SOCIOECONOMIC, MANAGEMENT, AND INSTITUTIONAL DETERMINANTS OF TECHNICAL EFFICIENCY: THE CASE OF SMALL PRODUCERS IN IRRIGATED AGRICULTURE IN NORTHEAST BRAZIL

SOCIOECONOMIC, MANAGEMENT, AND INSTITUTIONAL DETERMINANTS OF TECHNICAL EFFICIENCY: THE CASE OF SMALL PRODUCERS IN IRRIGATED AGRICULTURE IN NORTHEAST BRAZIL

by

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STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona.

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ABSTRACT

The Brazilian Government has invested heavily in irrigation projects for small farmers in the semi-arid region of Northeast Brazil. Projects along the San Francisco River have been particularly successful in developing important fruit and produce production centers. Despite the many efforts by government agencies to improve the production performance of small farmers in these projects, there prevails considerable variability in the technical efficiency of producers.

The primary purpose of this thesis is to provide a better understanding of the socioeconomic, management, and institutional factors influencing technical efficiency of small producers in an irrigation perimeter in the Petrolina/Juazeiro region. Data were collected from the national agricultural research agency and interviews with farmers and agencies involved in the perimeter. The results of this study indicate that farmer characteristics, such as education and the ownership of a commercial establishment, are important factors influencing efficiency. Results also show that, in general, small farmers in this study do not follow the management practices recommended by the agricultural research agency and extension agents. The analysis in this study concludes by suggesting that there are other factors besides basic farmer and farm characteristics that have considerable influence on technical efficiency.

CHAPTER ONE

INTRODUCTION

1.1 Problem Statement

In this study I attempt to identify the socioeconomic factors and management practices that significantly affect productive efficiency of tomato-producing farmers in the Senador Nilo Coelho Irrigation Perimeter in Petrolina, Northeast Brazil. Despite efforts by the project administration agency and research institutions to improve the production efficiency of small farmers, significant variability in productivity is observed. This study proposes to analyze the socioeconomic condition of the small producers and their management practices as determinants of technical efficiency. The producers' institutional setting is also considered as a contributing factor to efficiency.

The interest in estimating efficiency is two-fold: the estimate of efficiency itself and what explains inefficiency. The relative measure of farm-specific efficiency is based on the most efficient producer in the sample, and it can provide an indication of how well specific farms are performing relative to each other. Knowing the efficiency level of a farmer can indicate how much his productivity can be increased by improving the efficiency of resource-use in the farm. Once an efficiency index is developed, it can then be used to make inferences about particular characteristics of the farm and farmer which influence his efficiency level. Inferences can also be made about the impact of institutional setting on farm-level efficiency.

Interest in economic efficiency initially centered on whether small farmers in developing countries were economically rational and price responsive (Ali and Byerlee 1991). In the 1960s, Schultz challenged the perception that small farmers were inefficient with his "poor-but-efficient" theory (Schultz 1964). Moreover, he offered new insights into factors affecting farmer performance. Instead of focusing on agricultural extension, Schultz emphasized the importance of investment in agricultural research and human capital.

Krishna also emphasized the role of factors external to the farmer in influencing productivity. Specifically, he called for balanced price and technology policy, in which price policy and privatization would be promoted alongside development of technology, infrastructure, and human capital (Krishna 1982).

The question of efficiency thus shifted from the farm level to a focus on "system inefficiencies," which consider factors that are both internal and external to the farmer in restraining resource use below its full potential (Ali and Byerlee 1991). This "systems inefficiencies" perspective came about as a response to diminished gains from Green Revolution technologies. The Green Revolution prompted increases in productivity through the use of high yield varieties and complementary inputs, such as water, fertilizer, and pesticides. Many of the resources that contributed to the Green Revolution, however, have come to a standstill, and declining returns in traditional methods for increasing agricultural production set the stage of the so-called second generation Green Revolution, characterized by more efficient use of already existing resources (Ali 1995).

Improved resource-use efficiency is highly dependent on prevailing economic and institutional environments. In a stable environment, producers are expected to gain the experience and knowledge over time to make the most efficient use of their inputs, and there is a particularly important role for extension work and technical training. In a dynamic environment, one with continual technological and economic change, however, producers may find it more difficult to adjust their resource allocation decisions (Ali and Byerlee 1991). In many instances, and particularly in developing countries, small farmers often do not have the knowledge, resources, or managerial skills required to take timely advantage of the new technologies and to adapt to changing markets.

Agricultural production by small farmers in Petrolina is characterized by this dynamic environment, as reflected by the following factors: a) most of the small producers in the perimeter had previously worked with rainfed agriculture and had no experience with irrigation technology; b) the recommended crop mix for the perimeter has changed over the years from primarily annual crops to a mix of annual and perennial cash crops; and c) the local markets for fruits and produce are continuously changing as a result of local and world market forces. Farm efficiency in the irrigation perimeter is influenced by fixed farm resources and farmer characteristics as well as by the institutional setting. Understanding the weight of these factors in determining efficiency may indicate some steps that could be taken to improve overall efficiency.

1.2 Background and Justification

In the drought prone, semi-arid region of Northeast Brazil (NEB), access to irrigation has long been held as an important step towards improving the agricultural production, and hence the livelihoods, of the region's rural populations. Hundreds of irrigation projects have been developed through the decades with support from Federal and state governments, national development banks and international agencies. Among the projects developed in the region, those along the San Francisco River have received special attention because of the emergence of important fruit and produce suppliers.

The San Francisco River is an important perennial river in NEB, with estuaries covering a vast expanse of land throughout the region. In 1974, the San Francisco Valley Development Company (*Companhia do Desenvolvimento do Vale do São Francisco*, CODEVASF), was established to develop, implement, and maintain irrigation perimeters throughout the river basin. CODEVASF operates in over 421 municipalities in five states, with a total area of 691,075 km^2, 58% of which is in the "drought polygon"[1]. In establishing irrigation perimeters, the agency seeks to increase domestic production of agricultural production, assure a stable source of income for rural workers who otherwise depend on seasonal employment, and keep rural populations from migrating to the coastal cities or to southern states. In this sense, these public irrigation projects seek to provide a

---

[1] The "drought polygon" is a legally defined area that appears as a polygon on a map of Northeast Brazil and it encompasses an area that is eligible for special government support due to its susceptibility to droughts.

stable social and economic environment for rural populations in which they can increase their incomes as well as improve their livelihoods.

One of the largest irrigation projects undertaken by CODEVASF is the Senador Nilo Coelho Irrigation Perimeter, in Petrolina, Northeast Brazil. The project covers about 20,000 ha and has over 1,700 small farmers with farms averaging 6 ha. About 40% of the project area is allocated to large commercial farmers. Implementation of the Nilo Coelho had tremendous social and economic impacts on Petrolina and the neighboring town of Juazeiro. The introduction of irrigation transformed the production behavior of farmers, their use of technology, and their interaction with the market (Universidade Federal de Pernambuco, UFPE 1990). It substituted traditional dryland crops, such as corn and manioc, for irrigated commercial crops, including tomatoes, watermelons, melons, grapes, mangoes and bananas (UFPE 1990). Despite the ongoing efforts of CODEVASF and other agencies to improve the production capacity of farmers in the project, great variations in production efficiency prevail.

1.3 Research Objectives

The present study is based on a study by Mubarik Ali (1995) on the institutional and socioeconomic factors affecting productivity among farmers in Pakistan's Punjab. Ali first defines a second-generation Green Revolution, one based on the improvement of institutional and socioeconomic structures as a source of enhanced resource-use efficiency, as opposed to the use of innovative technology, high yield varieties, and chemicals, which defined earlier Green Revolution efforts. He finds that institutional and socioeconomic constraints significantly affect resource use efficiency. This inefficiency can in turn be explained by level of education of farmer, off-farm income generating activities, type of labor used, access to public infrastructure, and timing of inputs.

Building on the work done by Ali (1995), this study is based on the hypothesis that socioeconomic factors, management practices, and institutional setting are important determinants of efficient resource-use by small producers in the irrigation perimeter. To verify this hypothesis, my research objectives were as follows:

a) to develop a model to estimate a farm-level efficiency index and to compare the effectiveness of different conceptual models;

b) to identify characteristics of the farmer and his household which influence efficiency level;

c) to analyze farmers' management practices in light of the practices recommended by the agricultural research agency and in view of their impact on efficiency; and

d) to discuss the role of the institutional setting on the technical efficiency of small tomato-producing farmers in the irrigation perimeter.

It was expected that findings from this study could be helpful to efforts aimed at improving farm efficiency. In particular, it was hoped that findings would indicate whether farm-specific characteristics or institutional factors have a greater impact on efficiency, and also identify what farmer characteristics are desirable in the selection process of small farmers.

1.4 Thesis Organization

This study is organized as follows: Chapter Two is the descriptive chapter, covering the irrigation perimeter, its physical and institutional setting, its producers and agricultural production. It provides the backdrop for this study and is helpful in interpreting the empirical results. Chapter Three presents the theoretical and conceptual models used and reviews studies of technical efficiency measurements in agriculture. The data collection procedures are described in Chapter Four, along with descriptive statistics of the data used. The empirical models and results are presented in Chapter Five. Conclusions, limitations and suggestions for further research are discussed in Chapter Six.

CHAPTER TWO

THE IRRIGATION PERIMETER AND TOMATO PRODUCTION

This chapter describes the physical and institutional setting of the irrigation perimeter, its producers and agricultural production, and characteristics of tomato production in the Petrolina/Juazeiro region. These descriptions provide the backdrop for the study by presenting the irrigation perimeter and the small tomato-producing farmers within their physical environment and institutional setting. Understanding the role of the institutions which affect tomato production by small farmers will be especially helpful in interpreting some of the findings in later chapters.

2.1 Physical Setting

The location of the perimeter in the interior of the semi-arid region of Northeast Brazil makes it of particular interest for initiatives promoting the development of the region's agricultural sector. The Petrolina/Juazeiro region faces many of the common challenges facing agricultural production in other parts of Northeast Brazil, including the semi-arid climate and poor soils, in addition to socioeconomic and political problems. Understanding the physical setting of the perimeter of the region can give us a greater appreciation of the developments that have taken place in the past decades with irrigated agriculture and also provide some insights into what can be assimilated in irrigation projects in other semi-arid parts of the Northeast region.

2.1.1 Location

The Senador Nilo Coelho Irrigation Perimeter is located off the margins of the San Francisco River, just north of the city of Petrolina, Pernambuco, in Northeast Brazil. Most of the perimeter lies within the municipality of Petrolina and a small part of the perimeter is located within the state of Bahia (Figure 2.1). The perimeter lies next to the Sobradinho Dam, its water source, and is one of six irrigation projects in this region of the San Francisco River.

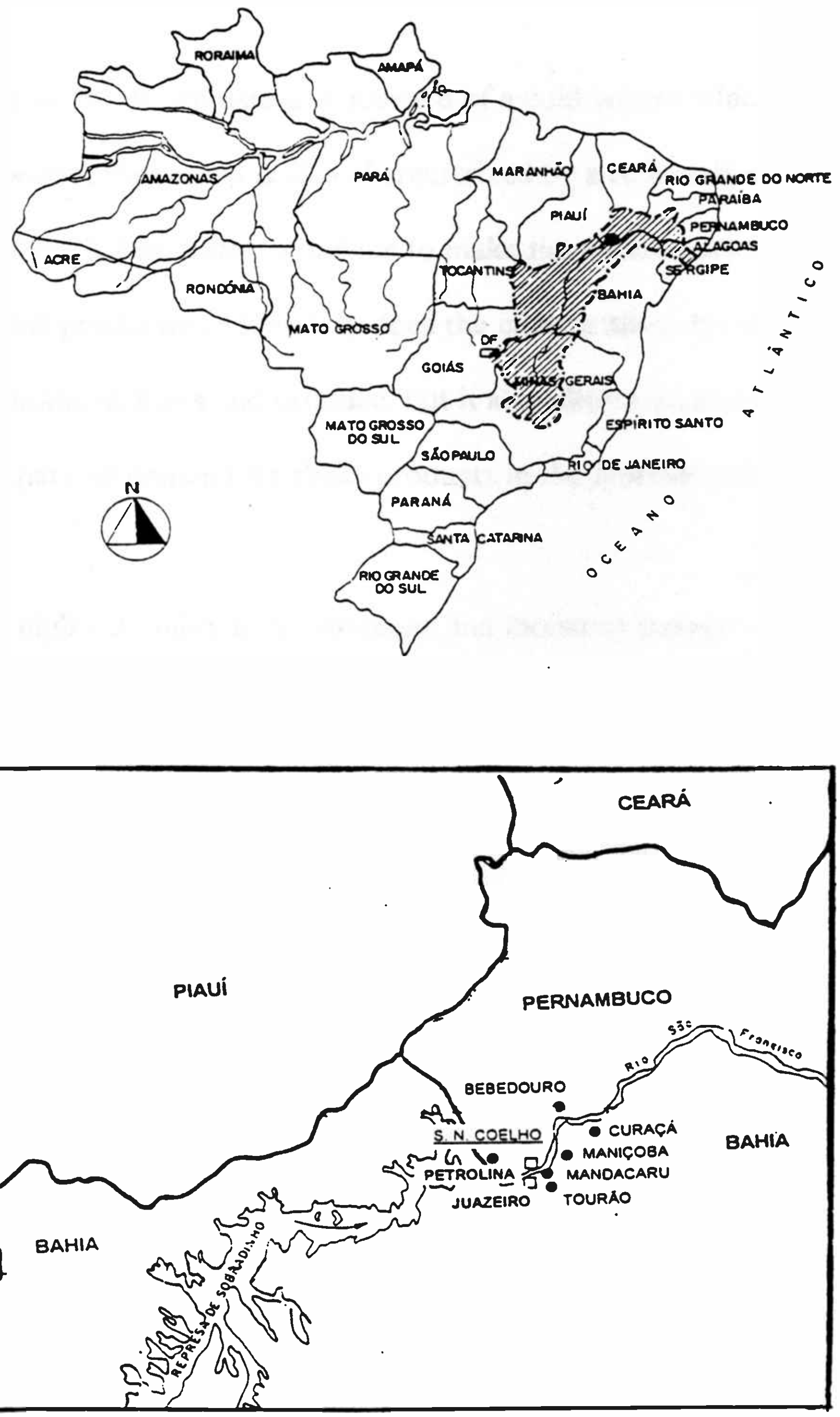
The site was chosen by CODEVASF because of the large amount of irrigable land, initially believed to be 120,000 ha[1], and the proximity to Petrolina and Juazeiro, important economic centers in this part of the San Francisco River. An underlying rationale for the irrigation projects along this portion of the San Francisco River is the government's desire to promote development in this semi-arid region, characterized by significant variability in its climate and soils (de Carvalho 1988).

2.1.2 Climate

Petrolina is situated in the so-called "drought polygon," the driest area within the semi-arid Northeast region of Brazil. The semi-arid climate is defined by its scarce rain, reduced frequency of rains and uneven spatial and temporal distribution of rainfall. Not only is the beginning of the rainy season uncertain, so too is the variability of rainfall within the rainy season (de Carvalho 1988). The average annual rainfall is 401 mm, with rains concentrated from December to March. Temperatures in the Petrolina region range

[1] One hectare (ha) is approximately 2.47 acres.

Figure 2.1 Location of the Senador Nilo Coelho Irrigation Perimeter



Source: Adapted from CODEVASF 1991c.

from 39.5 °C (103 °F) before the rainy season, to 12 °C (54 °F) in July (Regis and Gurgel 1980).

In addition to the dry climate and absence of a cold winter which constrains agricultural production, the region is also characterized by a relatively constant solar day (Quaglia *et al.* 1989). These factors combine to make the region very favorable to irrigated agricultural production. Not only does the climate allow for the production of high quality and abundant fruits and produce, but it also allows producers to take advantage of interharvest demand for these products in the Northern Hemisphere.

2.1.3 Soils

There is a high variability in the drainage and moisture storage capacity of soils within the perimeter. In general, the irrigable soils within the perimeter are sandy and have a high infiltration capacity (low water retention capacity) (Quaglia *et al.* 1989). Most of the soil in the perimeter has low natural fertility and moderate acidity , thus requiring fertilizer application for agricultural use (Regis and Gurgel 1980). In general, the soils also require lime (*calcário dolomítico*) to neutralize the effects of aluminum (Al), to balance the pH level, and to increase the percentage of calcium (Ca) and magnesium (Mg) (Quaglia *et al.* 1989).

2.2 Institutional Setting

The objective of this section is two-fold: first, to describe the main institutions involved in the perimeter and their respective roles with the small producers. Second, to discuss the linkages between these institutions and comment on some of the underlying political forces which define these relationships.

Tendler (1993) has shown the importance of institutions in affecting the productivity of small farmers in Northeast Brazil. In the case of the Senador Nilo Coelho Irrigation Perimeter, several institutions influence its management and operation, and consequently, the production of small farmers.

The administration of the perimeter follows a top-down structure, beginning with the San Francisco Valley Development Company (*Companhia de Desenvolvimento do Vale do São Francisco*, CODEVASF) headquarters in Brasília and following through to its regional office (*3ª Superintendencia Regional*), and the local perimeter District (*Distrito de Irrigação)*.

Other institutions which affect the perimeter are the Brazilian Agricultural Research Agency (*Empresa Brasileira de Pesquisa Agropecuária*, EMBRAPA) and the tomato pulp processing firms (*agroindústrias*). EMBRAPA collaborates with CODEVASF in many research activities in the perimeter and also carry out their own research on agriculture in the semi-arid region. The processing firm plays an especially important role in the production of tomatoes, for which it establishes contracts directly with the tomato- producing farmers, or *colonos*[2].

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[2] *Colono* refers to the farmers in the perimeter who own farms around 6 ha. The term *colono* is used in this study interchangeably with small farmer and producer.

2.2.1 CODEVASF

CODEVASF is the main government agency charged with the development, implementation and maintenance of irrigation projects in the San Francisco River valley[3]. The Companhia has its headquarters in Brasília, and five regional offices, called superintendencies. The 3rd Regional Superintendency is located in Petrolina and it oversees the Nilo Coelho perimeter, as well as other CODEVASF projects in Pernambuco and Bahia, including Bebedouro, Curaçá, Mandacarú, Maniçoba, and Tourão (Figure 2.1).

From the perimeter's implementation in 1984 until 1989, all the operation, maintenance and technical assistance activities of the perimeter were coordinated by the Regional Superintendency, while CODEVASF covered all the operation and maintenance costs. In principal, the perimeter was to be "emancipated" from CODEVASF, recognized as a completely independent entity, capable of internally generating the needed resources for operation, maintenance and administration of common-use infrastructure (CODEVASF 1991a). Producer associations and cooperatives were envisaged to take up these responsibilities. While some perimeters have become relatively self-managed, others maintain significant dependence on CODEVASF. The idea of emancipation was present since the project's inception, and its need became more evident with financial burdens

[3] The Companhia is the successor of the San Francisco Valley Commission (*Commisão do Vale do São Francisco*, CVSF) created in 1948, and later the Superintendency of the San Francisco Valley (*Superintendencia do Vale do São Francisco*, SUVALE) established in 1967. SUVALE was renamed CODEVASF in 1974, at which time it was linked to the Federal Government through the Ministry of the Interior. The Companhia then became a part of the Ministry of Agriculture and Agrarian Reform (CODEVASF 1991c), and in 1995 came under the auspices of the Ministry of Environment and Irrigation.

plaguing the Companhia in the late 1980s[4]. Due to structural and operational difficulties, including high operational costs and unfinished irrigation works, the local administration of the Senador Nilo Coelho perimeter is one based on an irrigation district (CODEVASF 1991a).

2.2.2 The Irrigation District

The concept of an irrigation district was conceived as a private, non-profit, collectively-owned entity (CODEVASF 1991a). Its main objective is to administer and maintain the common-use irrigation infrastructure and to provide the necessary conditions for agricultural production and the well-being of the producers (CODEVASF 1991a). The District of the Senador Nilo Coelho Irrigation Perimeter became operational in 1988 (CODEVASF 1991b). Its office is located in the perimeter and it consists of an Operation and Management Division, and a Technical Assistance and Rural Extension group. Among its responsibilities, the District is charged with administering water tariffs and providing technical assistance for producers, important factors in determining the producers' capacity to produce and their technical knowledge of irrigated agriculture.

