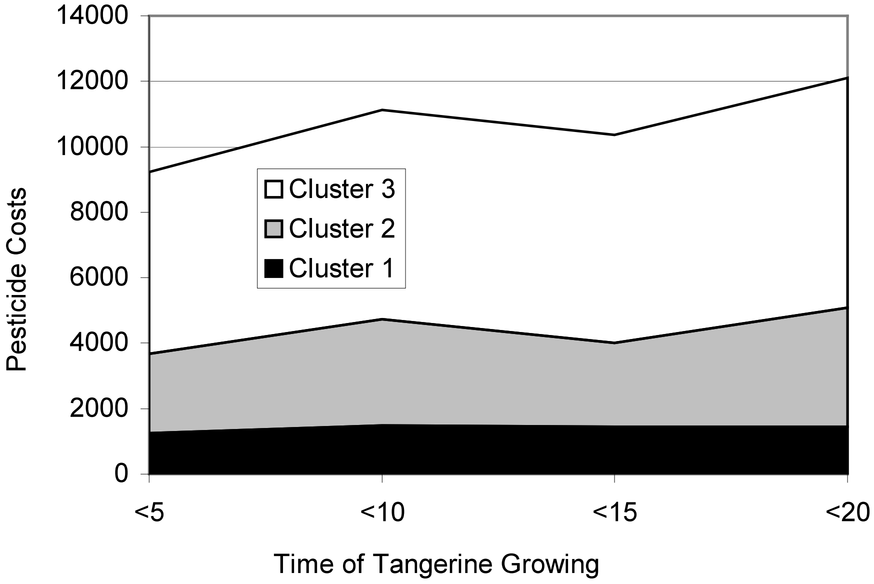
[114] For a table on the distribution of the clusters by region and growing stage refer Appendix, Table VI.1.

[115] The contrary assumption argues that less intensive farmers follow the path of the intensive producing farmers in the course of time.

[116] Refer to section 7.1.

data are treated as time series data. If the above hypothesis is true, an increase in pesticide use over time in each cluster should be observed. Figure 7.4 shows the average pesticide costs by cluster, according to the duration of tangerine growing in one place [117].

Figure 7.4: Development of Pesticide Costs by Cluster and Growth Stage
(average pesticide costs in Baht per rai)



Source: Author's Calculations

Figure 7.4 shows the trend in pesticide use according to the time of tangerine growing. In all clusters pesticide costs are higher in older orchards, however the level of pesticide costs differs by cluster.

A linear logarithmic curve has been fitted to pesticide costs and the growing time differentiated by cluster. The following functions has been estimated:

---

[117] This variable is not identical to the variable 'plantation age'. Here, orchards where replanting has occurred and who are currently producing in their second production cycle are taken account of with the total time tangerine is grown on the specific location. It is assumed that the time tangerine is grown in the same location has an influence on pesticide intensity due to impacts on the ecosystem.

(7.10) $\ln PC = a + \beta_1 \ln TG$

(7.11) $\ln PC = a + \beta_1 \ln TG + \beta_2 CL_2 + \beta_3 CL_3$,

where *PC = pesticide costs* and *TG = time of growing tangerine on the specific orchard*[118].

The results for function (7.10) is as follows:

$$\ln PC = 7.48 + 0.32 \ \ln TG$$

with an R-square = 0.1365 and a significance level of 0.01. Adding the clusters as dummy variables increases the R-square to 0.75 (Table 7.6).

Table 7.6: Parameter Estimates of Pesticide Cost/Age Relation

Para-meter	Variable	Parameter Estimate	t-ratio
a	Intercept	6.89	94.82***
β_1	Time of Tangerine Growing	0.14	4.45***
β_2	Cluster 2	0.75	10.94***
β_3	Cluster 3	1.52	22.22***
	R-square	0.7543	
	Adjusted R-square	0.7506	
	F-value	205.7***	

*** significance level < 0.01

Source: Author's Calculations

The regression parameter shows in a positive influence of the time of growing tangerine on pesticide costs. The improvements in the statistical quality of the equations as a result of adding the clusters as variables is an indicator that the groups belong to different production paths.

In regression (7.11) further explanatory variables were included. These are mineral fertilizer and costs of organic manure, orchard sizes and level of replanting costs. These variables are assumed to be related to crop protection. Table 7.7 shows that only replanting costs have a significant influence on pesticide costs. This is surprising as replanting in theory should improve the

---

[118] Thirty-one farmers (15%) are growing tangerine on their orchards for more than twenty years (range 20 – 47 years).

health status of an orchard. On the other hand replanting might be an indicator of prevailing pest and disease problems of an orchard.

Table 7.7: Parameter Estimates of Pesticide Costs Function

Parameter	Variable	Parameter Estimate	t-ratio
a	Intercept	6.12	15.89***
β_1	Time of Tangerine Growing	0.11	3.31***
β_2	Cluster 2	0.76	10.75***
β_3	Cluster 3	1.46	20.12***
β_4	Fertilizer	0.07	1.44
β_5	Organic Manure	0.03	1.47
β_6	Orchard Size	-0.01	0.28
β_7	Replanting Costs	0.04	1.79*
	R-square	0.7725	
	Adjusted R-square	0.7608	
	F-value	65.9***	

***	significance level < 0.01
**	significance level < 0.05
*	significance level < 0.1

Source: Author's Calculations

Table 7.8 shows the results for insecticides as the dependent variable. Insecticides are the major component of pesticide use in tangerine. Similar to the previous equations, development of insecticide costs over time depend on the time of tangerine growing and the cluster. Parameter estimates are similar to those of the pesticide cost function.

Table 7.8: Parameter Estimates of Insecticide Costs Function

Parameter	Variable	Parameter Estimate	t-ratio
a	Intercept	6.12	15.89***
β_1	Time of Tangerine Growing	0.13	2.01**
β_2	Cluster 2	0.70	4.97***
β_3	Cluster 3	1.28	8.74***
β_4	Fertilizer	0.07	0.76
β_5	Organic Manure	0.04	1.02
β_6	Orchard Size	-0.13	2.24**
β_7	Replanting Costs	0.08	1.66*
	R-square	0.3926	
	Adjusted R-square	0.3710	
	F-value	18.2***	

*** significance level < 0.01
** significance level < 0.05
* significance level < 0.1

Source: Author's Calculations

Summing up the results of all three equations shows little difference in the statistical quality of the equations. The fact that the variables fertilizer costs, costs of organic manure and the level of replanting costs have a significant positive sign underline earlier observations that farmers who use a lot of pesticides also use high level of other inputs. The fact that replanting costs positively affect pesticide costs indicate that a time dependence of pesticide costs may exist. This is further supported by the fact that other explanatory variables have very little influence on pesticide costs over time.