2.2.2.2 Administration of Water Tariffs

The District is required to generate its own resources by charging for water use in the perimeter. It does so through its Operation and Management Division, which bills the producers monthly based on farm-specific hydrometer readings. Upon each monthly visit,

[4] Although CODEVASF charged an annually fixed water tariff to the users, most producers never paid. This situation, coupled with high inflation rates kept revenue in the Nilo Coelho perimeter at less than 10% of the annual costs (CODEVASF 1991a).

the District's hydrometer "readers" (*leitoristas*) also check the amount of area being planted in each farm, and this information is used to generate monthly reports on each producer. By keeping track of the planted area, the District can follow the conditions of payment of each producer --it can verify whether or not a particular producer is capable of paying his monthly bill based on the expected earnings from a recently harvested crop (Rocha 1996).

The total cost of irrigation water to the producer includes variable and fixed costs, and an interest charge, as defined in Appendix A. The variable cost is based on the actual amount of water use per month. The fixed cost and the interest charge, however, are based on the total farm size and are collected regardless of the amount of water used.

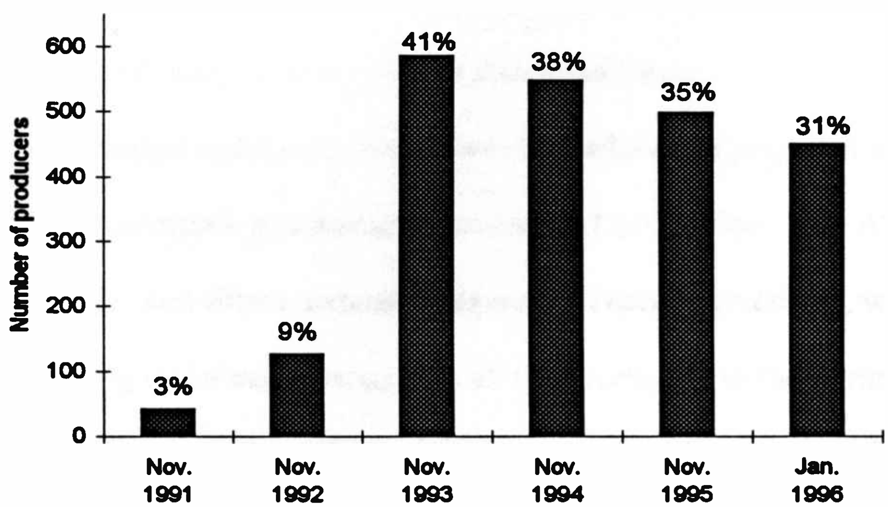
The establishment of these fees resulted in two important changes in the perimeter: first, more land was put under production; second, many farmers were forced to leave the perimeter. Prior to these fees, most farmers did not pay for the use of the land, local infrastructure, or water. Consequently, only about 30% of the irrigable land was occupied and the remainder lay idle for speculation (Rocha 1996). With the imposition of the fixed cost and the interest charge for all the farmers, additional land was put under production, reaching about 70% of the irrigable area in the perimeter today (Rocha 1996). The other major change was related to the process of "natural selection", in which many of the original occupants were indirectly forced to leave the perimeter because of poor productivity and production management which kept them from earning enough to pay for the increased production costs. Today only about 40% of the producers are original occupants (Rocha 1996).

Non-payment of water bills is common practice among the small producers. Recently it was believed that poor soil (*manchas de solo*) could be a factor in explaining low productivity and consequently non-payment. Soil studies, however, rejected this hypothesis. Neighboring producers, some very productive and others barely producing, shared the same quality soils (Noronha 1996). One factor which has not been formally investigated, but is generally accepted by the irrigation agency, is the importance of a "managerial vision" -- the producer's ability to manage his resources efficiently (Rocha 1996).

Non-payment of two or even three bills is usually expected by the District because of the gap between seasonal income and seasonal expenses. Producers often have to make considerable investments in the beginning of each growing season, yet have to wait several months before receiving any returns. To get around this problem, the producer must either have savings, access to other sources of credit, or diversify the crop mix. Many producers plant bananas, for example, which can be harvested every 15 days, thus providing a continuos source of income. CODEVASF's decision in 1995 to require each producer to purchase his farm has also induced non-payment by many producers. Many of those who were already in a dire situation were forced to sell their farm. Figure 2.2 shows the observed changes in the number of producers paying their water bills on time, emerging from a low three percent in 1991 to 41% in 1993.

Non-payment of water bills can have serious consequences for the producers. Initially, if the producer owed more than twelve payments, and took over thirty days to pay the latest bill, his water supply was shut off. In order to reinitiate water use, he had to pay 20% of his debt. Today, the producer suffers consequences after the sixth unpaid bill. In practice, however, there are many producers with over six unpaid bills that continue to receive water. The idea fostered by the District is not to penalize those producers who show a serious interest in continuing their agricultural activities in the perimeter. So instead of shutting off the water supply, the District requires that each producer pay the current water bill, avoiding increases in water debt. In the meantime, producers are given the option of devising a payment plan for the remaining debt (Rocha 1996).

Figure 2.2. Colonos in the Perimeter Who Pay Water Tariffs on Time, 1991-1995



Source: Distrito 1995, Rocha 1996.

In cases where the producer is highly indebted to the District and the bank, he may be forced into "selling" his farm. The producers settled in the perimeter are not landowners, but rather the legal occupants of their farms. So, in "selling" his farm, the producer passes the legal occupation on to another occupant. A parcel of 6 hectares can presently be sold for about R$ 30,000 (or about $ 2,000 per acre), which is usually enough to liquidate the debt with the District (Rocha 1996).

Another problem frequently encountered by the Operation and Management Division is the vandalism done to hydrometers by the producers. Many producers have found inventive means of altering or destroying hydrometers in hope of paying lower water bills. The District now charges the producer for each broken or altered hydrometer. Furthermore, when the hydrometer is damaged, the District turns to a crop water usage table as a way of estimating the total water usage for specific plots. So if a producer has 2.5 ha of tomato, 3.0 ha of guava, and 0.5 ha of papaya, he will be charged accordingly.

2.2.2.2 Technical Assistance and Rural Extension Services

Most of the technical assistance available to the colonos is provided by the District through its Technical Assistance and Rural Extension (ATER) office. The ATER is made up of seven agronomists and fifteen extension agents (*técnicos agrícolas*), who are responsible for providing technical assistance to all the producers in the perimeter. In addition to technical assistance, the ATER offers assistance with credit, works with producer organizations, collaborates with industries, and publishes agricultural booklets, as described below (Noronha 1996).

The technical assistance provide by the ATER consists of visits, technical meetings, and field days. Given only one extension agent per nucleus, it is the ATER's philosophy that the producer should seek the agent, and not vice-versa. Therefore, the visits by ATER agents are done solely upon request by the producer, which can be done in person at the ATER office in each nucleus. According to a recent survey carried out by the District, about 50% to 60% of producers seek technical assistance when it is too late to remedy the situation (Noronha 1996). Another 30% to 40% seek technical assistance on a monthly basis and show an interest in having more frequent visits. The most frequently asked questions concern production practices, including fertilizer use and pruning. There are also frequent requests for evaluation of crop losses (*avaliação de perda de plantio*) which are used to back up claims by the producers to the District, banks, and processing firms. Though the ATER offers its extension services to all the producers in the perimeter, a recent study revealed that only 13% of the small producers received assistance (Millar 1992).

With a limited number of agents, the ATER often resorts to technical meetings, special interest groups and field days to reach out to a greater number of producers and to focus on the management of particular crops during each season. The technical meetings are usually held in the evenings and cover issues ranging from sources of credit to administrative issues. Special interest groups meet to discuss the production and marketing of particular crops, including tomatoes, bananas, mangoes, and acerola. The field days provide hands-on experience, through which ATER agents show appropriate production practices, including seedbed preparation, transplanting techniques, safety measures, and appropriate types and quantities of inputs.

The ATER provides assistance with credit by serving as a liaison between the producers and the bank. The District sends the producer to the bank, the bank evaluates his financial situation and, if acceptable, the bank writes the District a letter saying the producer is qualified to receive credit. The producer then requests the ATER to develop a project, setting the loan amount and the schedule of payments.

The ATER is also involved with producer organizations. The ATER formed the Producer Training and Organization Group (*Equipe de Capacitação e Organização dos Agricultores*, ECOA) in 1994 to organize producers to take advantage of input and output markets. The Group also seeks stronger interaction between processing firms and producers, particularly with respect to contract negotiations.

The District works directly with processing firms by establishing contracts to provide technical assistance to the tomato producers. The processing firm (CICA) provides transportation and the District provides the salaries for three technical experts from the District who have previously worked with the industry. This arrangement allows for a more effective assistance for tomato producers, while also providing the industry the opportunity to continuously monitor the contracted colonos.

The District also develops agricultural pamphlets and booklets which are published through CODEVASF and are made available to producers at cost. The technical recommendations for the production of industrial tomatoes under irrigated conditions (de Carvalho *et al.* 1995) used in this study is one such publication.

Through all its activities and its permanent presence in the perimeter, the District has developed a stronger partnership with the small producers than any other institution or agency active in the perimeter.

2.2.3 The Agricultural Research Agency

The Center for Tropical Semi-Arid Agricultural Research (*Centro de Pesquisa Agropecuária do Trópico Semi-Árido*, CPATSA) is one of several field research centers of EMBRAPA. CPATSA's research agenda is focused on developing simple technologies adapted to the Brazilian semi-arid Northeast. Some of its achievements include the development of technologies to capture *in situ* rain water, water retention barriers, underground dams, saline water irrigation, rural cisterns, animal-traction implements, and the development of locally-adapted hay (*capim buffel* and *leucena*). CPATSA also invests in research and development of fruits and produce adapted to local conditions.

The Center is located 40 km north of Petrolina, near the Bebedouro project and it provides a number of services to the many irrigation perimeters in the region, including the Senador Nilo Coelho. CPATSA researchers are often called upon to investigate crop diseases and pests and also do soil studies for individual producers. One of CPATSA's contributions which is used throughout this study is its publications on recommended management practices for particular crops. In the case of tomatoes, it publishes a detailed manual on recommended practices, including the optimal types of inputs and timing of input use (EMBRAPA 1994).

2.2.4 The Pulp Processing Firms

The processing firm is an important component of the tomato production system in the perimeter. Unlike most other crops, tomato production by colonos is largely done through contracts with the pulp processing firms, where the firm provides all the inputs for tomato production, then receives in-kind payment from the colonos at harvest time.

The potential for tomato production in the perimeter stimulated the establishment of four main pulp processing firms in the Petrolina/Juazeiro region: Etti, Cica, Tat, and Palmeron. Though each firm processes independently, they all follow similar contracting procedures with colonos and adhere to the same output prices. Their main purpose is to process local tomatoes into tomato pulp, which is then trucked to the larger industries in São Paulo, where the pulp is transformed into tomato sauce, paste, and ketchup for nationwide distribution. Today, the tomato pulp processing firms in the Petrolina/Juazeiro region account for 70 % of Brazil's pulp processing capacity (CODEVASF 1995a).

Most of the tomatoes processed by the industries are from small producers in the perimeter (Janebro 1996). For the Etti industry, about 80% of the tomatoes processed is bought from the colonos, whereas the remaining 20% is bought from larger producers (*empresas*). There have been on average 400-450 colonos producing for Etti from 1994-1996. In 1996, there was a reduction in the area planted with tomatoes by large producers, who are increasing their investments to the production of fruits (Janebro 1996).

2.2.4.1 Contract with Tomato Producers

The contract established between the industry and the producers is a way of assuring the needed supply of tomatoes to the industry, while also providing financial support for the colono to produce. The importance of the firm for tomato production by small producers is reflected by the availability of financing for tomato production: 46% of tomato producers rely on the industry for financing, while 3% rely on bank loans, 7 % on sharecropping and the remaining 44% have no source of financing (Millar 1992). By providing the contract, the firm commits to supplying all the inputs (seeds, fertilizers, herbicides, pesticides, and water), preparing the field for tomato production, and providing transportation to the producer. In turn, the producer commits to planting a determined number of hectares and selling all his produce to that particular firm.

The contracting procedure begins in November, when industry representatives visit all the colonos in the perimeter to get an idea of how many are considering to plant tomatoes in the upcoming season. At this time, an initial production survey (*minuta*) is filled out for each potential supplier. A couple of months later, during January and February, the Tomato Committee discusses and announces the price for tomatoes. Finally, between February and April, input prices are presented to the producers and contracts are signed.

Producers are given tomato seeds at the time the contract is signed. To receive the other inputs, the producer must seed and plant the amount stated in the contract[5]. Industry

[5] Providing the inputs to the producers in intervals, rather than all at once, serves two main purposes: a) it allows the industry to provide some guidance on how the producers should use the inputs, giving

representatives visit the lots on a weekly basis during the season to verify the amount that is seeded, transplanted, and the amount that is germinating. Through these visits, the industry verifies the commitment of the producer and provides the additional inputs, as well as technical assistance. After transplanting, the industry checks the effective area planted and makes any needed adjustment to the contract.

The input package provided by the industry is based on recommendations from the *Receituário Agronômico*, the federally endorsed agricultural handbook, with adaptations made for local conditions. The input package contains fertilizers and pesticides and producers are presented with the unit price of each input as well as its equivalent in tomatoes (kg). The input package for 1996 is presented in Appendix B.

Water is among the inputs provided to the producers by the industry. The industry establishes a water contract with the irrigation District during the 3-month tomato season. The District commits to supplying water to the tomato producers, even those who are in debt, during the 3-month tomato growing season. In turn, the industry pays the water tariffs of the tomato-producing colonos directly to the District. For the industry, the contract is the only means of assuring continuous water supply to its producers. Without the contract, many indebted producers would risk having their water supply shut down. The contract is also advantageous for the District because it assures that all tomato

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particular attention to individual plots, and b) it discourages producers from selling their inputs in the market. In one case, a producer received the pesticide Vertimec which cost R$140.00 (equivalent to 2 tons of tomatoes) and sold it to the market for R$60.00. Not only did the producer have a lower productivity that year, but he also received a lower price for his lower quality tomatoes. Cases like this one are believed to be common.

producers will cover at least 3 water bills. Furthermore, the industry also withholds 5% of total earnings of each colono that is in debt with the District and, with prior consent of the producer, transfers it directly to the District.

The technical experts from the industry continue to visit the farms throughout the 90 to 110-day tomato season. Once harvesting begins, usually in June, trucks loaded with crates are delivered to each farm for the collection of tomatoes. The tomatoes are taken directly to the processing firm, where they first undergo a quality control test, as established by the Ministry of Agriculture, and are weighted and prepared for processing. The total weight of the tomatoes from each farm is used to determine how much the producer will receive. Once the total value of tomatoes from a farm is determined, the amount to cover for the inputs is discounted, as well as any additional discounts based on quality control standards.

Although the price for tomatoes is fixed prior to harvest time, there are a number of factors that affect the price received by the producer when he sells his tomatoes to the industry. One of these factors is the index of total soluble solids, or the brix of the tomato. The greater the brix level, the better the quality of the tomato for the industry (less water and more pulp). The most widely used type of tomato in the perimeter is the IPA-5 which has a brix level ranging from 4.4 to 5.3. There are hybrids which attain a brix level of 7.0. While the producer is not penalized for low brix levels, he is rewarded for higher brix levels (Janebro 1996)

The producer is, however, penalized for certain defects. Defect-related discounts follow the standards established by the Ministry of Agriculture. Basically, the price the producer receives can be lowered if his produce has insect fragments, exceeds the acceptable level of fungus, or is less than 75% red. Discounts are also given if the product presents any of defects, including discoloration, pest or fungal infection, cracks, sunburn spots, and if the stem is still present (Janebro 1996).

2.2.5 Institutions and the Producers in the Perimeter

CODEVASF, the District, EMBRAPA/CPATSA, and the processing firms are active participants in the development of the perimeter and each play an important role in the agricultural production of small producers. One issue not yet addressed in this chapter is the relationship between these institutions and the impact of these institutional linkages on the perimeter. Besides the already existing hierarchical structure of CODEVASF (i.e., Headquarters, regional office, District), there are strong underlying political forces which shape the linkages between these institutions one way or another, making them interactive relationships or mere bureaucratic formalities, depending on the ruling political party and officials. In Petrolina there are dominant families who have ruled the city for decades[6]. Their will is engraved throughout the irrigation projects, the industries, and the increasing foreign investment in the Petrolina region. Their will is also reflected through institutions active in the perimeter, particularly CODEVASF and CPATSA. Priorities often conflict and collaboration is not always viable.

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[6] Chilcote (1990) presents a detailed historical account of the political structure in Petrolina.

There are conflicting interests also between the processing firms and CPATSA. Though members from these two agencies occasionally meet to discuss tomato production, they too have different priorities. The processing firm wants large amounts of tomatoes and promotes agricultural practices primarily focused on obtaining high yields. While also concerned about yields, CPATSA has an important role in environmental conservation. So it would more likely recommend less toxic pest and weed control chemicals than the firms. In addition to the difficulties already encountered by the producers on their farms, they are also subject to mixed messages within their institutional setting.

2.3 The Irrigation Perimeter

The potentially irrigable lands of the project were identified in the 1960s in joint work done by the United Nations Food and Agricultural Organization (FAO) and the Superintendency for the Development of Northeast Brazil (*Superintendencia para o Desenvolvimento do Nordeste*, SUDENE). In 1969, SUVALE, the present day CODEVASF, carried out technical and economic feasibility studies of the project area and concluded that irrigated agriculture would be viable. The creation of the project received great momentum with the establishment of the National Integration Program (PIN) which had as one of its objective the integration of the Northeast and the creation of the Northeast Irrigation Program (PROINE) (Quaglia *et al.* 1989). The perimeter was implemented from 1979 to 1984, at which time it became operational (Quaglia *et al.* 1989).

The main objectives for the project were to increase agriculture production to meet the growing domestic demand and to take advantage of export possibilities; to place poor rural families from the region in an integrated rural development project; and to create new employment opportunities in rural areas to reverse the process of migration to the urban centers along the Northeastern coast or to the Southern region of Brazil (Quaglia *et al.* 1989). The perimeter, its producers and agricultural production are described below.

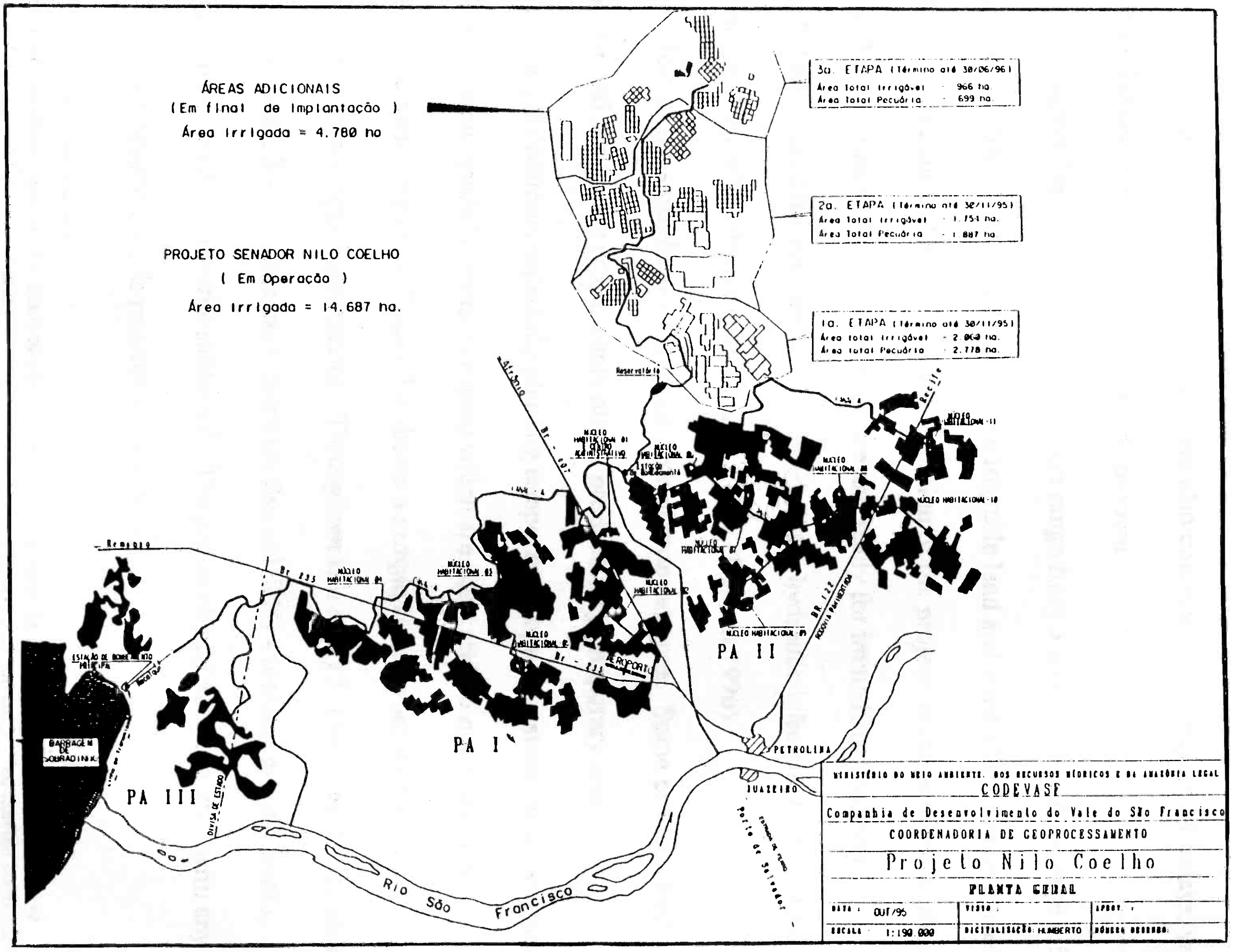
2.3.1 The Perimeter

The Senador Nilo Coelho Irrigation Perimeter covers about 20,000 ha. There are currently 14,687 irrigated hectares, allocated among small producers and large farmers (*empresas*), and an additional 4780 ha are being implemented (*Áreas Adicionais*) (Figure 2.3). This study focuses solely on the already operating irrigated areas allocated to small producers, or colonos.