7.3.3 Summary

The analysis of the age-yield relation showed that a major determinant for the output is the age of plantation. It is shown also that actual yields are below potential yields when using literature data as a reference. This might serve as a first indicator for suboptimal input use levels or even inefficient overall orchard management. On the other hand, there are farmers in every cluster who are able to reach those potential yields. The production increases quite rapidly in the first years, with a peak production period between year 11 and

13 and a slow decline in yields towards the later growth stages. As the regression coefficients of the age-yield relation are higher for cluster 1 the conclusion has been drawn that the plantation age explains the output to a higher degree than in the other clusters. The clusters differ less in the maximum yields obtained than in the shape of the age-yield curve. A test on the difference between the functions resulted in significant differences between cluster 1 and cluster 2.

The question arises why farmers in cluster 2 and cluster 3 are producing with high input levels relative to cluster 1. The explanations are twofold. Firstly, either the suboptimal use of some inputs has a negative effect on the development of the trees, thus yield increases due to the age-yield relation cannot be realized. Secondly, over time, farmers have to use increasingly higher levels of pesticides to obtain a given level of outputs. These two explanations can be derived from the production function analysis. Here, Cobb-Douglas specification was chosen. Pesticide costs were included as a variable in the production function. This deviates from the theoretical conclusions of treating pesticides in damage abatement framework. However, pest pressure in tangerine production is existent the whole year because of the rather continuous production process. As a cause of the methodology chosen, an overestimation of marginal productivity of pesticides may occur. Contrary to the damage abatement functions treating pesticides as an input variable in the Cobb-Douglas function there is no maximum.

However, use levels seem partly to be independent from profit maximization criteria. This statement is underlined by the negative marginal productivity of pesticides, implying a suboptimal intensity of pesticide use. Despite of the methodological short comings two major observations can be made. One is that sign of the variables that input use decisions may not always follow profit maximization criteria. The second observation is that the marginal product of pesticides may well be negative. Hence pesticides may not be contributing to crop loss reduction to an extent which is commonly assumed.

Under the assumption that pest pressure increases over time due to resistance and resurgence, the continuos high level of pesticide use suggests a grown dependency on pesticide use. As the institutional environment e. g. crop loss and pesticide benefit assessment procedures and the availability of information on alternative methods of control suggests some degree of path dependency in the survey area.

In a next step it has been asked whether conditions exists leading to path-dependency in tangerine production. On one hand, there are sunk costs borne by pesticide producers; i.e. pesticide development costs, costs for research and promotion of the pesticide and high yielding varieties requiring more chemical inputs. On the other hand, sunk costs exist originating from the tangerine production process, e.g. for pesticide application equipment. The use of other crop protection methods would require new investments. Another aspect of sunk costs is the orchard establishment. Here, the foundation is laid for future management options. The planting of rootstocks susceptible for diseases or already infected through marcotting technique increases the probability of intensive pesticide use in the future.

Increasing returns to scale exist in the gaining of experience through continuous pesticide use. This is an advantage other methods cannot offer as little experience with their use exists. As the benefits of pesticide use are often overestimated possible increasing returns of pesticide use are also overestimated.

Network externalities exists in several aspects in the survey area. As most of the farmers in the area produce tangerine, there is a large pool for information exchange. Furthermore, a pressure exists to continue chemical crop protection as the farmers believe exists that if one stops spraying, pest pressure on the other farmers will increase. Costs for changing current management systems can be further considered as too high for a system change.

Whether the existence of path-dependency can be analyzed with the survey data has been addressed in the final section of the chapter. The orchards have been differentiated by growing stages, regions and development within clusters. Although the interpretation of such an analysis' results is limited, enough evidence for the existence of path-dependency could be found. These differentiation underlines the assumption that a locked-in situation exists in tangerine production.

If all farmers are moving towards the same locked-in situation, currently being on different development levels or whether the three clusters depict systems locked-in on a certain level of pesticide use could not be completely answered. However, the differentiation by clusters revealed that the farmers within the clusters are moving on a development path which includes higher intensity levels. The farmers intensify their crop protection but stick to their cluster. The farmers move towards an equilibrium of pesticide use which can be regarded as a suboptimal one. This equilibrium is supposedly on different intensity levels for the three clusters. A regression analysis of pesticide costs, in relation to some explanatory variables, suggests the time dependence of pesticide costs combined with a strong influence of cluster belonging.

It has to be concluded that unless either a production crisis occur, or governmental extension service and policy directions are stronger promoting chemical alternatives, inefficiencies and most likely path-dependency will continue in current management strategies.

8 Summary and Conclusions

8.1 Summary

The study analyses the economic and political factors that influence pest management in citrus production. This topic draws its relevance from the ongoing political and institutional discussion about chemical crop protection methods and the increase in pesticide use despite growing concerns regarding external effects. Thailand is one of the case study countries selected within a larger international project on pesticide policies. It was found that several factors stimulate the use of pesticides in many agricultural production systems in Thailand. As one of the major fruits and most chemical-intensive crops, citrus has been chosen as a case study.

The analysis of the crop protection sector in Thailand has raised concerns related to the use and ongoing support of pesticides as the main crop protection strategy. Price factors, institutional factors and information factors have been determined as favoring the excessive use of pesticides and hindering development and dissemination of alternative strategies. The negative consequences of pesticide use are underestimated and are not incorporated in the decision making process, neither at farm nor at policy level. According to the WHO classification, most of the pesticides used still belong to the 'extremely' and 'highly' hazardous pesticide groups.

At all levels, the availability of information plays an important role in the agricultural decision making process. Biased or insufficient information acts as a constraint to the dissemination of alternatives to pesticides. Furthermore, it limits the options available in the political decision making process. Decision making is often based on information given by retailers and other farmers, as well as pesticide companies.

In Thailand, the liberal pesticide market has led many companies to be involved in the import and local distribution of pesticides. Controlling this market is difficult and the implementation of existing rules is lax. Tax reductions on pesticides increase the profitability in this market. It can be assumed that the current price of pesticides does not include all costs occurring in the ecosystem. So far, little has been done at the policy level to reduce the distortions in favor of pesticide use. While strong efforts are made to improve pesticide intensive management systems, in recent years an increased efforts have been taken to introduce Integrated Pest Management (IPM) methods. However, for a successful nationwide IPM program, its implementation must be accompanied by the enforcement of policies relating to pesticide imports, licensing, registration, control and pricing.

The negative side effects of current pesticide use result in considerable costs to society. If these pesticide-related health effects and other external effects such as i.e. resistance, resurgence, residues and water pollution are considered, then, in many cases the efficacy of pesticide use appears doubtful. The assessment of the external costs related to pesticide use in Thailand points towards a ratio of almost one to one, i.e. for each Baht spent on pesticides external costs of almost one Baht have to be taken into account.

This study suggests that the impacts of pesticide policies, like subsidies, biased information on costs and benefits of pesticides, resource costs and the possible existence of path-dependency are best studied with a crop like citrus where the high use of external inputs persists over a long period of time. All aspects of the theoretical discussion have therefore been analyzed for the tangerine sector, the most important citrus crop in the central region of Thailand.

In the theoretical part of the study, an economic framework for incorporating pesticides was conceptualized. In the discussion on production functions the methodological difficulties of incorporating pesticides were addressed. It was argued that in the economic assessment pesticides cannot be treated like other standard input factors. This is mainly due to three aspects, namely the methodological difficulties of incorporating pesticides in a production function, the divergence between perceived and real profitability of pesticides and the neglect of external effects. The discussion on current benefit cost assessment, the quantification of crop losses, information and risk constraints as well as resource costs and path-dependency support the profitability aspect while external effects are discussed in relation to pesticide use. The results of the theoretical analysis lead to the following working hypothesis:

- *Pesticides in citrus production in Thailand are used above their economic optimum from an private and social point of view.*
- *Cross-sectional differences in management strategies in citrus production regarding levels of input and especially pesticide use cannot solely be explained by economic maximization criteria.*
- *The citrus production in the central region of Thailand is in a situation of locked-in for pesticide use. Therefore, options for future management decision are limited and a pesticide dependent path is likely to continued.*

The analysis of the production situation in the Central region revealed that the natural conditions are not best suited for tangerine production. Nevertheless, the largest monocultural tangerine production area in Thailand developed there. In addition to the suboptimal natural conditions, some major shortcomings in the current production systems enhance the susceptibility to pests and diseases, which in turn leads to an increase in pesticide use. As tangerine is produced the whole year pest pressure is comparably high. The lack of knowledge on the necessity to use resistant rootstocks, their limited supply and the ongoing support of pesticide based production systems can be regarded as major shortcomings from the institutional side. The most influential factor identified is probably the strong dependence on the omnipresent pesticide salesmen and retailers, which create pesticide overfriendly environment and convince farmers of the absolute necessity of pesticide use. The discussion on alternatives to pesticide use revealed that relatively small changes in the management system would lead to more sustainable, less pesticide intensive management systems. Several options to improve current systems and thus reduce pesticide use have been presented.

A farm survey has been conducted in tangerine production in Central Thailand to analyze management systems and the use of pesticides. The sample covers the wide range of orchard sizes, plantation ages and of farmers' social background. The majority of pesticides used are insecticides, of which 90 percent belong to the WHO classes Ia, Ib and II, implying potential human health hazards. The farm level analysis showed that the variance in pesticide costs used per rai and year is comparably high, indicating the existence of different pest management systems. Therefore, the surveyed farmers were clustered according to the level of their production intensity. The production intensity has been defined as the intensity of pesticide and fertilizer use in terms of annual costs and the share of pesticide costs in percent of the total variable costs. The clustering procedure resulted in three clusters representing management systems producing at different intensity levels.

The analysis of differences in farm characteristics revealed that the clusters differ in several production factors. The third cluster, representing the most pesticide intensive cluster, hereby turns out to be as well the most intensive cluster for most other factors. However, this high level of intensity does not result in higher yields and revenues. A further differentiation of farm budgets by yield levels concludes that a higher input intensity does not correlate with higher outputs. This result is a first indicator for pesticide overuse in the area.

The data were further analyzed for specific indicators of differences in pesticide costs. Differentiation has been made in the types of pesticides used according to pesticide categories, the distribution of pesticide use within the production cycle and quantities and costs of pesticides. Major differences exist in terms of the spectrum of pesticides used. The more intensive clusters are using a higher share of pesticides other than insecticides. The timing of pesticide applications in the cropping cycle is similar across the clusters, indicating similar strategies, however at very different intensity levels. Major differences can be determined in the quantities of pesticides used. The most intensive producing farmers apply more than three times the amount used by the low intensive farmers. The analysis of average pesticide prices by WHO class revealed that the intensively producing farmers are, on the one hand, the ones using the more selective, less poisonous pesticides. However, on the other hand, they are also using the most hazardous pesticides.

In summary, cluster 1 farmers can be defined as the more efficient producing farmers, using lower input quantities, but obtaining high output. Their total variable costs in percent of revenue is the smallest, reaching from 60 percent in the lowest to less than 10 percent in the highest yield stages. Cluster 2 farmers produce less intensively in terms of the number of harvests per year and labor inputs, but more intensively than cluster 1 in terms of other input factors. It can be determined that cluster 2 farmers concentrate on the maximization of production considering the whole life span of the orchard instead of annual output maximization. Although cluster 3 farmers are by far the most input intensive producing farmers, their yields are not reflecting these high input uses.

Considering that the share of farmers with older orchards is higher in the more intensive clusters, the question arises what explains the yield, to what extent are pesticides contributing to it and whether pesticide intensity increases over time.

In this context pesticides have been treated as variables in the production function. Despite concerns raised in the theoretical chapter regarding the direct incorporation of pesticides in the production function this method has been chosen in the regression following three arguments. First, it is possible to jointly address pest treatment and private input behavior; secondly, it is safe to assume that pest pressure prevails throughout the year; and thirdly, no information exists on damage abatement. A yield-age relation and a production function have been estimated. The yield-age relation is based on the semi-logarithmic 'Hoerl' function which can most ideally picture the development of fruit tree crops. The results show that the impact of plantation age is highest in cluster 1. The highest yields are reached between year 11 and 13. However, the maximum yields calculated from the function are far beyond potential yields indicated by experts. Therefore, the assumption arises that other factors have a negative influence on output as the majority of farmers are not able to reach potential maximum yields. Further evidence on the role of pesticides in tangerine production has been investigated based on a production function analysis. A Cobb-Douglas function has been chosen as functional form for the production function.

The results confirm the previous assumptions on the overuse of pesticides. The marginal product of pesticides is negative. Clearly an unwanted outcome, as pesticides generally are assumed to reduce crop losses. However in this case, results support earlier made observation of a potential pesticide overuse. The belonging to cluster 2 and cluster 3 in itself has a positive marginal productivity. In line with observations from previous chapters, the function results in high replanting costs having a negative marginal productivity on output.

Main factors supporting the overuse of pesticides in the survey area have been identified as follows: the high profits discouraging the need of adoption of more efficient crop protection, the large monocultural area making a switch of a single farmer to other crop protection methods difficult, the long history of pesticide use in the region, the common belief of high pesticide benefits and the insufficient knowledge, information and extension on alternatives or management system improvements.