The area allocated for the small producers is divided into eleven areas, called nuclei, consisting of a residential village and neighboring farms (Figure 2.3). Each nuclei has from 80 to 180 standard built homes which were constructed during the project's implementation by the first group of colonos. Each village is located so that each colono has a maximum of 3 km from the village to his farm (CODEVASF 1983). The villages and farms are connected by a network of dirt roads. The perimeter provides its residents basic sanitation and electricity[7], and it operates elementary schools, commercial centers, a

[7] Electric energy is abundant in the region because of the Sobradinho, Paulo Afonso and Itaparica hydroelectric plants (Quaglia *et al.* 1989).

Figure 2.3 Layout of the Senador Nilo Coelho Irrigation Perimeter, Petrolina



Source: Coordenadoria de Geoprocessamento, CODEVASF, Brasília, 1995.

first aid station, a snack bar, a repair shop, and a large storage shed (Quaglia *et al.* 1989). Public transportation to and from Petrolina/Juazeiro is available along the main highways. Collective transportation (*paus-de-arara*) are also common, especially on Mondays, when most rural families take care of their errands in town.

The farms destined for small producers range from 5 ha to 7 ha and average 6.5 ha (Quaglia *et al.* 1989). All of the farms have irrigable land and most also have land used for rainfed agriculture. During the implementation of the project, colonos received their farms fully equipped with irrigation structure and ready for immediate production. CODEVASF cleared the land and implemented all the hydraulic infrastructure, and also covered the costs of the first two productive cycles (Janebro 1996).

Most of the small farmers produce several crops at once. Some produce both permanent and temporary crops, while others produce only temporary crops. Intercropping is common, especially planting temporary crops (tomatoes, melons) among young permanent stands (guavas, bananas) which are short and do not block direct sunlight from their neighbors. Figure 2.4 shows a sample farm layout with several purestand and intercropped plantations. Throughout this study I refer to each individual plantation as a subfield. In this case, there are five subfields - tomato, guava/tomato, coconut/tomato, and two acerola subfields[8]. The group of subfields, together with any fallow land and rainfed area, is referred to as a farm[9].

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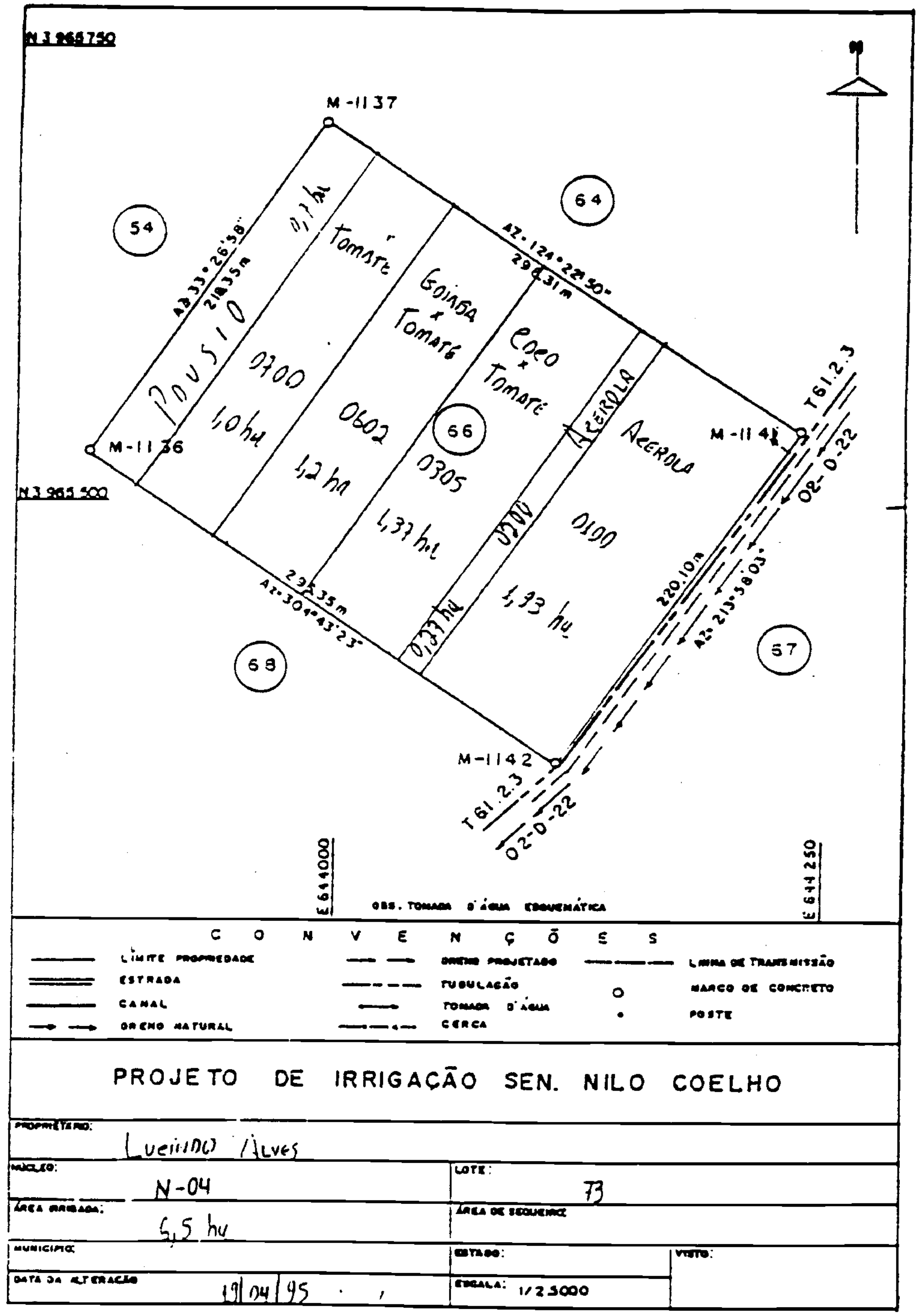
[8] Subfields are classified based on the crops planted and the planting date. In Figure 2.4, three subfields have tomatoes, yet only one is a purestand and the others are intercropped (guava and coconut). The acerola subfields are purestands, so the identification of two separate subfields imply they were planted on different dates. This convention is used by EMBRAPA in its producer database and is employed in this study for convenience.

[9] The term farm is used as the equivalent to the Portuguese *lote*.

Figure 2.4 Layout of Sample Farm in Irrigation Perimeter



Source: EMBRAPA/CPATSA 1996.

2.3.1.1 Irrigation Infrastructure

The water used in the perimeter is taken from the Sobradinho Dam through a pumping station capable of capturing 23.2m^3 of water per second (CODEVASF 1991c). The quality and quantity of water obtained from the dam is more than enough to meet the needs of the project, which is less than 1% of the maximum water flow (Regis and Gurgel 1980). Two main canals, extending 62 km, transport the water to secondary canals, which distribute water by gravity to thirty-one pumping stations in the perimeter. Each pumping station in turn provides pressurized tube water to the individual farms (CODEVASF 1991c). The irrigation infrastructure includes also 130 km of drainage (CODEVASF 1991c).

The most widely used irrigation system in the perimeter is the sprinkler and it is believed to be the most viable option given the physical and economic conditions of the region (Quaglia *et al.* 1989). The system consists of movable pipes and sprinklers and requires that the producer periodically move the pipes throughout the irrigable portion of the farm. Though a burdensome task, the pipes are relatively light-weight and moving the irrigation line throughout the farm can be easily done by one individual[10]. Irrigation pipes and sprinklers require basic maintenance, which occasionally involve new parts. Though all the small farms were originally equipped with standard equipment, producers are turning to various types of replacement parts. In some instances, the original parts are no

[10] For details on sprinkler system use by small farmers in an irrigation projects, see Ferreira (1993).

longer available in the local market. Even when parts are available in the local market, producers often turn to cheaper substitutes.

2.3.2 The Producers

The Nilo Coelho perimeter was projected to combine small producers and large farms[11] (*empresas*) in an effort to settle low income families, create jobs and develop an important pulp processing center (*pólo agrodindustrial*) (Quaglia *et al.* 1989). In implementing the project, CODEVASF envisaged that 60% of the land would be allocated to small producers, and 40% to the firms (Quaglia *et al.* 1989). There are currently 1,769 small producers in the perimeter with an average farm of 6.5 ha (CODEVASF 1995b; Quaglia *et al.* 1989). There are also 130 large farms, with plots ranging from 12 to 999 ha (Quaglia *et al.* 1989). There is great variation in the sizes of large firms. About 50% of large farms are within 12 ha to 75 ha. On the other extreme, about 5% of firms range between 501 ha to 999 ha, occupying 40% of the land destined for large farms and 10 % of the total irrigable land in the perimeter (Quaglia *et al.* 1989).

Figure 2.5 shows the share of irrigable land allocated to colonos and large farmers in the perimeter in 1985, 1988, and 1995. There has been a considerable increase in the total number of irrigable hectares allocated to both small and large farmers since 1985. The share of land for small farmers increased between 1985 and 1988 and decreased by about 9% between 1988 and 1995.

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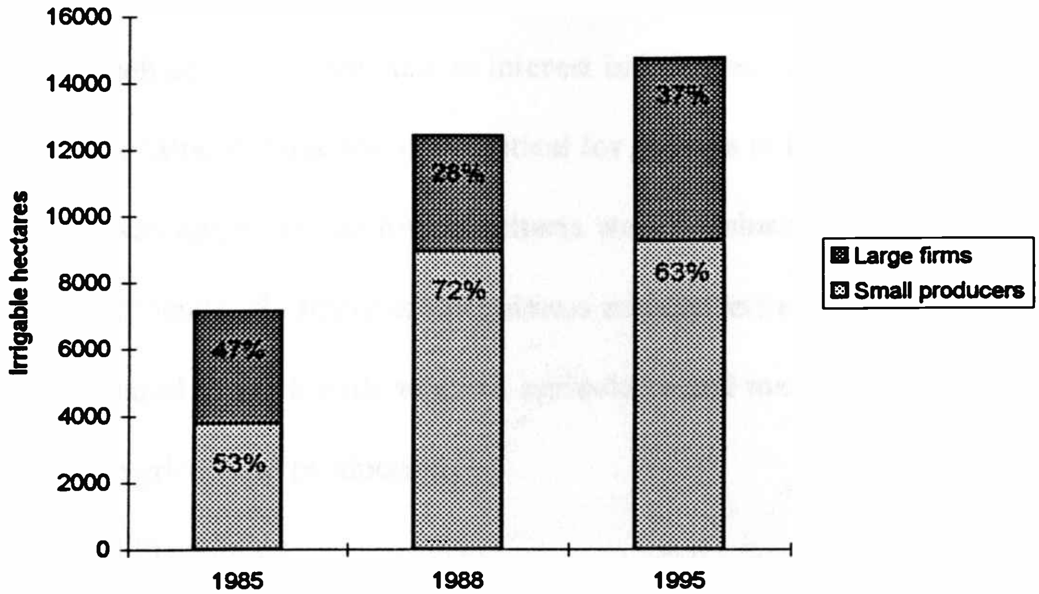
[11] These large farms refer to the large privately-owned farm operations and are not to be confused with the pulp-processing firms, which in fact were not entitled to any land within the perimeter.

Figure 2.5 Share of Colonos and Large Farms in the Perimeter



Source: Quaglia *et al.* 1989, CODEVASF 1995b.

CODEVASF had different policies regarding the allocation of land for each class of producers. While the small producers received their farms completely equipped and ready for agricultural production, large farms only were provided the land and water outlet (*tomada d'agua*); they were responsible for clearing and leveling their own land, as well as installing the irrigation system.

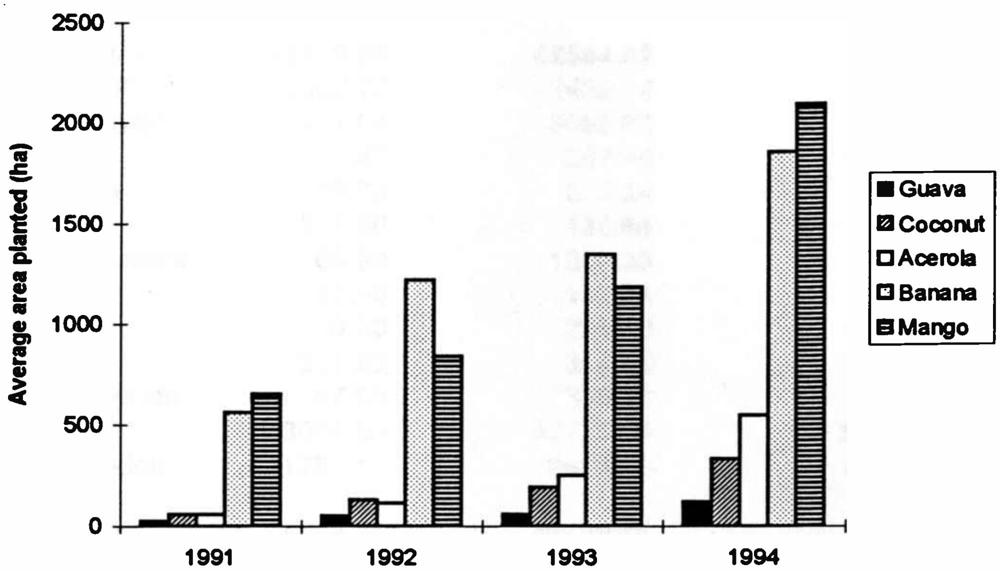
The procedure used for the selection of the colonos to settle in the perimeter had serious consequences and remains a debatable issue. As a general rule, the selection of colonos was based on social interest, which is reflected by the large portion of the project destined for low-income rural households. Maximum priority was given to farmers who had been displaced due to the disappropriation of their land. Second in line were the farmer residents in the municipality, then in the local region, and so forth. Other factors taken into consideration were the farmers' experience and aptitude with agricultural activities, the household labor force, and an interest in irrigated agriculture (CODEVASF 1987). Though the latter criteria are more critical for success in irrigated agriculture (experience, technical aptitude), the former criteria were dominant in the selection process (disappropriation of land). So many of the colonos initially settled in the perimeter were completely unprepared to work with irrigated agriculture and many did not have the basic skills required for agricultural production.

2.3.3 Agricultural Production

The Agricultural Plan for the project, based on ecological conditions and market factors, proposed that the main crops produced in the perimeter should be tomatoes, melons, onions, garlic, beans, and sugarcane. Other crops were then added to the list, including cotton, peanuts, corn, guava, grapes and sunflowers (Quaglia *et al.* 1989). Recommendations on crop mix were made for each category of producers by EMBRAPA. Many new crops have been introduced in response to changing market conditions and as a result of the development of locally-adapted varieties, including bananas, mangoes, papaya, and acerola.

The main permanent crops grown in the 1990-1994 period are shown in Figure 2.6. This figure shows the significant increases in area planted with permanent crops in the perimeter. The increasing trend reflects production by small producers and large farms in the perimeter.

Figure 2.6. Main Permanent Crops Produced in the Senador Nilo Coelho Irrigation Perimeter, Petrolina, 1991-1994



Source: Distrito 1995.

Despite the increasing trend in area planted with permanent crops, small producers still work extensively with temporary crops. In 1994, about 75% of the land destined for small producers was used for the production of temporary crops (CODEVASF 1995b). Temporary and permanent crops produced by the small producers are listed in Table 2.1.

Table 2.1 Crops Produced by Small Farmers in the Senador Nilo Coelho Irrigation Perimeter, 1994

Crop	Area planted	Net production value	% of production value
Temporary	**12573.94**	**62584.02**	
beans (PH)	2002.70	2432.64	2.43
beans (VG)	5231.64	3695.62	3.69
carrots	105.40	267.48	0.27
cassava	49.70	555.24	0.55
corn	335.00	135.64	0.14
green pepper	66.90	1252.33	1.25
melon	17.00	112.04	0.11
onion	30.30	226.32	0.23
squash	339.90	354.82	0.35
sweet potato	57.80	339.13	0.34
tomato	3054.50	50728.29	50.59
watermelon	1283.10	2484.47	2.48
Permanent	**4262.30**	**37679.47**	
acerola	479.80	2181.54	2.18
banana	2209.30	25890.10	25.82
cashew	2.50	--	--
citrus	36.80	101.93	0.10
coconut	322.10	1169.95	1.17
grapes	177.60	7164.55	7.15
guava	122.00	283.25	0.28
mango	899.70	871.96	0.87
papaya	4.00	--	--
pineapple	8.50	16.19	0.02
Total	**16836.24**	**100263.49**	100.00

Source: CODEVASF 1995b.

2.4 Tomato Production in the Irrigation Perimeter

When the perimeter was implemented in 1984, several pulp-processing firms established in the region as result of government incentives. This outlet for tomatoes triggered tomato production in the perimeter and has sustained it ever since. Without the industries, the production of tomatoes in the region would not have been viable because of prohibitive transportation costs. Not only is Petrolina distant from concentrated consumer markets along the coast and the processing firms in São Paulo, but transportation of tomatoes requires very careful handling and timing if they are to reach the markets with a competitive price.

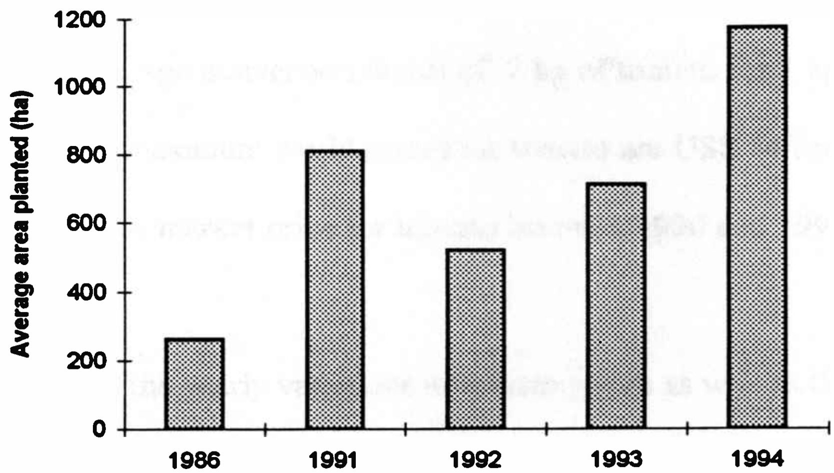
Despite the growing trend of colonos towards producing permanent fruit crops, tomato remains an important temporary crop for small producers in the Senador Nilo Coelho perimeter. In 1994, small producers harvested 3,055 ha of tomatoes covering 23% of total area planted by all the small producers in the perimeter. According to CODEVASF, the tomatoes harvested that year accounted for 51% of the producers' annual net production value (CODEVASF 1995b).