The question of the existence of path-dependency was addressed in the final section of the discussion on the determinants of management systems in tangerine production. Two aspects have been discussed in detail: first, whether from a theoretical point of view the pre-conditions for path-dependency are relevant in the survey area, and secondly, whether indicators can be identified from the survey supporting the theoretical considerations. The prevalence of suboptimal pesticide use in the study area has been explicitly demonstrated in previous analyses. The three aspects often indicating the existence of path-dependency, namely sunk costs, increasing returns to scale and network externalities, have been analyzed with regard to their existence in tangerine production. The results allow the conclusion that all mentioned three aspects are of importance in tangerine production in Thailand. Furthermore, the costs of technological change can be regarded as quite high, hindering an increase in the adaptation of alternatives to pesticide use. Therefore, tangerine production in the Central region of Thailand can be likely described as locked-in in chemical crop protection. To find indicators for path-dependency in the survey data, the sample has been grouped according to growth stages, regions and development over time. All this differentiation of the sample has led to the conclusion that indicators for path-dependency exists. The approach used, however, could not clearly answer whether the farmers are either currently producing on various levels of an intensity path, moving towards the same locked-in situation, or whether the clusters represent systems that are locked-in at various intensity levels on different development path. The analysis of the input intensity over time suggests the latter. It could further been shown that pesticide costs are largely depending on orchard age and cluster belonging. Farmers are locked-in their current crop protection strategies. They have reached a level of pesticide use which exceeds the optimal level. The continuous overuse of pesticides is likely to create more problems driving farmers deeper into pesticide-dependency.

8.2 Conclusions

The current crop protection policy design takes neither economic nor environmental implications into consideration. In addition, political interests appear to be directed towards maintaining the present status quo, resulting in the formulation of a suboptimal set of policies. The analysis of the tangerine sector has shown that the current political incentives do not limit pesticide overuse. A situation has develop in which farmers are locked in a pesticide intensive production strategy. One can thus assume that unless a production crisis occurs (which could be the case if the greening disease becomes more severe) or political efforts strongly focus on alternatives to pesticides, farmers will hardly leave their current production path. Thus, increasing internal and external problems related to tangerine production can be expected in the future.

To reach a more effective and adapted crop protection policy more information about the real benefits and costs of pesticides, the external effects related to pesticide use and alternative management systems are needed regarding the design of transferable and successful strategies for various crops. Additionally, effective training and extension methodologies are essential to spread the already available technologies. The amount of money currently spent on the outbreak budget, could be used more efficiently for other purposes e.g. farmer training.

As biased information has been identified as a major shortcoming in the current situation, improved training and information methods can enable farmers to use pesticides in a more sustainable way.

In short, pesticide policy needs to be integrated into the broader public policy debate concerning the nation's agricultural, environmental and health strategies. Pesticide policy cannot remain confined to specialists in the field of crop protection. Two general principles still apply. First, in depth analysis of the costs and benefits of pesticide use provide a useful tool for the formulation of rational policies. Second, the broader and more open the debate, the more likely it is that the outcome will serve the public rather than specific private interests.

A stronger role for non-agriculture interest groups in the political process could be a desirable step towards less biased decision making. As shortcomings in the current conduct of pesticide legislation have been identified as supportive of pesticide overuse, a critical assessment of forces and structures within the governmental procedures can be regarded as a useful step. A critical review of the incentive structure for pesticide use would therefore be helpful.

It would be advisable to introduce more economic instruments in crop protection policies and to put more incentives on alternatives to pesticide use. COWAN (1991) argues if there is uncertainty about the relative merits of two competing technologies, the market will undersupply experimentation. There is no incentive to experiment with the supposedly inferior technology (in this case the use of alternatives to pesticides) in the hope of improving its merits and practicability. Political focus can internalize this externality and support interventions. This would be an advisable step for a political motivated increase of research on alternatives to pesticides in crop protection. ARTHUR (1989) argues that in the case of increasing returns, laissez-faire of letting the superior technology reveal itself gives no guarantee that the superior technology will finally be the one that survives. Political directions have to be set to allow the alternative strategy to develop.

The study of KATZ and SHAPIRO (1985) concludes that public policy can have an important impact on private decisions in the case of the existence of network externalities. Private decision depends crucially on whether firms can act unilaterally if consensus is required (which is the case in tangerine production in Thailand's Central region) and on the feasibility of side payments. Public policy can influence both aspects. Similar conclusions are drawn by COWAN and GUNBY (1996) suggesting that it may be important to focus policy interventions in order to concentrate resources in such a way that they are able to overcome the locked-in on current situations.

As discussed in this study, these arguments apply for crop protection and the citrus sector in Thailand. The incorporation of economic instruments in crop protection policy might be able to give the required incentive and equally focus on alternatives to chemical crop protection. Developing a set of policies in crop protection that also serve the public interest requires, however, institutional changes that allow for a broad public participation in the policy dialogue.

References

Agne, S., G. Fleischer, F. Jungbluth, H. Waibel (1995): Guidelines for Pesticide Policy Studies - A Framework for Analyzing Economic and Political Factors of Pesticide Use in Developing Countries. Pesticide Policy Project, Publication Series No. 1, GTZ/University of Hannover, Hannover, Germany.

Antle, J.M. (1988): Pesticide Policy, Production Risk, and Producer Welfare - An Econometric Approach to Applied Welfare Economics. Resources for the Future, Washington D.C.

Arthur, W.B. (1989): Competing Technologies, Increasing Returns, and Lock-In by Historical Events. The Economic Journal, Vol. 99, pp. 116-131.

BAAC (1994): Annual Report 1993. Bank of Agriculture and Agricultural Cooperatives, 1 April 1993- 31 March 1994, Bangkok, Thailand.

Backhaus, K. et al. (1994): Multivariate Analysemethoden. Springer Verlag, 7th Edition, Berlin, Heidelberg, New York.

Balmann, A. (1995): Pfadabhängigkeiten im Agrarstrukturwandel: Begriff, Ursachen und Konsequenzen. Duncker & Humblot, Berlin, Germany.

Balmann, A., C. Hilbig (1998): Zur Identifikation von Pfadabhängigkeiten in hochdimensionalen dynamischen Systemen: eine Anwendung multivariater Analyseverfahren auf simulierte Agrarstrukturentwicklungen. Working Paper No. 47/1998 der Wirtschafts- und Sozialwissenschaften an der Landwirtschaftlich-Gärtnerischen Fakultät, Humboldt-Universität, Berlin, Germany.

Bangkok Post (1993): Farmers Encouraged to Switch Crops. Bangkok Post, October 16, 1993, Bangkok, Thailand.

Bangkok Post (1994): Bangkok Post Economic Review Year-End 1994 - Agriculture, Bangkok Post, Bangkok, Thailand.

Bank of Thailand: Quarterly Journal, various issues, Bangkok, Thailand.

Baumann, G. (1995): GTZ-Approach to the IPM in Tropical Fruit Diseases. Paper presented at the International Symposium on 'Integrated Pest Management of Insect-born Virus Diseases of Tropical Fruits', December 11-16 1995, Pingtung, Taiwan.

Baumol, W.C., W.E. Oates (1988): The Theory of Environmental Policy. Cambridge University Press, 2nd Edition, Cambridge, New York, Melbourne.

Boon-Long, J. (1995): Chemical Legislation and Infrastructure in Thailand. Paper presented at the Conference on International Trade of Dangerous Chemicals, Brussels, 5-7 July 1995.

Brandes, W., M. Odening (1992): Investition, Finanzierung und Wachstum in der Landwirtschaft. Verlag Eugen Ulmer.

Brandes, W. (1995): Pfadabhängigkeit: Ein auch für die Agrarökonomik fruchtbares Forschungsprogramm? Agrarwirtschaft, Vol. 44, No. 8/9, pp. 277-279.

Brandes, W., G. Recke, T. Berger (1997): Produktions- und Umweltökonomik. Band 1: Traditionelle und moderne Konzepte. UTB Taschenbücher 2001, Verlag Eugen Ulmer.

Burrows, T.M. (1983): Pesticide Demand and Integrated Pest Management: A Limited Dependent Variable Analysis. American Journal of Agricultural Economics, Vol. 65, pp. 806-810.

Burgstaller, H. (1995): Der intergrierte Pflanzenschutz im Zitrusanbau in Thailand: Ein Beispiel über das Verständnis des integrierten Systems. Info 1/95, Abt. 423, Gesellschaft für technische Zusammenarbeit GmbH (GTZ), Eschborn.

Campbell, H. F. (1976): Estimating the Marginal Productivity of Agricultural Pesticides: The Case of Tree Fruit Farms in the Okanagan Valley. Canadian Journal of Agricultural Economics, Vol. 24, pp. 23-30.

Cansier, D. (1993): Umweltökonomie. UTB für Wissenschaft: Uni-Taschenbücher 1749, Gustav Fischer Verlag, Stuttgart.

Carpentier, A., R.D. Weaver (1997a): Damage Control Productivity: Why Economietrics Matters. American Journal of Agricultural Economics, Vol. 79, pp. 47-61.

Carpentier, A., R.D. Weaver (1997b): Pesticide Productivity: Intertemporal, Interfirm Heterogenity. Presented at the Seminar 'Modelisation des Marches Agricoles', Montpellier, 10- 11 April 1997, France.

Carrasco-Tauber, C., L.J. Moffitt (1992): Damage Control Econometrics - Functional Specification and Pesticide Productivity. American Journal of Agricultural Economics, Vol. 75, pp. 158-162.

Chambers, R.G., E. Lichtenberg (1994): Simple Econometrics of Pesticide Productivity. American Journal of Agricultural Economics, Vol. 76, pp. 407-417, 1994.

Cowan, R. (1991): Tortoises and Hares: Choice Among Technologies of Unknown Merit. The Economic Journal, Vol. 101, pp. 801-814.

Cowan, R., P. Gunby (1996): Sprayed to Death: Path Dependence, Lock-In and Pest Control Strategies. The Economic Journal,Vol. 106, pp. 521-542.

Customs Department (1995): Customs Tariffs. Ministry of Public Finance, Bangkok, Thailand.

Department of Statistics (1996): Commodity Prices. Bangkok, Thailand.

DOA (1993): Vegetable Statistics. Department of Agriculture, Bangkok, Thailand.

DOAE (1993): Policy, Strategy, Measure for Agricultural Extension. Department of Agricultural Extension, October 1993, Bangkok, Thailand.

DOAE (1994): Fruit Statistics 1992. Department of Agricultural Extension, Bangkok, Thailand.

Dillon, W.R., M. Goldstein (1984): Multivariate Analysis. John Wiley and Sons, New York.

Division of Entomology and Zoology (1994): Annual Report 1993. Department of Agriculture, Bangkok, Thailand.

Dosi, G. (1997): Opportunities, Incentives and the Collective Patterns of Technological Change. The Economic Journal, Vol. 107, pp. 1530-1547.

Dougherty, C. (1992): Introduction to Econometrics. Oxford University Press, New York.

Everitt, B.S. (1993): Cluster Analysis. Third Edition, Arnold, London.

FAO: Production Yearbook, various issues and FAO website (www.fao.org).

FAO (1994): Economic Situation in Thailand. Regional Office for Asia and the Pacific, Bangkok, Thailand.

FAO-JICA (1995): Survey on Japan-FAO Association. March 1995, Thailand pp. 11-17.

Farah, J. (1993): Pesticide Policies in Developing Countries. Do They Encourage Exessive Pesticide Use? World Bank, Washington D.C.

Farrell, J, and G. Saloner (1985): Standardization, Compatibility, and Innovation. Rand Journal of Economics, Vol. 16, No. 1, pp. 70-83.

Feder, G. (1979): Pesticides, Information, and Pest Management under Uncertainty. American Journal of Agriculture Economics, Vol. 61, pp. 98-103.

Fischer, L. A. (1970): The Economics of Pest Control in Canadian Apple Production. Canadian Journal of Agricultural Economics, Vol. 18, pp. 89-96.

Fleischer, G. (1998): Ökonomische Ansätze in der Pflanzenschutzpolitik - Das Beispiel der Zulassungsprüfung. Landwirtschaft und Umwelt, Schriften zur Umweltökonomik, Band 15, Vauk Verlag Kiel.

GIFAP (1996): Manual for Extension of Safe Use Projects.

Grandstaff, S. (1992): Pesticide Policy in Thailand. Thailand Development Research Institute, Bangkok, Thailand.

Grenzenbach, E. (1994): Report on a Short Term Consultancy Mission: Study Economic and Social Impacts of the Project Activity No. 07.30.50. Integrated Pest Management Project, Deutsche Gesellschaft für technische Zusammenarbeit GmbH (GTZ).

Group Discussion (1996): Sara Buri Province, group discussion with twenty farmers regarding major concerns of tangerine production,16 April 1996.

Hanley, N, J.F. Shogren, B. White (1997): Environmental Economics In Theory and Practice. Macmillan Texts in Economics, Macmillan Press, London.

Headley, J.C. (1968): Estimating the Productivity of Agricultural Pesticides. American Journal of Agricultural Economics, Vol. 50, pp. 13-23, 1968.

IRRI (1994): Integrated Pest Management - The IRRI Perspective. IRRI Information Series No. 3, IRRI, Los Baños, Philippines.

Iwagaki, I. (1997): Citrus Production in Japan: New Trends in Technology. Extension Bulletin No. 440, Food and Fertilizer Technology Center, Taipei, May 1997.

Jiraporncharoen, S. (1993): The Use of Chemical and Organic Fertilizers in Crop Production in Thailand. Extension Bulletin No. 370, Food and Fertilizer Technology Center, Taipei, Taiwan.

Jourdain, D.J. and C. Rattanasatien (1995): An Analysis of Pesticide Use in Vegetable Farming: the Case of Thailand. Agro-Chemicals News in Brief, Vol. XVIII, No. 2, April-June 1995.