Given the many interests in the production of tomatoes in the area, there exists a committee composed of members from the industries, EMBRAPA, CODEVASF, the Pernambuco State Secretary of Agriculture and the Association of Producers. The Committee meets regularly to discuss the price of tomato for the upcoming season, classification policies, and transportation policies.

2.4.1 Tomato Production Trend

The recent trend in tomato production in the perimeter is shown in Figure 2.7. The dramatic increase in area planted with tomatoes from 1986 to 1991 reflects the increase in irrigable land made available to farmers.

Figure 2.7 Average Area Planted with Tomatoes in the Senador Nilo Coelho Irrigation Perimeter, 1986, 1991-1994



Source: Quaglia *et al.* 1989, Distrito 1995

Despite the increases in tomato production, there remain many challenges facing tomato producers. Tomato is a very high-risk crop, susceptible to many diseases and pests. In 1989, the appearance of the *traça*[12] decimated tomato crops in the perimeter. In addition to the *traça*, other pests and common diseases regularly affect tomato production

[12] The *traça do tomateiro* (*Scrobipalpuloides absoluta*) is one of the most common tomato pests in the region and can cause widespread crop damage.

in the region[13]. This high risk factor has lead the Banco do Nordeste to stop lending for tomato production. So the industry is the only formal source of credit available to the colono for the production of tomatoes.

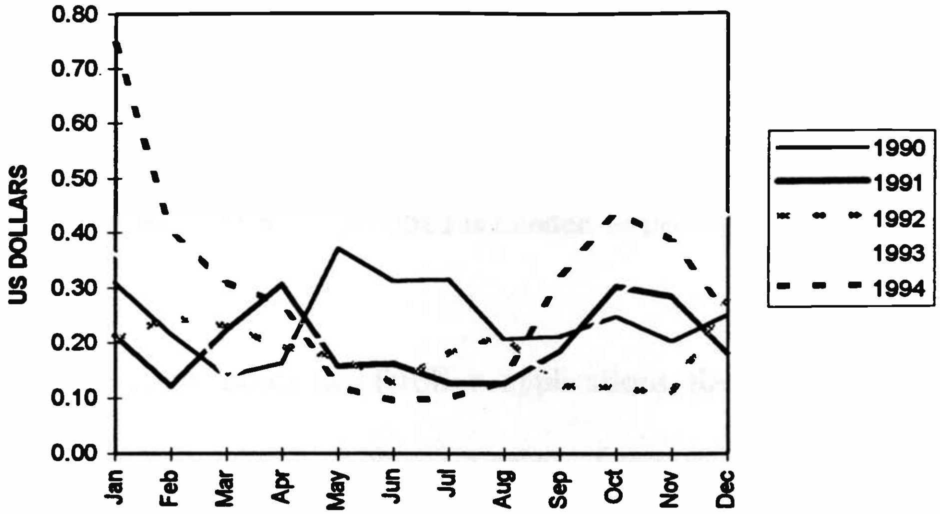
2.4.2 Tomato Prices

The price for tomato is fixed annually by the Tomato Committee and it is based on the world market price for tomato pulp. This price follows an oscillating pattern approximately every three years, with a minimum of US$ 520/ton and a maximum of US$ 1100/ ton. Given the average conversion factor of 7 kg of tomato for 1 kg of pulp, the equivalent minimum and maximum world prices for tomato are US$ 74/ton and US$ 157/ton, respectively. The market price for tomato between 1990 and 1994 are presented in Figure 2.8.

Figure 2.8 shows the yearly variations in tomato prices as well as the seasonal oscillations. The seasonal oscillations reflect the availability of tomato throughout the year. Market prices for tomatoes are at their lowest during the abundant harvest season, from May through August (1990 is the only year from 1990-1994 in which this pattern is not observed). Many producers will plant tomatoes out of season to take advantage of the higher market prices. Most small producers, however, produce tomatoes directly for the processing firms, which work with a single fixed price all year long.

[13] For a description of common tomato pests and diseases and recommended remedies, see EMBRAPA (1994) and de Carvalho *et al.* (1995).

Figure 2.8. Market Price for Tomato in Petrolina, 1990-1994



Source: Distrito 1996.

2.4.3 Recommended Management Practices and Input Use for Tomato Production in the Perimeter

Given the importance of tomato production in the region, both EMBRAPA and the Distrito publish recommendations for the production of tomatoes based on the soil and climate characteristics of the Petrolina region (EMBRAPA 1994, de Carvalho *et al.* 1995). Recommendations are given on production practices, from seedbed preparation to harvest, as well as pest control and prevention.

The tomato planting season in this region of the San Francisco River valley is between the months of March and June, as established in 1992 by the Ministry of Agriculture in an effort to reduce the incidence of particular pests (EMBRAPA 1994). Though tomatoes can be planted directly in the soil or initially in a seedbed and then transplanted, the majority of the small producers in the perimeter, and all of those in this study, use a seedbed. The seedbed should be made in an area close to the area the tomatoes will be planted, yet distant from other tomato crops and plantations to avoid any infestation. It should be made on leveled, well-drained soil and in a sunny and well-ventilated location. About $100m^2$ of seedbed is needed to produce high quality seedlings to transplant 1 hectare.

The seedbed initially needs two fertilizer applications, the foundation fertilizer and the cover fertilizer. The foundation fertilizer consists of manure and 06-24-12 (nitrogen, phosphorus, and potassium). The cover fertilizer consists of urea and is applied fifteen days after seeding. Chemicals are applied before covering the seedbed with hay, which protects the sprouting seedlings.

Prior to transplanting the seedlings, the field needs to be plowed and furrowed, and lime needs to be applied to the soil. The seedlings are ready for transplanting between twenty and thirty days after seeding (EMBRAPA 1994). Fertilizer is then applied fifteen to twenty days after the seedlings have been transplanted and twice more thereafter (de Carvalho *et al.* 1995).

The efficient use of irrigation water is important in obtaining high productivity, reduction of costs and soil conservation. It also reduces the risks of salinization, water logging, erosion and leeching of nutrients (de Carvalho *et al.* 1995). The irrigation District publishes a recommended irrigation schedule for tomato production in Petrolina which indicates average number of days, hours, and minutes that the producer should irrigate his tomato crop throughout the season. The amount of recommended irrigation time varies within the three-month long growing season and also changes depending upon the month in which the tomato is seeded (de Carvalho *et al.* 1995).

Harvesting of industrial tomatoes should occur when the tomatoes are as mature as possible, without beginning deterioration. For tomatoes planted in semi-arid regions, the general rule is to begin harvesting 110-120 days after seeding, when approximately 80% of the fruits are mature (EMBRAPA 1994). To obtain a higher brix level, it is recommended that irrigation be stopped ten to twenty days prior to harvest (EMBRAPA 1994). Tomatoes are manually picked and put into industry-supplied crates. After harvesting, the remains of the tomato plant must be plowed under immediately to avoid any proliferation of pests.

In this study, I assume that the above recommendations are favorable for the small producers, and if possible, they will want to follow these recommendations for a healthier, and more productive tomato crop. I also assume that extreme deviations from these recommendations will have a detrimental impact on the productivity of tomatoes. In particular, I expect that transplanting the seedlings too early or too late may decrease their chances of survival in the field and thus lower productivity. Likewise, applying fertilizer immediately after transplanting may injure the seedlings, which need several days to overcome the stress of transplantation. The timing of irrigation is also critical and I expect that deviations from the recommended schedule may lead to reduced output. The impact of these crop management variables on production efficiency will be considered in later chapters (Section 5.1.2).

CHAPTER THREE

THEORETICAL AND CONCEPTUAL MODELS

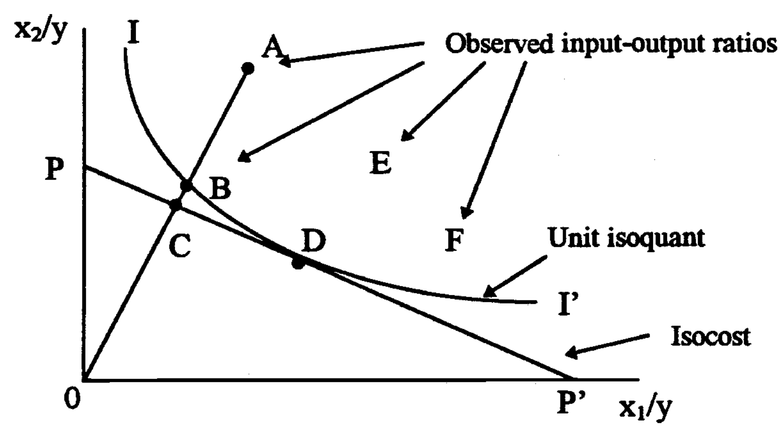
This chapter presents the theoretical model used to explain farm-specific technical efficiency and the conceptual model used to identify the determinants of efficiency. Technical efficiency is first defined and approaches to its estimation are presented. Likewise, the determinants of technical efficiency in agriculture are briefly discussed and the model for identifying these determinants is presented. A review of empirical studies on efficiency measures of agricultural production in developing countries also is presented.

3.1 Technical Efficiency Defined

An input-output vector is technically efficient if and only if increasing any output or decreasing any input is possible only by decreasing some other output or increasing some other input. This definition of technical efficiency was given by Koopmans, who was among the first to provide a rigorous approach to the measurement of efficiency (Färe, Grosskopf, and Lovell 1994). Farrell (1957) extended the work of Koopmans and others by making two important contributions to the measurement of efficiency. First, he proposed that Koopmans's definition of technical efficiency be measured in relative terms based on the best performer within a sample. Second, he defined economic efficiency as the combination of technical efficiency and allocative efficiency (Färe, Grosskopf, and Lovell 1994).

Farrell introduced his concept of efficiency with a hypothetical firm using two inputs, x_1 and x_2, to produce one output, y. For simplicity, he assumed the firm operates under constant returns to scale, allowing the frontier to be represented by the efficient unit isoquant, as shown in Figure 3.1. The horizontal and vertical axis show the input-output ratios (input-per-unit-of-output) for x_1 and x_2, respectively. The unit isoquant, II', defines the input-output ratios associated with the most efficient use of the inputs to produce the output involved (Battese 1991). Any deviation from the input-output ratios defined by the isoquant where said to be associated with technical inefficiency.

Figure 3.1. Isoquant Diagram of Economic Efficiency



Source: Adapted from Battese (1991) and Schmidt (1986).

Under this scenario, firms operating along the isoquant, namely B and D, are technically efficient. Firms operating above the isoquant are inefficient relative to the firms operating on the isoquant and their inefficiency level is measured by the ratio of the efficient input-output ratio (isoquant) and the observed input-output ratio. The level of technical efficiency of the firm operating at point A, for example, is OB/OA. So 1 - (OB/OA) measures the technical inefficiency of the firm -- the amount by which x_1 and x_2 could be reduced in the same ratio without reducing output, y (Schmidt 1986).

Allocative efficiency refers to adjustments of inputs and outputs to reflect relative prices (Ellis 1993). These adjustments are the conditions for profit maximization that marginal value product (MVP) should equal marginal value cost (MFC) for each variable input. In Figure 3.1, this condition is met at point D, where the isoquant is tangent to the isocost. So although B an D are both technically efficient, it costs considerably less to produce at D, making the input combination used by this firm allocatively efficient as well.

This study is only concerned with estimating technical efficiency. Measures of allocative efficiency require knowledge of the marginal physical products and prices of all inputs and outputs considered, and also assume firms face varying price levels. In the present study, all producers are assumed to face identical input and output prices as a result of the firm contracts established with tomato producers, as discussed in the previous chapter (Section 2.2.4). Allocative efficiency is not explicitly estimated, though given the constant prices we can assume that a farmer's technical efficiency also reflects his allocative efficiency.

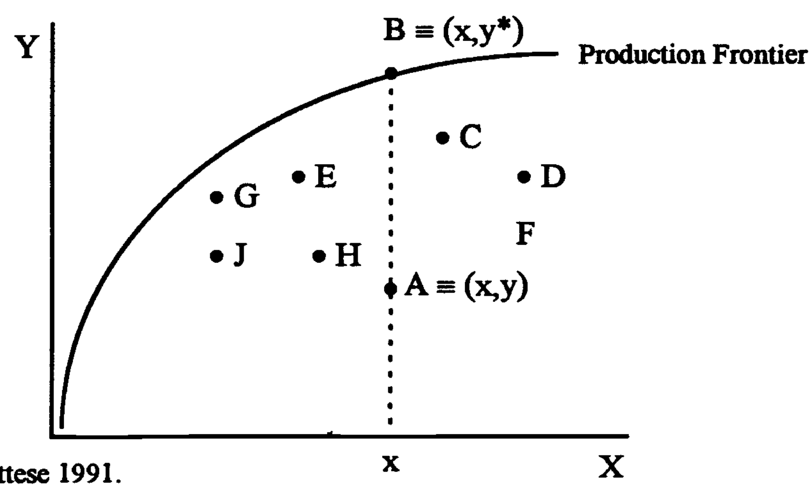
3.2 The Theoretical Model for Estimating Technical Efficiency

The model used in this study is based on the notion of a frontier as presented by Battese (1991)[1]. Battese (1991) applies the Farrell definition of efficiency in the context

[1] Comprehensive surveys on frontier approaches to measuring efficiency have been done by Battese (1991), Schmidt (1986) and Forsund, Lovell and Schmidt (1980).

of a production frontier, representing the maximum output, Y, for each level of input use, x, as in Figure 3.2. The term frontier implies that the function sets a limit to the range of possible observations (Forsund, Lovell, and Schmidt 1980), so in the case of a production frontier, no points can lie above it[2]. This restriction is what differentiates a production frontier from a production function. Whereas estimates of a production function give both positive and negative residuals, estimations of production frontiers allow only non-positive residuals. The observed input-output values are given below the frontier, representing that, under the given technology, the firms do not reach the maximum attainable output for the given inputs. The technical efficiency measure based on the frontier is analogous to that based on the Farrell isoquant -- it is reflected by the distance between a firm and the frontier. Technical efficiency for firm A, for example, is the ratio of the actual output, y, to the maximum attainable output for the same input combination under the same technology, y* (firm B).

Figure 3.2. Technical Efficiency Based on a Production Frontier



Source: Battese 1991.

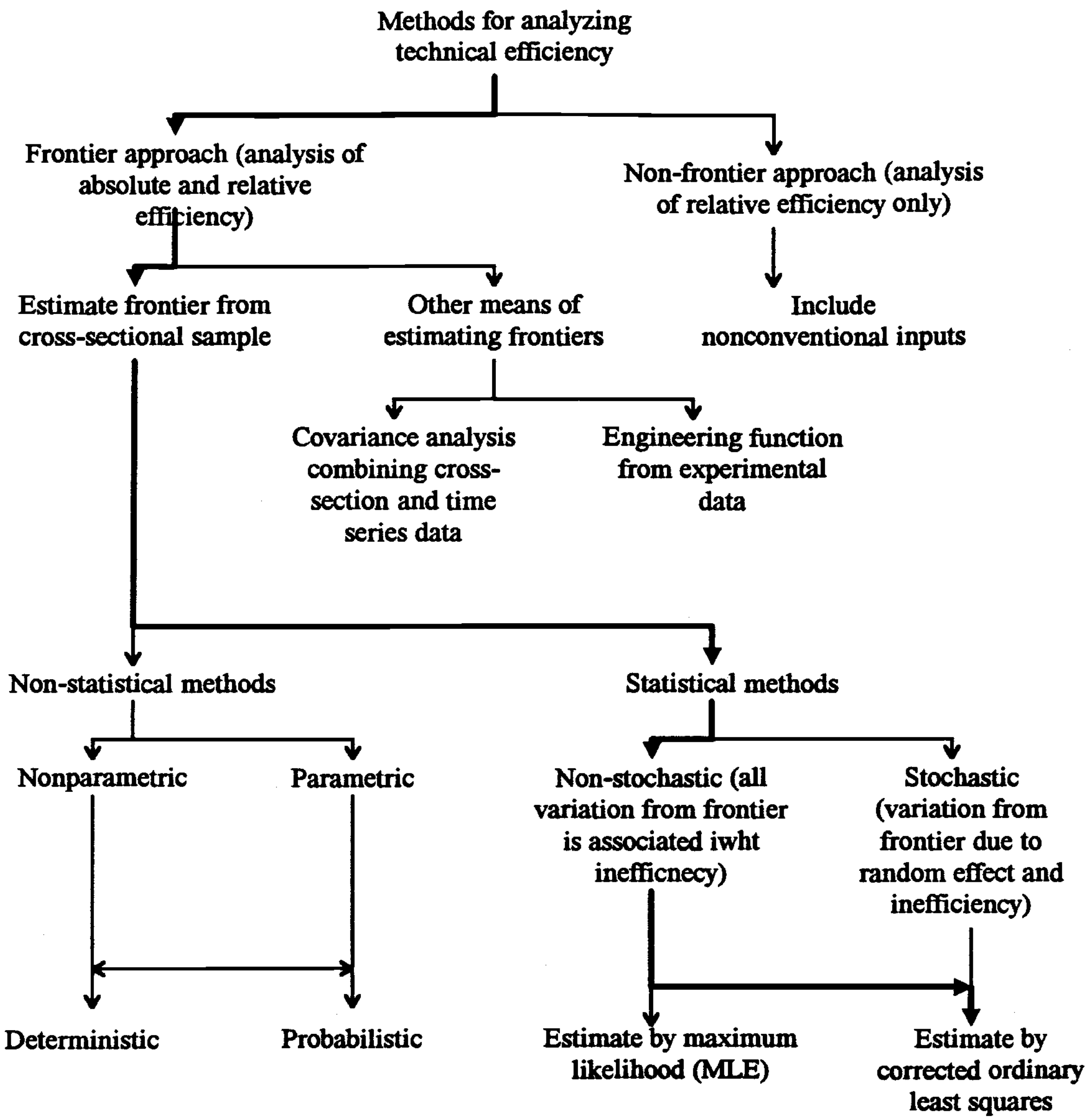
[2] The inverse would be true for cost frontiers, where no points would lie below the cost frontier.

A number of frontier and nonfrontier approaches have been developed to estimate technical efficiency, as shown in Figure 3.3. Frontier approaches can be either statistical or non-statistical, depending on whether or not assumptions are made about the disturbance term. The non-statistical frontier is very sensitive to outliers so technical efficiency can be highly overestimated (Forsund, Lovell, and Schmidt 1980). Despite possible advantages of some non-statistical approaches (e.g. avoiding distortions to data by not imposing a functional form under a non-parametric approach), statistical methods are more widely used for the estimation of technical efficiency.

Statistical methods can be either deterministic or stochastic, depending on the interpretation of the respective residuals. In a deterministic frontier, the entire deviation of an observation from the frontier is attributed to technical inefficiency, as illustrated in Battese's approach in Figure 3.2. The use of deterministic frontiers to measure efficiency is questioned for several reasons, especially its single one-sided error term representing both the effects of inefficiency and measurement error (Forsund, Lovell, and Schmidt 1980; Aigner, Lovell, and Schmidt 1977; Bauer 1990). Statistical problems present other downfalls of deterministic models, including that there are no assumptions made on the disturbance term (Schmidt and Lovell 1979; Bagi and Huang 1983).

A stochastic frontier allows for the decomposition of the error term into random noise and farm-specific inefficiency. The stochastic frontier model was separately introduced by Aigner, Lovell, and Schmidt and van den Broeck in 1977 (Schmidt 1986) and has since been the most widely used approach to measure technical efficiency. In

Figure 3.3 Methods for Analyzing Technical Efficiency



Note: Solid line represents approach used in this study.
Source: Ali and Byerlee 1991.

specifying a stochastic frontier, the output of each firm is bounded above by a frontier that is stochastic -- its placement is allowed to vary randomly across firms (Schmidt and Lovell 1979). This approach allows firms to be inefficient relative to their own frontier rather than to a sample mean (Schmidt and Lovell 1979). Discussions on the use of stochastic models to measure technical efficiency are found in Aigner, Lovell and Schmidt (1977), Jondrow *et al* (1982), and Bauer (1990). Schmidt (1986) believes that the only intrinsic problem with the stochastic frontier is that the decomposition of the error term into noise and inefficiency is highly dependent on strong distributional assumptions. He does contend, however, that ignoring this two-component residual and assuming a deterministic approach with no statistical noise is "empirically false."