Jungbluth, F. (1996): Crop Protection Policy in Thailand - Economic Factors Influencing Pesticide Use. Pesticide Policy Publication Series, No. 5, University of Hannover, Germany.

Kahneman, D., A. Tversky (1979): Prospect Theory: An Analysis of Decision under Risk. Econometrica, Vol. 47, 1979, pp. 263-291.

Kaosard, M. and S.S. Pednekar (1996): Environmental Strategy of Thailand, Natural Resources and Environment Program, Thailand Development Research Institute, Bangkok.

Katz, M.L, and C. Shapiro (1985): Network Externalities, Competition, and Compatibility. American Economic Review, Vol. 75, No. 3, pp. 424-440.

Kenmore, P.E., F.O. Carino, C.A. Penez, V.A. Dyck, A.P. Gutierrez (1984): Population Regulation of the Rice Brown Planthopper (Nilaparvata Stal) within Rice Fields in the Philippines. Journal of Plant Protection in the Tropics, Vol. 1, No. 1, pp. 19-37.

Kenmore, P.E. (1996): Integrated Pest Management in Rice. In G.J. Persley (ed.): Biotechnology and Integrated Pest Management, The World Bank, pp. 76-97, CAB International.

Khuankaew, O. (1995): IPM and Women. Report on Short Term Consultancy, Integrated Pest Management in Selected Fruit Trees Project, Thai-German Plant Protection Programme, Department of Agricultural Extension, Bangkok, Thailand.

Kim, J.-O., C.W. Mueller (1978): Introduction to Factor Analysis - What It Is and How to Do It. Sage University Paper Series on Quantitative Applications in the Social Science, 07-013, Newbury Park, CA, U.S.A.

Kramer R.A., W.T. McSweeny, R.W. Stavros (1984): Soil Conservation with Uncertain Revenues and Input Supplies. American Journal of Agricultural Econmics, Vol. 65, pp. 694-702.

Landell Mills (1994): Consultant Report on Pesticide Use in Various Countries, London, United Kingdom.

Lichtenberg, E. and D. Zilberman (1986): The Econometrics of Damage Control: Why Specification Matters. American Journal of Agricultural Economics, Vol. 68, pp. 261-273.

Lichtenberg, E. (1992): Alternative Approaches to Pesticide Regulation. North Eastern Journal of Agriculture and Resource Economics, Vol. 21, pp. 83-92.

Liebowitz, S.J. and S.E. Margolis (1994): Network Externality: An Uncommon Tragedy. Journal of Economic Perspectives, Vol. 8, No. 2, pp. 133-150.

März, U. (1990): Farm Classification and Impact Analysis of Mixed Farming Systems in Northern Syria. Farming Systems and Resource Economics in the Tropics, Wissenschaftsverlag Vauk Kiel.

Meenakanit, L., P. Meenakanit, M.M. Escalada, K.L. Heong (1996): Farmers Participatory Research in Pest Management for Women Rice Farmers in Central Thailand. Rice IPM Network, IRRI and Department of Agricultural Extension, Thailand.

Ministry of Agriculture (1992): Hazardous Substances Act. Ministry of Agriculture, Bangkok, Thailand.

Ministry of Agriculture (1994): Production Restructuring Program. Office of the Board of Structural Adjustment in the Agricultural Sector, Ministry of Agriculture, Bangkok, Thailand.

Ministry of Public Health (1996): Annual Epidemiological Surveillance Report. Food and Drug Division, Ministry of Public Health, Nontaburi, Thailand.

Ministry of Public Health (1997): Preliminary Annual Summary 1995. Division of Epidemiology, Nontaburi, Thailand.

Mukherjee, C., H. White, M. Wuyts (1998): Econometrics and Data Analysis for Developing Countries. Routledge, New York.

Mumford, J.D. and G.A. Norton (1984): Economics of Decision Making in Pest Management. Annual Review of Entomology 1984, Vol. 29, pp. 157-74.

Munasinghe, M. (1993): Environmental Economics and Sustainable Development. World Bank Environment Paper No. 3, Washington, D.C.

Oerke, E.-C., H.W. Dehne, F. Schönbeck, A. Weber (1994): Crop Production and Crop Protection - Estimated Crop Losses in Major Food and Cash Crops. Elsevier.

Office of Agricultural Economics: Agricultural Statistics of Thailand, various issues. Ministry of Agriculture, Bangkok, Thailand.

Office of Agricultural Economics (1995): Targets for Some Important Agricultural Products 1994/1995. Ministry of Agriculture, Bangkok, Thailand.

Ooi, P.A.C., G.S. Lim, T.H. Ho, P.L. Manalo, J. Waage (eds.) (1992): Integrated Pest Management in the Asia-Pacific Region. Proceedings of the Conference on Integrated Pest Management in the Asia-Pacific Region, 23-27 September 1991, Kuala Lumpur, Malaysia, CAB International, Asian Development Bank.

Opschoor, J.B. and R.K. Turner (1994): Environmental Economics and Environmental Policy Instruments: Introduction and Overview. In Opschoor, J.B. and R.K. Turner (eds.): Economic Incentives and Environmental Policies: Principles amd Practice, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Oskam, A.J., H. van Zeijts, G.J. Thijssen, G.A.A. Wossink, R. Viftingschild (1992): Pesticide Use and Pesticide Policy in the Netherlands. Wageningen Economic Studies, No. 26, Wageningen Agricultural University.

Pannell, D.J. (1991): Pest and Pesticides, Risk and Risk Aversion. Agricultural Economics, Vol. 5, pp. 361-383.

Palakool, S., S. Sukamak, B. Deenruy (1995): Pesticide Residues in Fruit and Vegetables. Proceedings of the First Technical Conference of the Agricultural Toxic Substances Division. Agricultural Toxic Substances Division, Department of Agriculture, 23-25 August 1995, Bangkok, Thailand.

Paradornuwat, A. (1995a): Tangerine Farming in the Royal Rangsit Irrigation Area. Paper presented at the 'Semi-annual Workshop on Integrated Pest Management in Fruit Orchards', Thai-German Plant Protection Programme, June 12-14 1995, Rama Garden Hotel, Bangkok, Thailand.

Paradornuwat, A., R. Paradornuwat (1995b): The Establishment of a Tangerine Orchard of 100 Rai. Department of Plant Pathology, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand.

Pearce, D.W., R.K. Turner (1990): Economics of Natural Ressources and the Environment. Baltimore: The John Hopkins University Press.

Pearce, D., R. Tinch (1998): The True Price of Pesticides. In W. Vorley, D. Keeney (eds.): Bugs in the System - Redesigning the Pesticide Industry for Sustainable Agriculture. Earthscan Publications Ltd., London.