Though most studies seem to favor the use of a stochastic frontier for measures of efficiency, a deterministic frontier is used in this study because of its relative simplicity and comparable efficiency. The stochastic frontier requires the decomposition of the two-part error term for the estimation of efficiency, a rather complex step. Though this decomposition allows for a more accurate estimate of farm-specific efficiency (because it separates out the random noise from the farm-specific inefficiency), it does not alter to the relative measure of efficiency among farms, which is the measure of interest in the present context.

3.3 Determinants of Technical Efficiency in Agriculture

Thus far, the theoretical model presented has been concerned only with the estimation of technical efficiency. The objective of this study requires us to take the analysis beyond the estimation of efficiency and consider the institutional, social and economic factors underlying the level of farm-specific efficiency.

Technical efficiency in agriculture is a function of factors which are both internal and external to the farmer. Failure to operate on the production frontier may be due to errors in determining the level of input use, as well as errors in the timing and method of application of inputs (Ali and Byerlee 1991). In turn, these management practices are a function of farm-level characteristics and external factors such as institutional constraints.

3.4 The Conceptual Model for Estimating Efficiency and Identifying its Determinants

The conceptual model used in this study is a modification of the approach used by Ali (1995) in his study of the institutional and socioeconomic constraints on the efficiency of rice producers in Pakistan's Punjab. Ali looked at both the variation in input level and the determinants of efficiency, and he did so in separate steps. To look at the variation in input level, he regressed each input on factors determined by marketing institutions, access to public infrastructure, farm resources, and physical environment. He then used a two-step approach for identifying the determinants of efficiency. Ali first estimated a stochastic production frontier to obtain a farm-specific efficiency index, then regressed this index directly on socioeconomic and institutional conditions that affect farmers' production-related characteristics, socioeconomic conditions that determine farm management practices, access to public infrastructure, and farm resource-based factors.

In this study, an intermediary step is added to Ali's two step approach in identifying the factors affecting farm-specific efficiency. Instead of regressing the efficiency index directly on the socioeconomic characteristics, I first regress the index on management variables reflecting the timing of input application. The rationale behind this step is that efficiency is a function of input quality, quantity and timing of use, in addition to external factors, such as weather. The quality of the inputs used by colonos in the irrigation perimeter is assumed to be homogeneous, given that most of them obtain their inputs from the processing firm. The variations in the amount of input use are taken into account in the production function. So that leaves timing and external factors. I assume that a farmer's management practices (timing of input use) are determined by his level of education, technical knowledge, access to labor, and access to credit. The management practices, in turn, are the determinants of resource-use efficiency. This three step logic is what determines the added step to Ali's approach. The three-step model used in this study is presented in Figure 3.4. Details on each part of the model are given below.

3.4.1 The Production Frontier

The first part of the model consists of estimating a production frontier. The deterministic production function model is

$$Y = F(X)\, e^{-u} \quad , \quad 0 < e^{-u} < 1$$

where Y is the total farm output, X is a matrix of productive inputs, and u is a residual -- non-negative random variable associated with farm-specific factors which contribute to the i^{th} farm not attaining maximum efficiency.

Figure 3.4 Conceptual Model Used to Identify Socioeconomic, Management and Institutional Factors Affecting Technical Efficiency of Colonos

Production frontier is estimated and efficiency index is obtained.

$$Y_i = f\text{ (inputs, farm characteristics)} \rightarrow TE_i$$

↓

Efficiency index is regressed on management variables.

$$TE_i = f\,(MGMT_i),$$

where $MGMT_i$ are the management variables available.

↓

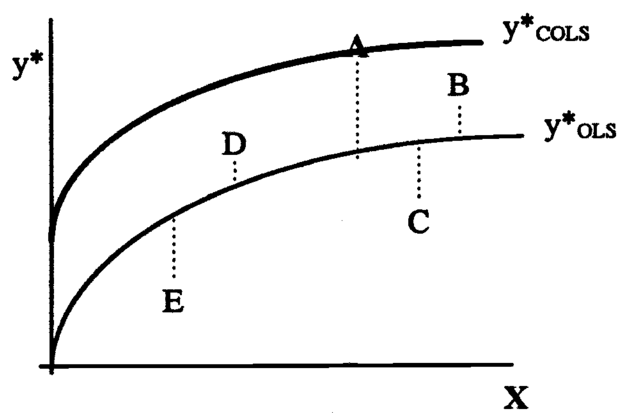
Management variables are regressed on variables representing the farmers' knowledge base, family composition, and investment capacity.

$$MGMT_i = f\text{ (socioeconomic variables)}$$

The estimation procedure used should identify a maximum possible output -- the standard against which firm-specific efficiency will be measured. Estimating the production function with standard statistical techniques, such as ordinary least squares (OLS) however, would yield both positive and negative residuals because a regression estimates the mean output rather than the maximum output for a given level of inputs. To get around this problem, the function is estimated using corrected ordinary least squares (COLS), as presented in Schmidt (1986), Russell and Young (1983), and Førsund, Lovell, and Schmidt (1980).

COLS estimates the model by ordinary least squares and then "corrects" the intercept by shifting the function until no residual is positive and one is zero. The intercept is shifted by using the largest positive estimated residual within a sample, as given in the OLS estimation results. This "correction" is illustrated in Figure 3.5, where the most efficient farmer is on the frontier and the remaining are below the frontier.

Figure 3.5. An Illustration of the Corrected Ordinary Least Squares Approach



Using the COLS allows us to go from the initial production function to the frontier, the backbone of efficiency measurement. The resulting farm-specific residuals provide the information needed for the measurement of farm-specific technical efficiency, TE_i. TE_i is defined by the ratio of the actual yield of a farmer, y_i, to the frontier output, y^* (Battese 1991):

$$\begin{aligned} TE_i &= y_i/y^* \\ &= [\, f(x_i)\, e^{-u}\,] \,/\, [f(x_i)] \\ &= e^{-u} \end{aligned}$$

A perfectly efficient producer, one not constrained by institutional or socioeconomic factors and operating on the frontier, has a TE_i equal to 1. All the producers operating below the frontier have a TE_i that is less than one and postive, allowing us to have a relative measure of efficiency. The farm-specific inefficiency index can then be related to characteristics of the farm and farmer to test hypothesis about the causes of inefficiency (Ali and Byerlee 1991; Schmidt 1986).

3.4.2 Management Variables

In addition to random events, factors which may restrain a farmer from producing on the frontier include inadequate information, insufficient technical skills, or untimely input supply (Ali and Byerlee 1991; Ellis 1993). The second step in this approach involves using the efficiency index to make inferences about the impact of farm-specific management variables, specifically timing of input use, in the production of tomatoes. Both EMBRAPA (1994) and the District (de Carvalho *et al.* 1995) publish recommendations on the optimal timing of transplanting, irrigating, applying fertilizers, pesticides, and insecticides. Appropriately following these recommendations can in principal lead to higher yields. Disregarding some of these recommendations can have disastrous affects on the crop.

The model for measuring the significance of timing of input use on efficiency is

$$TE_i = f\,(T_i),$$

where TE_i is the farm-specific efficiency index and T_i are the variables reflecting timing of input-use.

The results from this regression indicate to which extent timing determines efficiency and which timing variables are most significant in determining efficiency.

3.4.3 Socioeconomic Characteristics

Given the significance of timing on production efficiency, the third step in this approach aims to identify the household characteristics which significantly affect the timing of input use. It is expected that timing of input use can be affected by a farmer's knowledge base (years of formal education, technical skills, years in the irrigation perimeter, contacts with extension agents), his economic condition (access to labor, access to credit, ownership of property), and the institutional setting (contract with processing firm). The impact of these household characteristics and institutional setting on timing of input use can be estimated by individually regressing each management variable on the set of socioeconomic and institutional variables, namely

$T_i = f(K, SE, I)$,

where T_i are the individual timing variables,

K is a matrix for farmers' knowledge base,

S is a matrix for the socioeconomic condition of the farmers, and

I is a vector for the farmers' institutional setting.

The results from these regressions will indicate the importance of household characteristics and institutional setting on management. The results will also indicate which socioeconomic and institutional factors most significantly affect production efficiency among the small tomato-producing farmers in the perimeter.

3.5 Empirical Studies

The frontier approach has been widely used to measure farm-specific technical efficiency[3]. Extensive surveys of efficiency studies using agricultural farm-level data have been done by Ali and Byerlee (1991) and Battese (1991). Many of these studies have taken the next step in relating farm-specific inefficiency to characteristics of the farmers the their surroundings. A summary of the main findings from these and other studies are presented in Table 3.1. These results show that technical efficiency is partly explained by the farmer's knowledge base, management practices, economic condition, and institutional setting.

[3] Studies have also used the frontier approach to measure technical efficiency of other economic activities. Aigner, Lovell, and Schmidt (1977) applied the approach to U.S. primary metals, and Schmidt and Lovell (1980) used data from the steam electric generating plants in the U.S.

The farmer's knowledge base is defined by formal education, experience, and contact with extension agents. All of these factors have been shown to have a positive impact on technical efficiency (Ali 1995; Ali and Flinn 1989; Belbase and Grabowski 1985; Flinn and Ali 1986; Kalirajan 1981, 1989; Kalirajan and Flinn 1981, 1983; Lingard, Castillo and Jayasuriya 1983; Lockheed, Jamison and Lau 1980; Phillips and Marble 1986). Education seem to be particularly important. Lockheed, Jamison, and Lau (1980) survey the findings of 18 studies in developing countries focused on quantifying the role of education on production efficiency. Their overall conclusion is that farm productivity increases, on the average, 7.4% as a result of a farmer completing four additional years of elementary school rather than none. Lockheed, Jamison, and Lau (1980) also present findings on the impacts of informal education on agricultural productivity. When measured by number of direct contacts between farmer and extension agent, the informal education variable in four study sites in Brazil were shown to have a R^2 ranging from .44 to .82.

Correct management practices are also important in determining efficiency. Management practices include all the methods used in the field, from planting to harvesting, and include application and timing of fertilizer, pesticides and water. Kalirajan (1989) has shown the impact of timing of crop establishment and harvesting date. Other studies which analyze the influence of management practices on efficiency include Ali and Flinn (1989), Flinn and Ali (1986) and Kalirajan and Flinn (1981, 1983).

A producer's economic condition is defined by the level and sources of income. Belbase and Grabowski (1985) show that income level has a positive effect on the technical efficiency, though other studies show that off-farm employment has a negative impact (Ali 1995; Ali and Flinn 1989). The negative impact of off-farm employment on efficiency may reflect that less attention is given to agricultural activities when a farmer works outside his farm.

A producer's institutional setting is an important exogenous factor in determining technical efficiency. We can think of institutional setting as all the constraints imposed by the agencies which in some away affect the producers, such as the input and credit suppliers, and the water administration agency in the case of irrigated agriculture. Very few studies have considered the effect of institutional setting explicitly on technical efficiency. Ali and Flinn (1989) and Lingard, Castillo and Jayasuriya (1983) have shown positive influence of availability and access to credit. On the other hand, Taylor, Drummond and Gomes (1986) have shown that participation in a credit program by farmers in Minas Gerais show no significant influence on efficiency. The results from the Taylor, Drummond and Gomes studies may reflect shortcomings of the credit program, and not a causality between credit availability and the level of farm specific technical efficiency.

The above comment on the Taylor, Drummond and Gomes (1986) study also applies to the other factors considered to effect technical efficiency. Not all the findings reported necessarily reflect a direct cause-effect relationship between factors believed to affect efficiency and the level of efficiency itself. Attention must be paid to what variables are used and how these are measured. Formal education, for instance, can be represented by number of years of schooling or by dummy variables reflecting literacy/illiteracy or level of schooling (primary/secondary). Likewise, late fertilizer application can be measured with respect to different phases of the crop cycle (i.e., it can be measured with respect to seeding or transplanting) and it may be the case that the timing of fertilizer application is more critical for plant growth (and farm efficiency) at some point than others.

Table 3.1 Summary of Empirical Studies of Technical Efficiency in Agricultural Production in Developing Countries

Source, Location and Year	Crop	Method of Estimation[a]	Average Efficiency	Determinants of Efficiency
Ali 1995 *Punjab, Pakistan, 1981-1982*	Rice	Stochastic Pf. COLS	70%	Education (+)* Off-farm business (-)**** Fertilizer timing (-)* Transplanting timing (-)**** Water stress (-)*** Access to public infrastructure (-)****
Ali and Chaudry 1990 *Punjab, Pakistan, 1984-1985*	Various crops analyzed separately	Probabilistic and deterministic frontiers. Linear programming.	80% - 87%	na
Ali and Flinn 1989 *Punjab, Pakistan*	Rice	Stochastic profit frontier. MLE, OLS	64%	Education (+)* Off-farm employment (-)** Credit nonavailability (-)** Water constraint (-)* Late fertilizer application (-)** Location of village*
Battese and Tessema 1992 *India, 1975-1985*	(Gross output value)	Stochastic Pf. (CD) MLE	59% - 92%	na
Belbase and Grabowski 1985 *Nepal, 1974-1975*	Sum of various crops	Probabilitistic Pf. (CD) COLS	76% - 80%	Education (+)* Experience (+) Nutrition (+)* Income (+)*

Table 3.1 (Continued)

Source, Location and Year	Crop	Method of Estimation[a]	Average Efficiency	Determinants of Efficiency
Dawson and Lingard 1989 *Central Luzon, Phillippines, 1970, 1974, 1979, 1982*	Rice	Stochastic Pf. (CD) MLE	60% - 71%	na
Ekanayake and Jayasuriya 1987 *Sri Lanka, 1984-1985*	Rice	Stochastic Pf. (CD) COLS	50% - 53%	na
Flinn and Ali 1986 *Punjab, Pakistan, 1982*	Rice	Stochastic Pf. (CD) MLE	79%	Education (+)*** Own tenancy (+) Farm size (-) Crop establishment (-)** Later fertilizer (-)*** Water problem (-)**
Bagi and Huang 1984 *Haryana, India 1978*	Rice	Stochastic Pf. (TL) MLE	89%	Farm size (no effect)
Kalirajan 1981 *Tamil Nadu, India 1978*	Rice	Stochastic Pf. (CD) MLE	47%	Experience (+)*** Education (+) Knowledge (+)*** Extension contact (+)*** Share tenant (-)

Table 3.1 (Continued)

Source, Location and Year	Crop	Method of Estimation[a]	Average Efficiency	Determinants of Efficiency
Kalirajan 1989 Pandan, Patnongon	Rice	Stochastic Pf. (CD) MLE, COLS	61% - 75%	Education (+)**[b] Age (+)** Harvesting date (+)** Timing of crop establishment (+)** Tenure status (-)**
Kalirajan and Flinn 1981 *Bulcan, Phillipines, 1980*	Rice	Stochastic Pf. (CD) MLE	80%	Age (+) Education (+) Tenant (+) Extension contact (+)*** Planting method**
Kalirajan and Flinn 1983 *Bicol, Phillipines, 1980*	Rice	Stochastic Pf. (TL) MLE	50%	Age (+) Experience (+)*** Extension contact (+)** Planting method**
Kalirajan and Shand 1986 As cited in Ali and Byerlee 1991 *Malaysia, 1980*	Rice	Stochastic Pf. (TL) MLE	65% - 69%	Non-farm income (+) Motivation in farming (+)**
Lingard, Castillo and Jayasuriya 1983 *Central Luzon, Phillipine, 1970-1979*	Rice		50%	Age (+) Education (+)** Credit access (+)*** Share tenant (-)

Table 3.1 (Continued)

Source, Location and Year	Crop	Method of Estimation[a]	Average Efficiency	Determinants of Efficiency
Lockheed, Jamison and Lau 1980 *13 countries in Africa, Asia Europe and Latin America, 1961-1975*	(Gross output)	(CD)	(c)	Overall, formal and nonformal education was postive and significant. Some studies showed nonformal education as negative.
Phillips and Marble 1986 *Guatemala*	Maize	Stochastic Pf. (CD)	(c)	Education (+)***
Taylor, Drummond and Gomes 1986 *Minas Gerais, Brazil, 1981-1982*		Deterministic Pf. (CD) MLE, COLS	17%	Participation in credit program insignificant for technical efficiency[d]

* Significant at 1% level.

** Significant at 5% level.

*** Signficant at 10% level.

**** Significant at 15% level.

[a] Pf = Production frontier, MLE = Maximum liklihood estimate, OLS = Ordinary least squares, COLS = Corrected ordinary least squares, CD = Cobb-Douglas, TL = Translog.

[b] Kalirajan focuses on the contribution of human capital to agricultural production. The factors listed in this column are determinants of human capital, and not directly of technical efficiency.

[c] These studies consider output to be a direct function of education. An estimate of technical efficiency per se is not given.

[d] Taylor, Drummond and Gomes are solely concerned with the impact of farmer participation in credit program on technical efficiency.

CHAPTER FOUR

DATA COLLECTION AND DESCRIPTIVE STATISTICS

The objective of this chapter is two-fold: to summarize the data collection procedures and to present summary statistics of the data obtained. Many of the findings presented in subsequent chapters rely heavily on the data and the data limitations presented below.

4.1 Data Collection Procedures

The data used in this study were collected during field work in Petrolina, Brazil, during February of 1996. The three main sources of data were an EMBRAPA database, a producer survey, and interviews with CODEVASF and other agencies involved in the perimeter. Details on the collection of production, management, and household data are given below.

4.1.1 Production Inputs and Yields

The data on production inputs and yields were obtained from an EMBRAPA database. The database was implemented in 1993 and has since been updated and maintained by three field experts (*técnicos agrícola*) and a computer specialist in the Secretary of Agriculture of the Municipality of Petrolina (SEAGRI). The main objective of the data collection effort is to keep a continuous record of the agricultural activities of a select group of colonos[1], and it does so on the basis of weekly and yearly surveys. Weekly surveys contain production information, including area planted, crops, yield, labor and the quantity, type, and

[1] The colonos in the database were selected by EMBRAPA based on a combination of their economic characteristics and the soil quality of farms. For details on the selection process, see Appendix E.

timing of inputs used. The inputs in the database include labor, water, fertilizer, pesticides, fungicides, and herbicides. A sample spreadsheet of inputs by subfield[2] is given in Appendix C. Annual surveys cover household composition, ownership of machinery, equipment, and farm animals, labor use (number of permanent workers), irrigation infrastructure, and stored supplies of fertilizers, agrotoxics, seeds, and feed.

For analytical purposes, several variables were aggregated in this study so that they could be used in the estimation of the production frontier. The use of each individual labor activity, fertilizer, and chemical input would not have permitted the use of regression analysis, given that there were twenty-two labor activities, seven fertilizers, and sixty-four pesticides, fungicides, and herbicides. The labor activities were all aggregated into one labor variable (LABOR). The fertilizers and pesticides, herbicides, and fungicides were also consolidated (FERT and PEST, respectively), but because of the variations in measuring units (kg and liters), they were aggregated with the use of an index, as shown in Appendix D.

Data on soil quality were obtained from a recent unpublished EMBRAPA/CPATSA study (unpublished) which used soil type, soil depth, and soil texture to classify soil and water drainage quality in each farm. EMBRAPA analyzed each farm accordingly and divided them into three "geoenvironmental classes", representing good, average and poor combinations of soil and water drainage quality. In this study, the three groups are represented by a dummy soil variable (1 = poor, 2 = average, and 3 = good) .

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[2] Subfields refer to the individual plots within a farm. See Figure 2.4 for details.

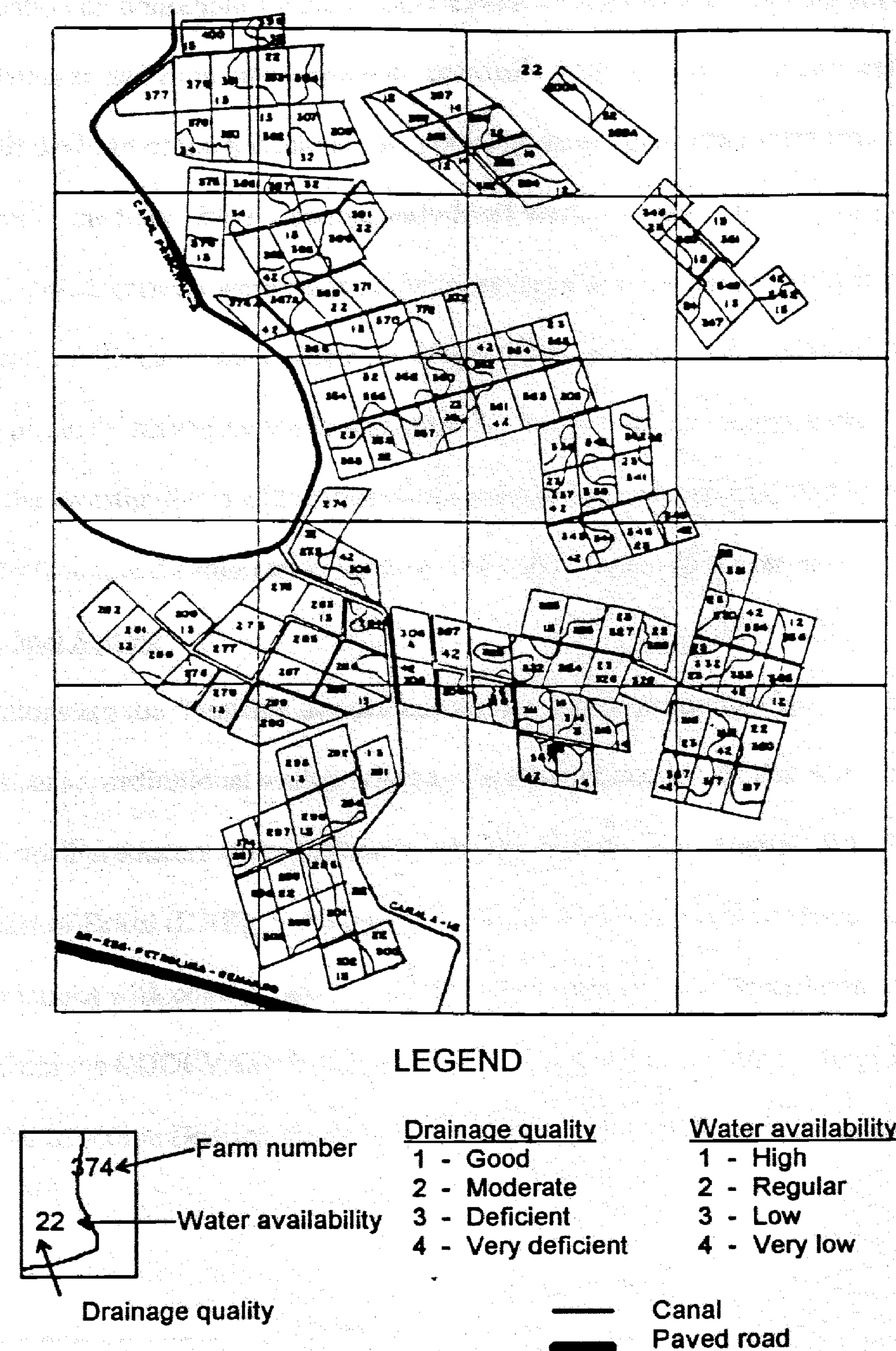
Unlike all the other inputs, soil quality is defined by farm and not by subfield. The soil classification therefore does not fully capture the affects of soil quality on output. All the subfields from a particular farm were assumed to have the same soil quality, when in effect there can be two or even three geoenvironmental classes in one farm, as shown in Figure 4.1.

4.1.2 Management Practices

The management variables used in this study were complied from the EMBRAPA database and the producer survey. Crop management refers to the agricultural practices carried out by the farmer to enhance crop quality and productivity. These practices may include the types and amounts of inputs a farmer uses, as well as a farmer's timing of activities. In this study, crop management is represented by variables reflecting the timing of input-use. In the case of tomato production, there is an optimal season for seedbed preparation, and there are optimal timing for all the activities thereafter, from transplanting the seedlings, to applying fertilizers and pesticides, to harvesting.

The timing variables used in this study refer to the timing of transplanting (DAYSTRAN), the timing of fertilizer application (DAYSFERT) and the timing of irrigation (DAYSIRRI). All three timing variables were based on the log of activities (by subfields) from the EMBRAPA database. A sample log is shown in Appendix F. The dates of daily activities allowed the estimation of the days between seeding and transplanting (DAYSTRAN), days between transplanting and first fertilizer applicationafter transplanting (DAYSFERT), and days between the last irrigation and the first harvest (DAYSIRRI).

Figure 4.1 Variations in Soil Quality by Farm, Nucleus 3, Senador Nilo Coelho Irrigation Perimeter, Petrolina



Source: Adapted from EMBRAPA/CPATSA 1996.

4.1.3 Socioeconomic Characteristics

Information on household socioeconomic characteristics were obtained from the EMBRAPA database and from interviews with colonos[3]. Most of the interviews were conducted with the head of the household. In a few instances, interviews were conducted with the worker in the field, either a permanently-hired worker or the eldest son or daughter of the colono. The interviews were made in the mornings and afternoons, over a two-week period, both in the field and in the residential villages. The interviews for the most part were guided by the producer survey shown in Appendix G. An EMBRAPA agronomist accompanied the investigator to all the interviews to locate the needed plots and identify the colonos, and to facilitate the interaction between the investigator and the farmers.

4.1.4 Institutional Setting

Institutions are the "humanly devised constraints that shape human interaction" (North 1990). In this sense, institutional setting refers to the institutions that facilitate, or constrain, the actions of small producers in the perimeter, namely CODEVASF, EMBRAPA, the Bank of the Northeast of Brazil (BNB), and the processing firms. Information on these institutions and their interactions with colonos was obtained from interviews and informal conversations with experts from the CODEVASF headquarters in Brasilia, the CODEVASF Regional Office in Petrolina, the Irrigation District, the local branch office of the BNB, and Etti processing

[3] The 24 colonos interviewed were among the 29 tomato-producing colonos in the EMBRAPA database. Five of the original 29 were discarded from the study sample because they no longer produced tomatoes or they abandoned their farms.

firm. The information on institutional setting is not used in the empirical estimation of efficiency, but is used to complement empirical findings.

4.2 Descriptive Statistics

The study was based on observations of 94 subfields from 24 farms during the 1993-1995 period. The subfields are fields within farms which are defined based on three factors: the transplanting date, whether it is a purestand or intercropping, and the variety of tomato planted. Farms in the study sample have anywhere from 1 to 9 total subfields for the three years, as shown in Table 4.1. Summary statistics for the subfields on production data, household characteristics and management practices are given below.

4.2.1 Production Inputs and Yields

Table 4.2 presents descriptive statistics for the variables used in estimating the production frontier. Mean subfield size was 2.4 hectares, with a range from 0.4 to 8.0 hectares. Given that soil quality on each farm was assumed to be homogenous for all the subfields, about 28% of the subfields planted with tomatoes had poor soils. Input use varied substantially between farmers. For example, while the mean use of water was 4283 m^3/ha, the range of water use varied from one subfield that used 680 m^3/ha to another that used 6883 m^3/ha. Likewise, the amount of labor also varied between 43 man-days/ha to 207 man-days/ha, and fertilizer use ranged from 9 to 1649, as represented by the aggregate fertilizer index.

Desegregating these data by year also reveals an important trend (Figures 4.2 and 4.3). Figures 4.2 and 4.3 are based on average values, so we cannot assume input use and yield by all farmers followed this trend. We can infer, however, that some year-based factor was important in determining these yearly variations, especially with respect to yield, fertilizer and labor.

Table 4.1 Subfields Used in Study, Senador Nilo Coelho Irrigation Perimeter, Petrolina, 1993-1995

Nucleus	Farm Id. Number	No. of Subfields	1993	1994	1995
1	1569	5	1	2	2
1	461	2	--	1	1
1	478	3	1	1	1
3	289	3	--	2	1
3	309	7	--	3	4
3	316	2	--	1	1
3	324	2	--	1	1
3	327	8	2	4	2
3	328	8	3	1	4
3	337	4	1	1	2
3	345	3	1	1	1
3	385	1	--	--	1
4	101	9	1	5	3
4	104	2	--	2	--
4	53	5	1	2	2
4	73	4	--	1	3
4	81	4	1	3	--
4	91	2	--	1	1
4	93	3	1	1	1
5	193	5	1	1	3
5	194	4	--	1	3
5	211	1	--	1	--
5	219	5	--	2	3
5	245	2	--	1	1
Total	24	94	14	39	41

Source: EMBRAPA/CPATSA 1996.

Table 4.2 Descriptive Statistics of Production Data for Tomato-Producing Colonos, Petrolina, 1993-1995

Name	Measuring Unit	Mean	Std. Dev.	Min.	Max.
Sample size	94 subfields				
Land	hectares	2.4	1.6	0.4	8.0
Yield	kg/ha	38430	14799	6109	75714
Labor	man-days/ha	122	42	43	207
Water	m^3/ha	4283	1392	680	6883
Fertilizer	aggregate index[a]/ha	190	251	9	1649
Pesticide	aggregate index[a]/ha	2.5	1.9	0.6	10.1
Soil quality		Number of farms			
	Good soil	28			
	Average soil	40			
	Poor soil	26			

Source: EMBRAPA/CPATSA 1996.

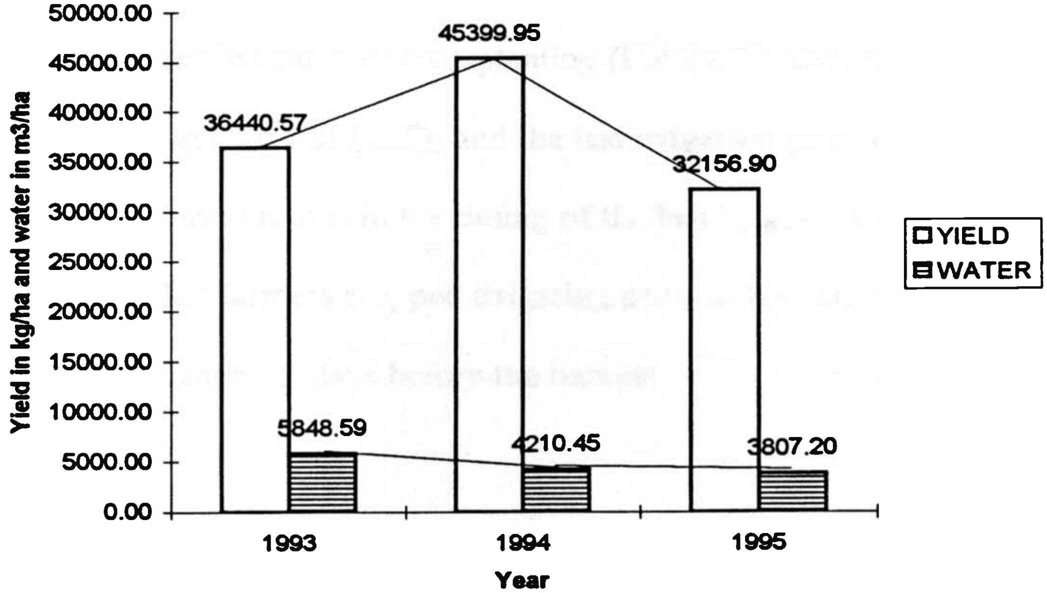
[a] Method used for calculating aggregate index is presented in Appendix A.

Table 4.3 Descriptive Statistics of Management Variables of Tomato Producing Colonos, Petrolina, 1993-1995

Variable	Name	Measuring Unit	Mean	Std. Dev.	Min.	Max.
Transplanting	DAYSTRAN	Days between seeding and transplanting	23	7	14	30
First fertilizer application after transplanting	DAYSFERT	Days between transplanting and fertilizer application	10	8	0	41
Last irrigation prior to harvest	DAYSIRRI	Days between last irrigation and first harvest	21	12	2	67

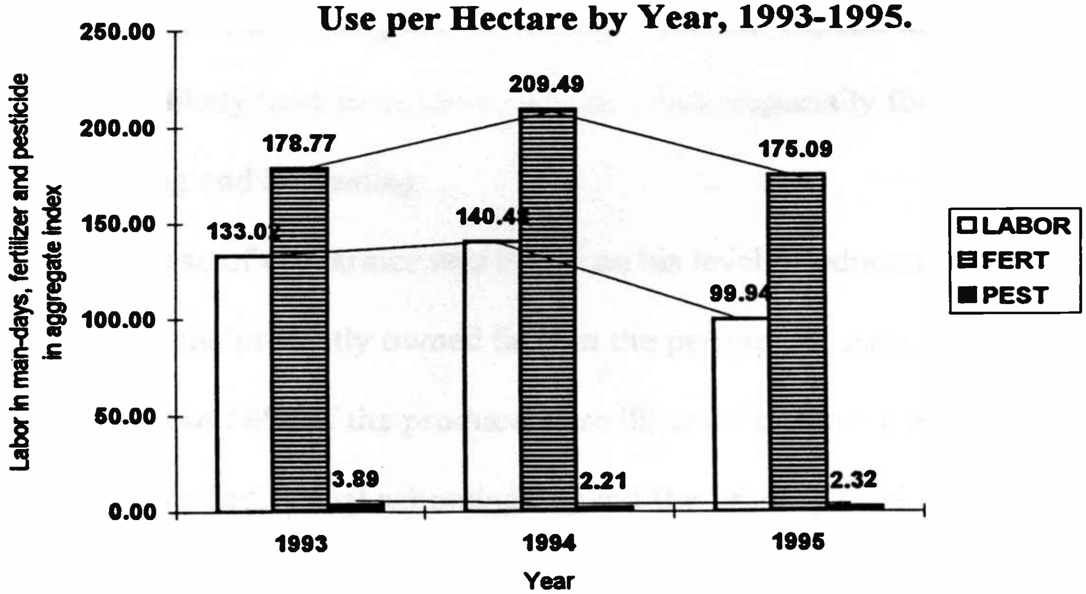
Source: EMBRAPA/CPATSA 1996.

Figure 4.2 Average Yield and Water Use per Hectare by Year, 1993-1995.



Source: EMBRAPA/CPATSA 1996.

Figure 4.3 Average Labor, Fertilizer and Pesticide Use per Hectare by Year, 1993-1995.



Source: EMBRAPA/CPATSA 1996.

4.2.2. Management Variables

Descriptive statistics on the management variables are presented in Table 4.3. This data shows the high variations in timing of transplanting (DAYSTRAN), the first fertilizer application after transplanting (DAYSFERT), and the last irrigation prior to harvest (DAYSIRRI). The greatest variation is in the timing of the last irrigation prior to harvest. The mean number of days that farmers stopped irrigating prior to harvest was 21 days, but at least one farmer stopped irrigating 2 days before the harvest, while another stopped 67 days prior to harvest.

4.2.3 Farmer Characteristics

Basic characteristics of the farmers analyzed in this study are presented in Table 4.4. These data show that there was considerable variation in household composition, the knowledge base of the farmer, and his investment capacity. In particular, family size ranged form two to twelve members, indicating that some farmers could depend more on family labor, while others more likely have to contract outside labor, especially for labor intensive activities like transplanting and harvesting.

The knowledge base of the farmer was based on his level of education and on the number of years spent on the presently owned farm in the perimeter. According to the EMBRAPA database, about 58% of the producers are illiterate or have incomplete primary education, while 25% have had formal schooling beyond the primary level. Years in the farm, expected to reflect technical knowledge of irrigated agriculture, varied form one to twelve years, indicating that newcomers are working side by side with farmers that have been in the perimeter since its establishment twelve years ago, in 1984.

Three criteria were used to reflect the colonos' investment capacity: the ownership of a bodega[4], vehicle or farm animals. A dummy variable was used to represent the ownership of each of these goods. According to Table 4.4, half of the farmers in the sample own a vehicle, while only 17% own a commercial establishment and 13% own farm animals.

These data provide only limited insight into the colonos' socioeconomic condition. Many other factors determine his socioeconomic condition. Two important factors which became very apparent during the field interviews related to the farmer's relationship with the technical assistance agents, and the farmer's health and the health of their families.

The relationship between the colonos and the extension agents from the District varied a great deal. Several colonos complained that they rarely saw the agents. Given the District's policy that extension agents will only visit the farms upon requests from the colonos, those colonos who claimed they rarely saw the agents likely never sought technical assistance. On the other hand, many colonos praised the agents and kept a good rapport with them, reflecting confidence in their roles as extension agents. We can expect that those producers who have greater contacts (and positive contacts) with the agents are better prepared to manage their crops. This is especially true in cases of diseases and pests, where the agent is likely to be more prepared in identifying signs and recommending remedies.

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[4] A bodega is a small, family-owned and operated, commercial establishment. Every residential nuclei in the Senador Nilo Coelho has at least one bodega, which is owned by one of the local farmers.

Table 4.4 Descriptive Statistics of Socioeconomic Characteristics of Colonos

Characteristic	Variable Name	Mean	Min.	Max.
Farmers interviewed (24)				
Total farm area				
Irrigated area	--	6.78	5.30	9.26
Rainfed area	--	4.3	0	15
Household composition				
Family size	FAMSIZE	7	2	12
Knowlege base				
Age of household head	AGE	44	21	66
Years in presently-owned farm	YRSLOTE	8	1	12
		Number of farmers		
Level of education of household head				
Illiterate	EDU = 1[a]	4		
Incomplete primary education	EDU = 2[a]	10		
Complete primary, but not beyond	EDU = 3[a]	4		
Beyond primary	EDU = 4[a]	6		
Investment capacity				
Owns commercial establishment	COMMERCE[a]	4		
Owns vehicle	VEHICLE[a]	12		
Owns farm animals	ANIMAL[a]	3		

Source: EMBRAPA/CPATSA 1996.
[a] Dummy variable.

The health condition of the farmers and their family may also affect their technical efficiency. Common ailments throughout the perimeter include diarrhea, dizziness, headaches, back pains, and the common cold. Though malnutrition did not seem to be a problem because of the constant availability of fruits and vegetables, two main factors seemed to cause these health problems. First, about half of the households interviewed drank untreated irrigation water. This water is transported in open canals, susceptible to all kinds of sediments and pollution (including animal dung). Consumption of this water without any kind of treatment (filtration and chlorination) is a likely contributor to the above ailments, especially diarrhea in children.

A second factor which likely contributes to health problems in the perimeter is the use of highly toxic pesticides, fungicides and insecticides. Safe handling of these agrotoxics require the use of a mask, boots, gloves, and in some cases, protective overalls. None of the colonos interviewed used masks nor overalls, and very few used boots or gloves. The majority of the colonos apply these agrotoxics by using a back sprayer, so they are susceptible to full contact with the agrotoxics. Another problem associated with the toxic chemicals is the careless disposal of contaminated containers throughout the field and the irrigation perimeter.

CHAPTER FIVE

EMPIRICAL MODELS, ESTIMATION AND RESULTS

This chapter presents the empirical models used to estimate farm-level technical efficiency and to identify some of the factors explaining efficiency of tomato producing colonos in Petrolina. The first model presented is the three-step model (introduced in Section 3.4). Though conceptually a good model, the empirical results of the three-step model are statistically weak. In view of the weakness of the three-step model, a two-step model and different levels of data aggregation are then introduced in an effort to better capture the determinants of efficiency. Empirical results are presented and findings are discussed.

5.1 Three-Step Model using Subfield-Level Data

The first model involved the following three steps: first, results from the production frontier estimation were used to generate an efficiency index for the producers; second, the index was regressed on management variables believed to affect the level of technical efficiency; and third, household characteristics were examined as factors influencing production management.

5.1.1 The Production Frontier and Efficiency Index

The production technology of the farmers was represented by a Cobb-Douglas production function. Though it is a relatively restrictive form, its estimated results were comparable to the more flexible translog function (Appendix H), proving itself to be representative of the technology used in this case. The general form of the Cobb-Douglas production frontier is

$$y_j = e^{\alpha} \prod^{n}_{i=1} x_{ij}^{\beta i} e^{uj}$$

where y_j is total tomato output (kg) of the j^{th} farm, x_{ij} is the level of the i^{th} input on the j^{th} farm, and u_j is the farm-specific error term. The production function was also estimated in terms of yield (kg/ha), in which case land was excluded as an independent variable and the inputs were specified on a per hectare basis. The inputs used in this equation were land (hectares planted with tomatoes), labor (total man-days used in production), water (m^3), fertilizer and pesticides (both represented by an aggregate index, as shown in Appendix D). Other variables used in this equation included a dummy variable for the year the crop was planted (1 = 1993, 2 = 1994, 3 = 3995), a dummy for purestand crops (1 = purestand, 0 = intercropped), and a dummy for soil quality (1 = poor, 2 = average, and 3 = good). Interaction variables to represent the relationship between the inputs and the purestand crops were also used (crop × water, crop × fertilizer, crop × pesticide).