Pimentel, D., H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordano, A. Horowitz, M. D’Amore (1993): Assessment of Environmental and Economic Impacts of Pesticide Use. In D. Pimentel and H. Lehmann (eds.): The Pesticide Question - Environment, Economics and Ethics, Chapman & Hall, New York, London.

Poapongsakorn, N. (1994): Transformation in the Thai Rural Labor Market. In B. Koppel, J. Hawkins, W. James (eds.): Development or Deterioration? Work in Rural Asia, Lynnes Riemer Pub., Boulder, London.

Poapongsakorn, N., L. Meenakanit, H. Waibel, F. Jungbluth (1999): Approaches to Pesticide Policy Reform – Building Consensus for Future Action. Pesticide Policy Project, Publication Series No. 7, GTZ/University of Hannover, Hannover, Germany.

Prannok Vidhaya Publisher (1996): Map of Bangkok and Adjacent. Bangkok Noi, Bangkok, Thailand, ISBN 974-7675-49-8.

Ratanawaraha, C., P. Sricharoen, S. Wong-ek (1992): The Pesticide Registration in Thailand. Paper presented at the Workshop on 'Assessment and Management of Risks from Pesticide Use in South East Asia', Bangkok, Thailand, 9-12 Nov. 1992.

Regulatory Division: Statistics of Imported Pesticides 1995, various issues. Department of Agriculture, Bangkok, Thailand.

Regulatory Division (1994): Registration of Toxic Substances in Thailand. Department of Agriculture, Bangkok, Thailand.

Regulatory Division (1995): List of Banned and Registered Pesticides. Department of Agriculture, Bangkok, Thailand.

Reichelderfer, K.H. (1981): Economic Feasibility of Biological Control of Crop Pests. In G.C. Papavizas, B.Y. Endo, D.L. Klingman, L.V. Knutson, R.D. Lumsden, J.L. Vaughan (eds.): Biological Control in Crop Production, Allanheld, Osmun Publishers.

Rola, A., P. Pingali (1993): Pesticides, Rice Productivity, and Farmers' Health - An Economic Assessment. IRRI, Los Baños, Philippines.

Roistacher, C. N. (1995): Outline of A Citrus Certification Program for Thailand. Short Term Consultancy Report to Thai-German Plant Protection Programme 'Integrated Pest Management in Selected Fruit Trees', February 1995.

Romesburg, H. C. (1990): Cluster Ananlysis for Researchers. Robert E. Krieger Publishing Company, Malabar, Florida.

Ruhs, M., N. Poapongsakorn, N. Rattanadilok (1998): Pesticide Use in Thai Agriculture: Problems and Policies. In: 'Approaches to Pesticide Policy Reform, Building Consensus for Future Action', Proceedings of the Workshop, 5.-7. July, Hua Hin, Pesticide Policy Project, Publication Series No. 7, GTZ/University of Hannover, Hannover, Germany.

Saha, A., C.R. Shumway, A. Havenner (1997): The Economics and Econometrics of Damage Control. American Journal of Agricultural Economics, Vol. 79, pp. 773-785.

SAS (1989): SAS System for Elementary Statistical Analysis. SAS Institue Inc., NC, USA.

SAS (1992): SAS/STAT User's Guide. Volume 1 and Volume 2, Version 6, 4th Edition, SAS Institue Inc., NC, USA.

Seitz, W. D., G.C. Nelson, H.G. Halcrow (1994): Economics of Resources, Agriculture, and Food. Agriculture Series, McGraw-Hill International Editions.

Setboonsarng, S. (1993): Environmental Constraints to Thai Agriculture. In A.M. Rae and A.D. Meister (eds.): Environmental Constraints to Pacific Agriculture, Centre for Agricultural Policy Studies, Massey University, New Zealand.

Sethpakdee, R. (1997): Citrus Production in Thailand. Extension Bulletin No. 437, Food and Fertilizer Technology Center, Taipei, March 1997.

Siamwalla, A. et al. (1992): Public Policies Toward Agricultural Diversification in Thailand. In Barghouti et al.: Trends in Agricultural Diversification, World Bank Technical Paper No. 180, Washington, D.C.

Siamwalla, A. (1994): Rural Credit and Rural Poverty. In: Rural Poverty in Asia: Priority Issues and Policy Options. pp. 287-315.

Sinchaisri, N. (1988): Pesticide Resistance in Thailand. In P.S., Teng, K.L. Heong (eds.): Pesticide Management and Integrated Pest Management in Southeast Asia, USAID.

Sinhaseni, P. (1990): Regional Pesticide Review - Thailand. International Development Research Centre, Chulalongkorn University, March 1990, Bangkok, Thailand.

Sinhaseni, P. (1994): Toxicological Concepts, Regulatory Provision and Appropriate Technology for Pesticide Safe Use: an Experience in Thailand. Pesticide Safe Use Unit, Faculty of Pharmaceutical Sciences, Chulalongkorn University, June 1994, Bangkok, Thailand.

Songsakul, T. (1991): Effects of Urbanization and Environment on Vegetable Cultivation: A Case Study of Village No.3 Ban Mai Sub-District, Pathum Thani Province. Master Thesis, Asian Institut of Technology, Bangkok, Thailand.

Spiegel-Roy, P., E.E. Goldschmidt (1996): Biology of Citrus. Biology of Horticultural Crops, Cambridge University Press.

Sriplakich, C. (1997): Pesticide Residues in Drinking Water. In: Proceedings of the Second Technical Conference of the Agricultural Toxic Substances Division, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Sukmak, S. (1997): Pesticide Residues in Agricultural Products. In: Proceedings of the Second Technical Conference of the Agricultural Toxic Substances Division, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

Tayaputch, N. (1988): Pesticide Residues in Thailand. In P.S.Teng, K.L. Heong (eds.): Pesticide Management and Integrated Pest Management in Southeast Asia, Proceedings of the Southeast Asia Pesticide Management and Integrated Pest Management Workshop, February 23-27, 1987, Pattaya, Thailand, pp. 341-347.

Tayaputch, N. (1992): Fate of Pesticides in Tropical Environments of Thailand. PhD Thesis, University of Agriculture Tokyo, Japan.

Tayaputch, N. (1994): Pesticide Residues in Rice Paddy Environment in Selected Villages in Central Thailand. Toxic Substances Division, Department of Agriculture, Bangkok, Thailand.

TDRI (1995): The Monitoring and Control of Hazardous Waste: Hazardous Waste Management in Thailand. Natural Resources and Environment Program, Thailand Development Research Institute, February 1995, Bangkok, Thailand.

Teng, P.S. (1990): Crop Loss Assessment: a Review of Representative Approaches and Current Technology. In: Crop Loss Assessment in Rice, Proceedings of the International Workshop on Crop Loss to Improve Pest Management in Rice and Rice-based Cropping Systems in South and Southeast Asia, 11-17 October 1987, IRRI, Los Baños, Philippines.

Thai-German Plant Protection Programme (1993): Project Presentation. Integrated Pest Management in Selected Fruit Trees Project, Department of Agricultural Extension, Bangkok, Thailand.

Thai-German Plant Protection Programme, Tangerine Team (1995): Quarterly Report. Internal Report of the Integrated Pest Management in Selected Fruit Trees Project, Department of Agricultural Extension, Bangkok, Thailand.

Thai-German Plant Protection Programme (1996): Organization, Content and Steps of IPM Technology Development in Selected Fruit Trees in Thailand. Paper presented at the ASEAN Workshop 'IPM in Fruit Trees', May 1996, Integrated Pest Management in Selected Fruit Trees Project, Department of Agricultural Extension, Bangkok, Thailand.

Thailand in Figures (1996): Published by Alpha Research Co. and Manager Information Service Co., 3rd Edition 1995-1996, Bangkok, Thailand.

Tietenberg, T. (1992): Environmental and Natural Resource Economics. 3rd Edition, Harper Collins, New York.

Tisdell, C.A., B.A. Auld, K.M. Menz (1984): On Assessing the Value of Biological Control of Weeds. Protect. Ecol., Vol. 6, pp. 169-179.

Trébuil, G. (1995): Pioneer Agriculture, Green Revolution, and Environmental Degradation in Thailand. In Rigg, J. (ed.): Economic Growth and Environmental Change in Thailand, Institute of Southeast Asian Studies, Singapore.

Tumrongsikul, J. (1997): Pesticide Degradation in Agricultural Products. In: Proceedings of the Second Technical Conference of the Agricultural Toxic Substances Division, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

USDA (1996): Agricultural Chemical Usage – 1995 Fruits Summary. National Agricultural Statistic Service, Economic Research Service, Ag Ch 1 (96), United States Department of Agriculture, Washington, D.C., U.S.A.

Van den Bosch, R. (1989): The Pesticide Conspiracy. Berkley, University of California Press, reprint; originally published: Garden City, N.Y., Doubleday, 1978.

Verheij, E.W.M., R.E. Coronell (eds.) (1991): Edible Fruits and Nuts. Plant Resources of South-East Asia, Pudoc, Wageningen, Netherlands.

Waibel, H. (1990): Pesticide Use and Pesticide Policy in Thailand. Paper presented at the Workshop on Environmental and Health Impacts of Pesticide Use in Rice Culture, 28-30 March 1990, Los Baños, Philippines.

Waibel, H. and S. Setboonsarng (1993): Resource Degradation due to Chemical Inputs in Vegetable-Based Farming Systems in Thailand. Journal of the Asian Farming Systems Association, Vol. 2, 1993, pp. 107-120.

Waibel, H. (1994): Towards an Economic Framework of Pesticide Policy Studies. In S. Agne, G. Fleischer, H. Waibel (eds.): Proceedings of the Göttingen Workshop on Pesticide Policies, ed. by, Göttinger Schriften zur Agrarökonomie, Vol. 66. Institute of Agricultural Economics, University of Göttingen, 1994.

Waibel, H., J.C. Zadoks (1996): Institutional Constraints to IPM. Papers presented at the XIIIth International Plant Protection Congress (IPPC), The Hague, July 2-7, 1995. Pesticide Policy Project Publication Series, No. 3, Hannover.

Waibel, H., G. Fleischer (1998): Kosten und Nutzen des chemischen Pflanzenschutzes in der deutschen Landwirtschaft aus gesamtwirtschaftlicher Sicht. Agrarökonomische Monographien und Sammelwerke, Wissenschaftsverlag Vauk Kiel.

Waibel, H. (1998): Staatseingriffe oder Marktwirtschaft: Voraussetzungen für den Erfolg des Integrated Pest Management (IPM) in Entwicklungsländern. PLITS 1998/16(5), pp. 35-49.

Waibel, H., F. Jungbluth, J.C. Zadoks (1998): Guidelines on the Economic Evaluation of Integrated Pest Management Projects. Pesticide Policy Project, unpublished Report, GTZ/University of Hannover, Hannover, Germany.

Wesseler, J. (1997): Die Ökonomik der Einführung von Obstkulturen in der Cordillera Central von Nordluzon, Philippinen. Forschungsberichte zur Ökonomie im Gartenbau, Bd. 84, Hannover.

Whangthongtham, S. (1990a): Economic and Environmental Implications of Two Alternative Citrus Production Systems - A Case Study from Pathum Thani Province. Master Thesis, Asian Institute of Technology, Bangkok, Thailand.

Whangthongtham, S. (1990b): Brown Planthopper Outbreak in Thailand. Report on the Seminar of 'Brown Planthopper and Rice Ragged Stunt Virus', June 28 1990, Department of Agriculture, Bangkok, Thailand.

WHO (1994): The WHO Recommended Classification of Pesticides by Hazard and Guidelines of Classification 1994-1995. International Programme on Chemical Safety, United Nations Envrionment Programme, International Labour Organization, World Health Organization.

Wongpanich, M. et al. (1985): Pesticide Poisoning among Agricultural Workers: a Research Report. Mahidol University, Bangkok, Thailand.

Wongsiri, N. (1990): List of Insect, Mite and other Zoological Pests of Economic Plants in Thailand. Technical Bulletin, Entomology and Zoology Division, Department of Agriculture, Bangkok, Thailand.

Wood Mackenzie (1993): East Asian Agrochemical Markets. Consultant Report.

World Bank (1994): Thailand - Impact Evaluation Report. Second Tree Crops Project, June 1994, Rep. No. 13244-TH, World Bank, Washington, D.C.

Wossink, G.A.A., G.H. Peters, G.C. van Kooten (1998): Introduction to Agro-chemical Use. In G.A.A. Wossink, G.H. Peters, G.C.van Kooten (eds.): Economics of Agrochemicals – An International Overview of Use Patterns, Technical and Institutional Determinants, Policies and Perspectives, Aldershot: Ashgate, pp. 1-18.

Zadoks, J.C. (1990): Crop Loss Assessment: a Historical Perspective and Rationale. In Crop Loss Assessment in Rice, Proceedings of the International Workshop on Crop Loss to Improve Pest Management in Rice and Rice-based Cropping Systems in South and Southeast Asia, 11-17 October 1987, IRRI, Los Baños, Philippines.

Zadoks, J.C. and S. Schein (1979): Epidemiology and Plant Disease Management. Oxford University Press.

Zilberman, D., M. Marra (1993): Agriculture Externalities. In: G. Carlson, D. Zilberman, J.A. Miranowski (eds.): Agricultural and Environmental Resource Economics, Oxford University Press, New York.

Zilberman, D. K. Millock (1997): Pesticide Use and Regulation: Making Economic Sense Out of an Externality and Regulation Nightmare. Journal of Agricultural and Resource Economics, Vol. 22, No. 2, pp. 321-332.