For estimation purposes, the Cobb-Douglas function was linerized by taking logarithms on both sides, yielding

$$\ln y_j = \ln\alpha + \sum^{n}_{i=1} \beta_i \ln x_{ij} + \ln u_j \,.$$

This function was initially estimated using ordinary least squares (OLS). Several iterations were done and statistically insignificant variables (significant beyond the 20% level based on a two-tailed test) were removed from the regressions. Results for the best estimates, based on the normal criteria of goodness of fit (R^2), signficance level of the regression equation (F value), and signs and signficance levels of the regression coefficients, are shown in Table 5.1. The inputs used in this regression explain about 86 % of the variation in output. Results of this estimation allow us to analyze returns to scale and factor elasticities, which can provide insights into the production performance of small producers (Truran and Fox 1979). Results also allow us to look at marginal products.

A nicety of the Cobb-Douglas function is that the sum of the estimated coefficients reflects the returns to scale of the technology used. In this case, the sum of coefficients is 1.3, implying increasing returns to scale. If all the inputs are increased by 10%, for instance, output will increase by 13%.

The estimated coefficients are the elasticity of production for each input, indicating how much output will change given a 1% increase in each input, holding all others constant. The most significant variables are land and labor, followed by water and the interaction between water and purestand crops. Fertilizer is also significant, but only at the 20% level.

The positive signs for land, labor, and fertilizer are as expected -- an increase in each of these inputs will increase output. The negative sign for water, however, is counter-intuitive. In principle, one would expect a positive relationship between water and output, particularly in a semi-arid environment. Assuming the data used are correct, the negative sign could indicate the possibility of some producers oversaturating their tomato crops. Excessive water use could lead to a rise in the water table, which in some locations in the perimeter is very near the soil surface, limiting the respiration of tomato

Table 5.1 OLS Estimates of Output and Yield-Based Cobb-Douglas Production Functions for Tomato Producers, Petrolina, 1993-1995

Independent Variables	Unit	Dependent Variable: Output	Dependent Variable: Yield[a]
(94 observations)			
Land	hectares planted with tomatoes	0.55*	-
		(3.604)	-
Labor	total man-days used in production	0.82*	0.83*
		(8.346)	(8.197)
Water	m^3	-0.20**	-0.22**
		(-2.119)	(-2.286)
Fertilizer	aggregate index[b]	0.05****	0.07***
		(1.303)	(1.772)
Crop	dummy (1=purestand, 0=intercropping)	0.08	-0.57**
		(0.628)	(-2.259)
Crop x Water	interaction variable	0.00***	0.00**
		(-1.744)	(2.124)
Intercept		7.92*	8.05*
		(10.122)	(9.813)
Adjusted R^2		0.86	0.45
F Value		97.74*	16.32*

Note: Figures in parenthesis are t-statistics. Significance levels based on two-tailed test.
[a] Yield is regressed on input use per hectare: water/ha and fertilizer/ha.
[b] Method used in calculating aggregate index is shown in Appendix D.
* Significant at 1% level.
** Significant at 5% level.
*** Significant at 10% level.
**** Significant at 20% level.

plants and causing a fall in average productivity (EMBRAPA 1994). The negative sign for the interaction term between purestand crop and water further emphasizes the possibility of oversaturation in purestand crops. The magnitude of the remaining variables was considerably lower than what had been expected, showing that pesticide use, year planted and soil quality did not seem to influence output.

The partial derivative of the production function with respect to one of its inputs provides an estimate of the marginal productivity of that input. Marginal products could be used with output prices to determine the marginal value product of each input. The marginal value products can then be compared with the input prices and inferences about the allocative efficiency of the production process can be made.

In the present case, the focus is on technical efficiency and input prices were not collected, so marginal value products cannot be calculated. Something can be said, however, about the signs of the marginal products. One of the limitations of the Cobb-Douglas function is that the signs of the marginal products are constant regardless of the level of input use. For example, the sign of the marginal physical product of water would remain negative regardless of the level of water used. The Cobb-Douglas does not allow for the possibility of the production process to have increasing returns at low output levels, constant returns at intermediate output levels, and decreasing returns at high output levels (Pindyck and Rubinfeld 1992).

The Cobb-Douglas function was used in this study despite the negative coefficient for water because the overall results of the Cobb-Douglas allowed us to make more inferences about the productive inputs than results obtained from the translog estimation.

The overall results for the yield regression were not as robust as those for the output regression, yet labor, water, fertilize, and the interaction term between purestand

and water also were significant. The crop variable showed up as significant in the yield-based regression, yet I have no explanation for its negative sign. Given the relatively better results of the output regression, and the interest in looking at technical efficiency based on total output, only the output-based results are used in the remaining discussion.

The residuals from the estimated production function were used to obtain the farm-specific technical efficiency index. The residuals were first "corrected" as a result of the shift in intercept by the value of the highest positive residual (0.7929), according to the COLS approach. The only difference between the OLS and COLS estimates lies on the "corrected" intercept, which is 8.7129 for the COLS. The inverse function of the natural logarithm then provided a relative measure of efficiency among the observations, where the most efficient producer has a technical efficiency of one and all others have a technical efficiency level less than one and non-negative (Russell and Young 1983). Descriptive statistics for the efficiency index are presented in Table 5.2. The efficiency index by subfield and by farm is presented in Figure 5.1 and Figure 5.2, respectively. The distribution of efficiency levels in the sample is shown in Figure 5.3.

Table 5.2 Descriptive Statistics of Technical Efficiency Index for Small Tomato Producers, Petrolina, 1993-1995

Efficiency Index	Mean	Std. Dev.	Min.	Max.
(94 observations)				
Output-based (TE1)	0.473	0.137	0.100	1.000

Two important points to be made about the resulting efficiency index concern its magnitude and its distribution among subfields. First, the average efficiency level is considerably lower than efficiency levels presented in other studies of agricultural activities in developing countries (Table 3.1). These relatively low estimated levels of efficiency can be partly attributed to the deterministic model, which tends to overestimate inefficiency when compared to the more widely used stochastic models (Battese 1991; Ekanayake and Jayasuriya 1987; Schmidt 1986). As Battese (1991) explains it, a particular farm is judged technically more efficient relative to unfavorable conditions associated with its own productive activity than if its production is judged relative to the maximum value associated with a deterministic frontier.

The second point concerns the high variation of efficiency level among subfields belonging to the same farmer. The range of efficiencies within subfields of the same farm is shown in Figure 5.2. The 24 farms are represented on the horizontal axis and the technical efficiency level is given on the vertical axis. The observations within each farm are represented as the points adjoined by a common line. Farm 1, for instance, has five subfields and their efficiency levels range from about 32% to 58%.

Figure 5.1 Subfield-Level Technical Efficiency

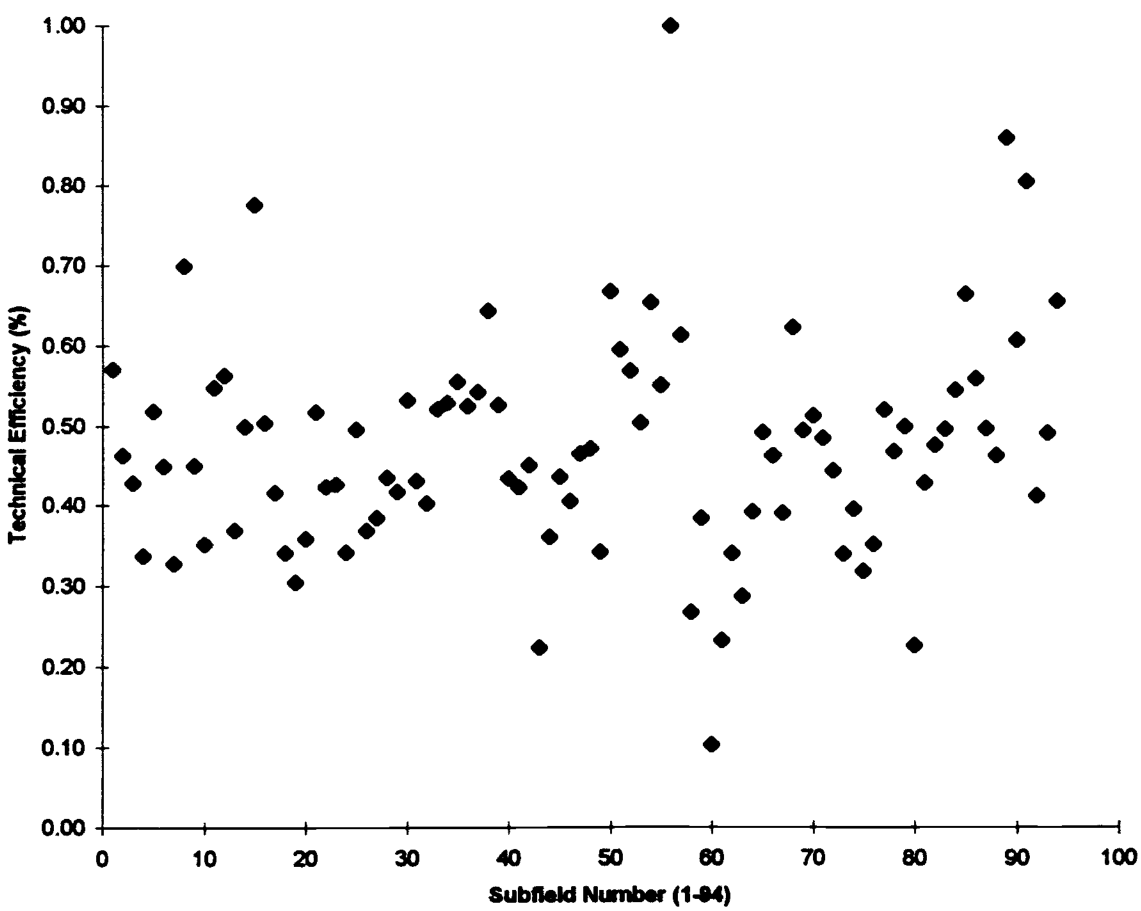


Figure 5.2 Range of Farm-Level Technical Efficiency

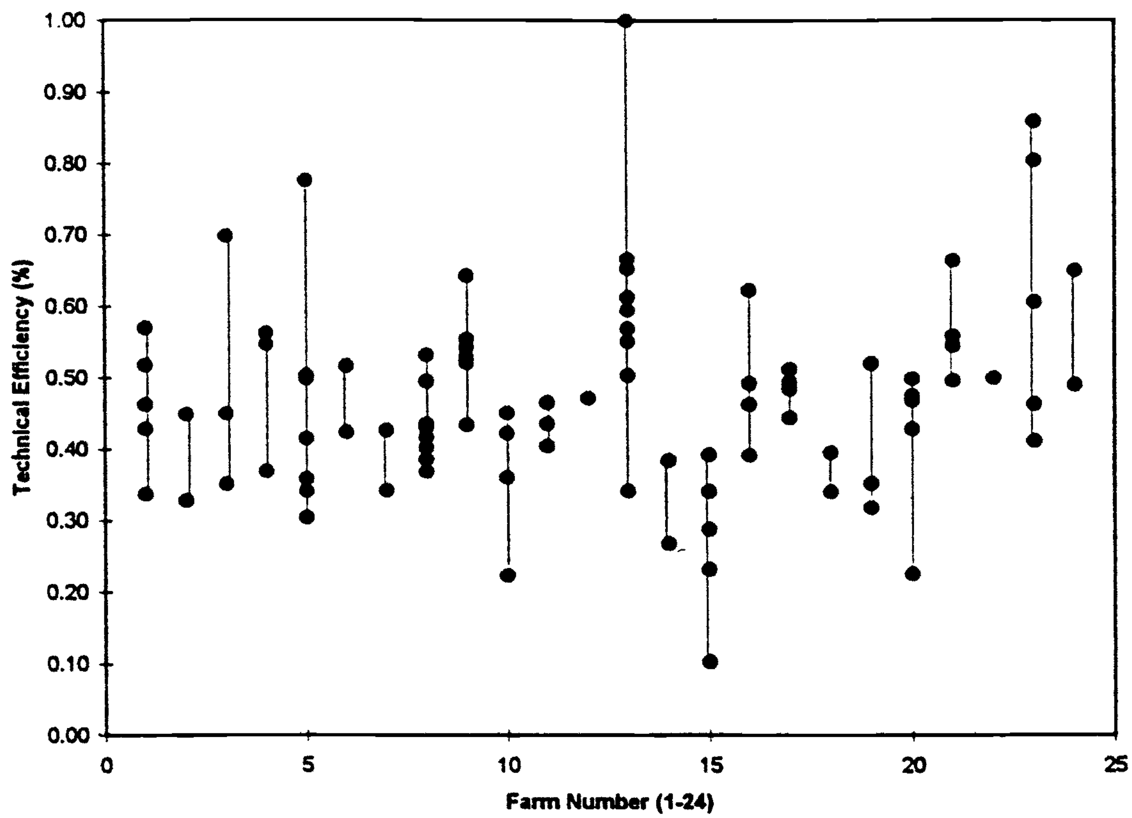
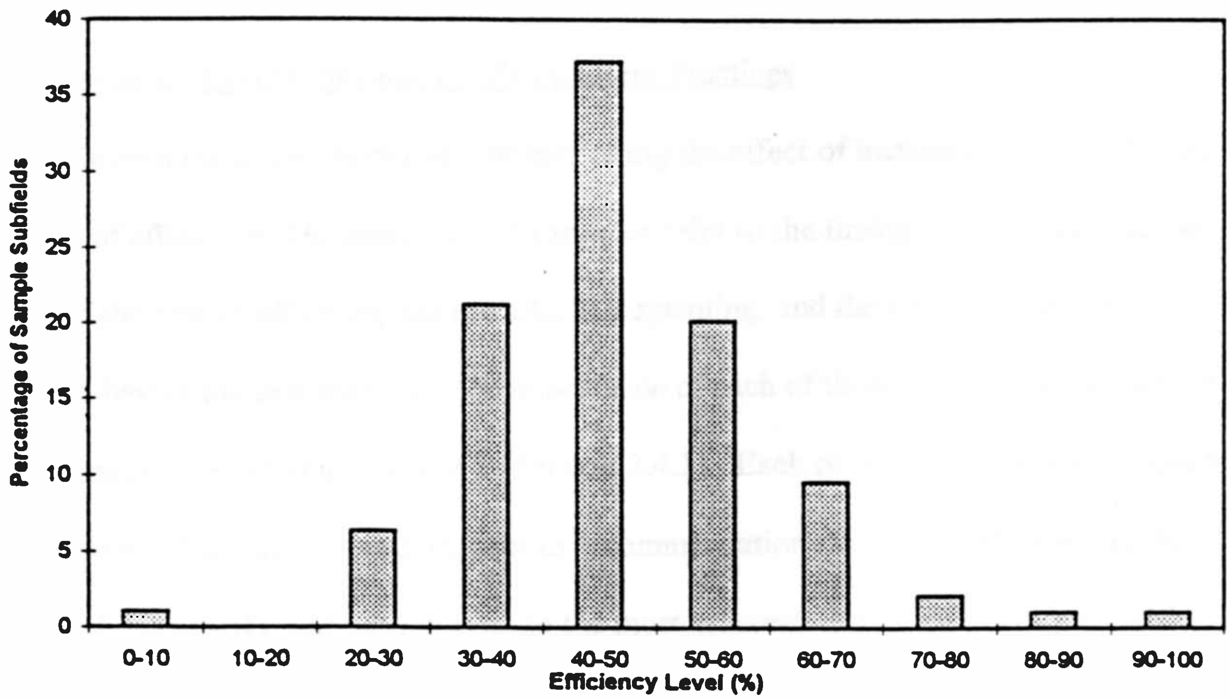


Figure 5.3 Distribution of Efficiency Index



This study was based on the hypothesis that there is significant differences in technical efficiency *among* farmers in the sample; high variation in efficiency level *within* the same farm was a puzzling outcome. The within farm variations in technical efficiency will have important implications for interpreting the final results. One such implication is that technical efficiency may be influenced by factors outside the farmers' control. In other words, assuming that farm and farmer characteristics are constant for all the subfields belonging to the same farmer, variations in technical efficiency within each farm is probably attributable to factors beyond the farm.

5.1.2 Efficiency Level Explained by Management Practices

Several equations were used for estimating the effect of management variables on the level of efficiency. The management variables refer to the timing of transplanting, the timing of the first fertilizer application after transplanting, and the timing of the last irrigation before the first harvest. The importance of each of these steps in the production of tomatoes is presented in Chapter 2 (Section 2.4.3). Each of these factors was measured in actual days (Equation I), with respect to recommendations from EMBRAPA and the District (Equation II), and with respect to the most efficient observation (Equation III).

Equations I, II and III were estimated using two-stage least squares (2SLS) because the endogenous variables used as regressors (the management variables) are correlated with the disturbance term in each equation. For details on the application of 2SLS, see Appendix I.

5.1.2.1 Equation I

Equation I measured the effects of actual timing of input use by each farmer on his technical efficiency. The equation included the timing of transplanting, the timing of fertilizer application after transplanting, and the timing of the last irrigation, as measured by the following variables:

DTRAN = days between seeding and transplanting,

DFERT = days between transplanting and first fertilizer application after transplanting, and

DIRRI = days between last irrigation and harvest.

Estimates for Equation I are presented in Table 5.3. Overall, the estimates were very poor, as reflected by the very low R2 and insignificant F value. The only significant variable was the timing of fertilizer application after transplanting. The negative sign implies that the greater the interval between transplanting and fertilizer application, the lower the efficiency level.

Table 5.3 Equation I Estimates: Effects of Timing on Technical Efficiency

Variable	Estimate
DTRAN	-0.004
	(-0.618)
DFERT	-0.016***
	(-1.563)
DIRRI	0.00
	(1.136)
Adjusted R2	0.0001
F Value	1.003

Note: Figures in parenthesis are t-statistics.
Significance levels based on two-tailed test.
* Significant at 1% level.
** Significant at 5% level.
*** Significant at 10% level.
**** Significant at 20% level.

5.1.2.2 Equation II

Equation II tried to measure how much of the farm-specific efficiency was based on EMBRAPA (1994) and District (de Carvalho *et al.* 1995) production recommendations[1] by verifying whether farmers who follow the recommendations are more efficient than those do not. Dummy variables were used for each management practice, indicating whether or not each farmer transplanted (DTREC), applied fertilizer (DFREC) or stopped irrigating (DIREC) in each of his subfields within the recommended intervals, as shown below:

DTREC = 1 if $21 < DTRAN < 31$, 0 otherwise;

[1] These recommended management practices are discussed in Section 2.4.3.

DFREC = 1 if $14 < DFERT < 21$, 0 otherwise; and

DIREC = 1 if $9 < DIRRI < 21$, 0 otherwise.

The results from this model were all insignificant and are presented in Appendix J. In principle, we would expect that the farmers who follow the EMBRAPA and District recommendations to be more efficient than those who do not. Yet if we look at the distribution of the timing of transplanting, fertilizer application, and irrigation, we see there is considerable variation in the observed timing from the recommended timing (Figure 5.4A - Figure 5.4C).

Figures 5.4A - 5.4C show the observed timing of each of the management practices in each subfield. The vertical axis shows the actual number of days and the horizontal axis show the subfield number, from 1 to 94. Figure 5.4A show that transplanting in about half of the observations was done within the recommended time interval of twenty to thirty days after seeding.

Figure 5.4B show that fertilizer application in the majority of the subfields was done outside the recommended interval. Specifically, fertilizer application in about 80% of the subfields was done before the recommended interval. Though in the case of fertilizer application, producers are not following the recommended timing, they are being consistent among themselves in applying the fertilizer earlier than what is recommended. We can therefore infer the following: a) there are other factors more important than the EMBRAPA and District recommendations in determining the timing of input use among the producers; b) the farmers completely disregard the recommendations and use their

Figure 5.4A Comparison of Observed Transplanting Date and Recommended Transplanting Interval

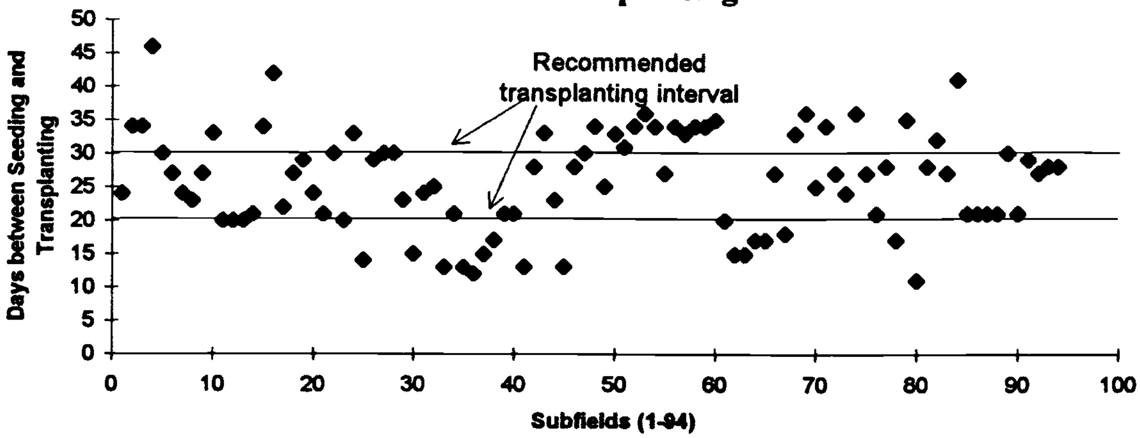


Figure 5.4B Comparison of Observed Timing of Fertilizer Application and Recommended Timing

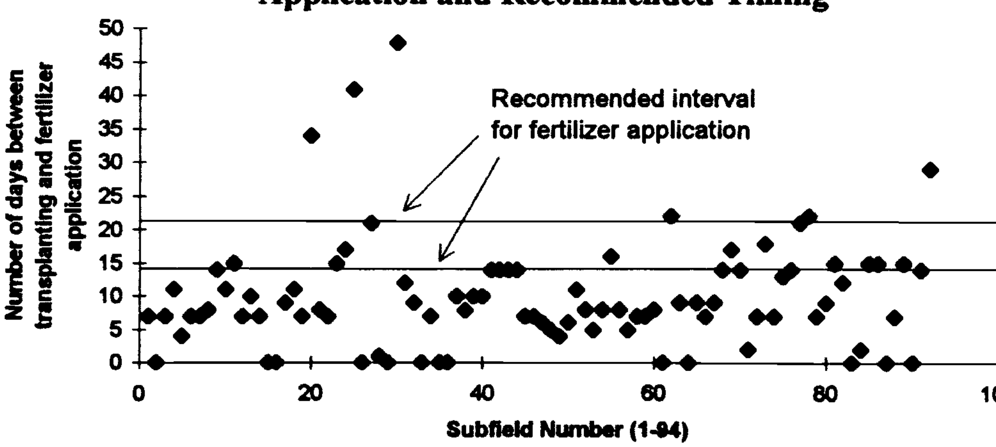
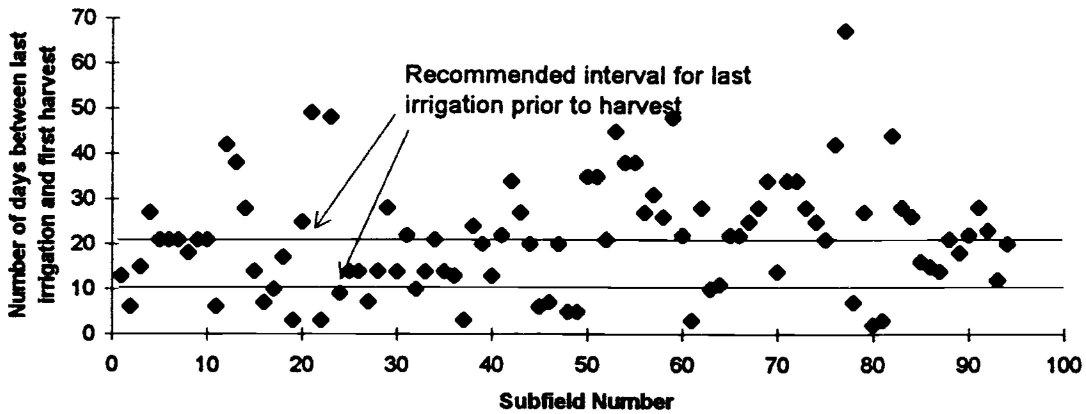


Figure 5.4C Comparison of Observed Irrigation Timing and Recommended Timing



own knowledge (or their neighbor's advice) for timing input use; or c) the producers have a better understanding of tomato production in the perimeter than the EMBRAPA experts.

The timing of the last irrigation, as presented in Figure 5.4C is similar to the distribution observed in the case of transplanting. The last irrigation on about 40% of the subfields occurs within the recommended interval; irrigation of the remaining subfields is outside the recommended interval.

5.1.2.3 Equation III

Given the weakness of Equation II in identifying critical timing variables based on technical production recommendations, Equation III used the management variables associated with the most efficient observation. This approach allowed the management practices of each producer to be compared to those of most efficient producer in the sample. As such, the management variables reflected the difference between the management practices of the most efficient producer (as reflected by the most efficient subfield, 56) and that of the other observations, as shown below:

$DT56 = DTRAN_{56} - DTRAN_i$,

$DF56 = DFERT_{56} - DFERT_i$, and

$DI56 = DIRRI_{56} - DIRRI_i$,

where $i = 1...94$

The results from this equation also were insignificant (Appendix K).It was expected that the closer each farmer was to the dates of the most efficient farmer, the more efficient he would be. In principle, this is sound logic. But in practice, using the most efficient observation as a benchmark for the others in terms of the management variables is unreasonable if we once again consider the high variations in efficiency observed in subfields managed by the same farmer (Figure 5.1). Though resource-use efficiency was highest for observation 56, that particular subfield is managed by the same farmer who also operates eight other subfields (observations) with efficiency levels ranging from 33% to 63%.

5.1.3 Management Practices Explained by Socioeconomic Factors

The third part of the three-step model involved identifying the socioeconomic characteristics which most significantly affect the management variables. For the purpose of this study, the socioeconomic condition of the farmer was defined by household composition, the farmer's knowledge base, and his investment capacity. Household composition was given by the size of the family and the age of the farmer. The farmer's knowledge base was meant to capture both formal and informal education. Formal education was presented in years of schooling and informal education as the years he has spent in the irrigated farm. The colono's investment capacity was measured by his ownership of a commercial establishment (*bodega*), vehicle and farm animals. The effect of the above factors on management was estimated by linearly regressing the management variables separately on the household characteristics, as shown below:

$$MGMT_i = \alpha + \beta_1 FAMSIZE_i + \beta_2 AGE_i + \beta_3 YEARSLOTE_i + \beta_4 EDU_i + \beta_5 COMM_i + \beta_6 CAR_i + \beta_7 ANIMAL_i + \varepsilon,$$

where $MGMT_i$ are the three management variables associated with Equation I (DTRAN, DFERT, and DIRRI);

FAMSIZE is the size of the farmer's family;

AGE is the farmer's age;

YEARSLOTE is the number of years the farmer has been in the irrigation perimeter;

EDU is a dummy for formal education (1 = no education; 2 = some education, but incomplete primary; 3 = complete primary, but not beyond; 4 = beyond primary);

COMM is a dummy for ownership of a *bodega* (1 = owns *bodega,* 0 = otherwise);

CAR is a dummy for ownership of any type of vehicle (1 = owns vehicle, 0 = otherwise); and

ANIMAL is a dummy for ownership of farm animals (1 = owns animals, 0 = otherwise).

The results for these regressions are presented in Table 5.4. AGE and YEARSLOTE were removed from the equation because of their correlations with other variables. In particular, AGE was highly correlated with YEARSLOTE (positive) and with EDU (negative). Despite the overall poor results of this equation, we can make some (limited) observations. The ownership of a commercial establishment is the only significant variable across all three management practices. It has a negative influence on the timing of fertilizer application (DFERT) and irrigation (DIRRI). This negative relationship is consistent with studies showing a negative relationship between off-farm establishment and efficiency (Ali 1995; Ali and Flinn 1989). This same variable has a positive sign for timing of transplanting. The ownership of farm animals influences both the timing of transplanting and the timing of irrigation.

Table 5.4 Three-Step Model: Socioeconomic Determinants of Management Practices of Small Producers, Petrolina, 1993-1995

Independent Variable (94 observations)	Dependent Variable		
	DTRAN	DFERT	DIRRI
FAMSIZE	--	--	25.70***
	--	--	(-1.772)
COMM	4.01***	-4.14***	-5.67****
	(1.719)	(-1.571)	(-1.491)
CAR	3.20**	--	--
	(2.093)	--	--
ANIMAL	5.59*	--	9.92*
	(2.798)	--	(3.034)
Intercept			
Adjusted R^2	0.101	0.0155	0.1178
F Value	4.465*	2.468****	5.138*

Note: Figures in parenthesis are t-statistics. Significance levels based on two-tailed test. Each of the dependent variables were regressed on all the household characteristics repeatedly and only the signficant variables from the most robust estimations are shown.

* Significant at 1% level.
** Significant at 5% level.
*** Significant at 10% level.
**** Signficant at 20% level.

The results from Equations I, II, and III were statistically very weak and nowhere near the results expected. These poor results may partly be attributable to two factors: the three-step approach and the distribution of the efficiency index. Though the three-step approach should better represent the causal chain of events between efficiency, management and household characteristics, most efficiency studies (and all those reviewed in Section 3.5) use a simpler two-step approach, which regresses the efficiency index directly on household characteristics and management variables jointly. So in attempting to improve the results, the two-step model was used on the subfield-level data as shown below (Section 5.2).

The distribution of the efficiency index also explains the low R^2 of the three-step model. In the third step of the model, household characteristics (based on 24 households) were used to explain variations in management practices (based on 94 subfields). So household characteristics were meant to explain variations in efficiency among subfields of different farms, and not variations among subfields of the same farm. Since it was initially expected that variations in efficiency levels were higher among the farms than within the farms, using household-level data was expected to pick up variations across farms. Yet we have seen that there was considerable within-farm variation in efficiency level. So the household characteristics picked up some of the variation among farms, but it did not (and could not) explain any of the variation within farms. To get around this problem, subfield-level data was aggregated by farm to generate an equation based on the 24 farms instead of the 94 subfields (Section 5.3).

5.2 Two-Step Model Using Subfield-Level Data (Equation IV)

The two-step model involved obtaining the efficiency index from the production frontier estimate, then regressing this index directly on all the factors believed to influence efficiency, which in this case are household characteristics and management practices. The efficiency index used in this model is the same obtained for the above models. The second step is as follows:

$$TE_i = \alpha + \beta_1 LFAMSIZE_i + \beta_2 LAGE_i + \beta_3 EDU_i + \beta_4 COMM_i + \beta_5 CAR_i + \beta_6 ANIMAL_i + \beta_7 LDTRAN_i + \beta_8 DFERT_i + \beta_9 LDIRRI_i + \varepsilon,$$

where all the variables are the same as defined above. AGE was not used because of its high correlation with EDU, COMM, and ANIMAL. The equation was initially regressed using all the variables, then several iterations were made in which insignificant variables were removed until the best results were obtained.

Equation IV estimates are presented in Table 5.5. The overall model is statistically better than the three-step model discussed, as reflected in the higher adjusted R^2, F-value and the number of significant coefficients. Several parameters show up as having an important influence on efficiency. From the household characteristics, the education level of the farmers appears as the most significant factor affecting efficiency level. Another significant farmer characteristic is family size, though its significance level is much lower than that for education. The ownership of a commercial establishment had a negative relationship with efficiency and was significant at the 20% level.

The timing of the last irrigation (DIRRI) was the only management variable that showed up as significant, having a positive sign at the 5% level. This result implies that longer intervals between the last irrigation and the first harvest are associated with higher levels of efficiency.

Table 5.5 Equation IV Estimates: Socioeconomic and Management Variables Affecting Technical Efficiency

Independent Variables	Dependent Variable TE
(94 observations)	
LFAMSIZE	0.04***
	(1.597)
EDU	0.05*
	(4.051)
COMM	-0.06****
	(-1.436)
LDIRRI	0.19**
	(1.996)
LDIRRISQ	-0.03***
	(-1.769)
Intercept	0.02
	(0.193)
Adjusted R^2	0.2
F Value	5.522*

Note: Figures in parenthesis are t-statistics.
Significance levels based on two-tailed test.
* Significant at 1% level.
** Significant at 5% level.
*** Significant at 10% level.
**** Signficant at 20% level.

Despite the improvements of the two-step model versus the three-step model using subfield-level data, the adjusted R^2 remains low, showing that household characteristics and management practices only explain about 20% of the variation in technical efficiency. Though using the two-step model removes the dependence on management variables to explain the variations in efficiency levels by instead using all the farm and farmer characteristics believed to influence efficiency, we are still constrained by the data scale issue. We are still using farm-level data to explain variation among farms and within farms. So the adjusted R^2 primarily reflects the amount by which the farm-level data explain variations in efficiency among farms. The only variable that picks up within farm variations in efficiency level is timing of irrigation (DIRRI) because it is given on subfield level.

5.3 Two-Step Model Using Average Farm-Level Data (Equation V)

The inability to (significantly) explain the variations in efficiency among subfields using farm-level data lead to the aggregation of all subfields for each farm. All the subfields belonging to the same farm, regardless of the total number, were aggregated into a single farm measure. The production frontier was estimated based on total output (average output per farm) and on average yield (average yield per farm), and the results are shown in Table 5.6.

Results for the production coefficients using farm-level data were very similar to those obtained from subfield-level data, with land and labor the most significant inputs and water trailing behind with a negative sign. The residuals from the production function allowed the development of the farm-level efficiency index. Just as in Equation IV, Equation V consisted of having the index regressed directly on household characteristics and management practices. Since we are now considering farm-level data, the management practices were averaged across the subfields of each farm.

Table 5.6 OLS Estimates of Output and Yield-Based Cobb-Douglas Production Functions for Farm-Level Data for Tomato Producers, Petrolina, 1993-1995

Independent Variable	Unit	Dependent Variable: Output	Dependent Variable: Yield[a]
(24 observations)			
Land	hectares planted with tomatoes	0.68**	--
		(2.695)	--
Labor	total man-days used in production	0.76*	0.62*
		(4.042)	(3.923)
Water	m^3	-0.38***	-0.46**
		(-1.867)	(-2.703)
Pesticide	aggregate index[b]	--	-0.17**
		--	(-2.366)
Intercept		10.09*	11.57*
		(6.051)	(7.639)
Adjusted R^2		0.91	0.49
F Value		76.334*	8.423*

Note: Figures in parenthesis are t-statistics. Significance levels based on two-tailed test.
[a] Average yield per farm is regressed on averge labor/ha, water/ha, and pesticide/ha.
[b] Method used in calculating aggregate index is shown in Appendix D.
* Significant at 1% level.
** Significant at 5% level.
*** Significant at 10% level.
**** Significant at 20% level.

Results of the estimation of Equation V are given in Table 5.7. The equation was initially regressed using all the household and management variables. Several iterations were then done using the most significant variables until the best estimate was obtained, as reflected by the adjusted R^2, the F value, and the number of significant coefficients. The results show that EDU and the ownership of a commercial establishment are the most important farmer characteristics determining farm-level efficiency.

Table 5.7 Equation V Estimates: Socioeconomic and Management Variables Affecting Technical Efficiency (Farm-Level Data)

Independent Variables	Dependent Variable TE
(24 observations)	
EDU	0.08*
	(4.555)
COMM	-0.11**
	(-2.167)
Intercept	0.64*
	(13.226)
Adjusted R^2	0.47
F Value	11.503*

Note: Figures in parenthesis are t-statistics.
Significance levels based on two-tailed test.
* Significant at 1% level.
** Significant at 5% level.
*** Significant at 10% level.
**** Signficant at 20% level.

5.4 Summary of Results

The results from the two-step model were considerably better than those for the three-step model, as reflected by the higher adjusted R^2, higher F values, and the greater number of significant coefficients in the case of Equation IV. Aggregating the data across farms, as was done for Equation V, also improved the results relative to the three-step model, but did not show any significant improvements from Equation IV. Table 5.8 presents a summary of the results from the two models and the equations used to identify the determinants of technical efficiency.

Table 5.8 Summary of Results from Two-Step and Three-Step Models

Model/Equation[a]	Adj. R2	F value	Significant dependent variables
Three-step model			
DTRAN = SE	0.10	4.465*	COMM (+)***, CAR (+)**, ANIMAL (+)*
DFERT = SE	0.02	2.468****	COMM (-)****
DIRRI = SE	0.12	5.138*	FAMSIZE (-)***, COMM (-)****, ANIMAL (+)*
Two-step model			
Eq. IV: TE = SE, MGMT	0.20	5.522*	FAMSIZE (+)****, EDU (+)*, COMM (-)****, LDIRRI (+)**, LDIRRISQ (-)***
Eq. V: TE = SE, MGMT	0.48	11.503*	EDU (+)*, COMM (-)**

Note: Significance levels based on two-tailed test.
[a] SE represents all the household socioeconomic variables (FAMSIZE, AGE, EDU, COMM, CAR, ANIMAL). MGMT represents the three managment variables (DTRAN, DFERT, DIRRI).
* Significant at 1% level.
** Significant at 5% level.
*** Significant at 10% level.
**** Signficant at 20% level.

Results from the two-step model show that education (EDU) is the most significant farmer characteristic in determining farm efficiency. The positive sign of the education coefficient indicates a direct relationship between education level and technical efficiency -- the higher the education level, the higher the efficiency level. This finding is consistent with several studies discussed in Chapter 3 showing the role of formal education in efficiency.

Another significant farmer characteristic was the ownership of a commercial establishment (COMM). This variable was originally used as a proxy for the farmer's investment capacity and the hypothesis was that the ownership of a commercial establishment, like the ownership of farm animals or vehicles, would imply a higher investment capacity and therefore greater efficiency. The negative sign, however, is consistent with previous studies. A simple explanation for the negative relationship between the ownership of a commercial establishment and efficiency may be attributable to labor constraints. A farmer who owns a business is likely to allocate a considerable amount of his time to the business rather than to the farm. This is especially true if the marginal returns for labor are higher in the business than in the farm.

The negative sign for COMM therefore does not imply lower efficiency for farmers who own a business. Though they may be less efficient in the production of tomatoes relative to other small tomato-producing farmers, they may be allocating their labor to activities with relatively higher marginal productivity. The possiblity of this result implies that farmers who own commercial establishments have a higher opportunity cost for labor than farmers who only work on the farm. These possible differences in opportunity cost for labor may limit the assumption that producers face idenfical prices for all inputs.

The timing of the last irrigation prior to harvest was the only significant management practice. This results implys that the timing of the last irrigation is more important in determining efficiency level than the timing of transplanting or the timing or fertilizer application after transplanting. Furthermore, the positive sign for LDIRRI implies that the longer the interval between the last irrigation and the first harvest, the higher the efficiency.

CHAPTER SIX

CONCLUSIONS

Even though the most robust results obtained in all the empirical trials were somewhat discouraging in view of the objectives laid out for this study, it is possible to make several conclusions about the method used, its limitations, and some of the factors believed to influence farm-level efficiency. Moreover, the results indicate that several factors that affect farm efficiency were not considered in the analysis.

6.1 Conclusions

Four important conclusions can be made about the models used to estimate efficiency and the results obtained:

a) The two-step model is better than the three-step model in trying to identify the determinants of efficiency in this case, as seen by the results presented in Table 5.8. The main weakness of the three-step model may be its dependence solely on the management variables to explain the variations in efficiency. This dependence on a single factor is especially important if the explanatory variables used are not the most significant variables affecting efficiency.

b) There was high variation in efficiency levels among subfields on the same farm. This was an unexpected outcome and it partly explains the statistically poor results obtained in the second step of the two-step approach. Using farm-level characteristics to explain the estimated variations in efficiency level only accounted for the variations in efficiency among farms. No variables were used to explain variations in efficiency in subfields belonging to the same farm.

c) Some of the household characteristics and management practices believed to affect efficiency did show up as significant factors. In particular, EDU appeared as an important determinant of efficiency and was also highly correlated (negative) with AGE. So the older the farmer, the less efficient he is. The inference from this result is that formal education is more important in determining the efficiency level of these farmers than is experience. In general, the older farmers had spent considerable more years in the irrigation perimeter, yet the younger farmers, with less experience and more formal education, appear as more technically efficient.

Despite the poor results of Equation II, in which the efficiency index was explained by EMBRAPA recommended practices, comparing the observed management practices to the EMBRAPA recommended practices revealed that farmers, in general, do not follow the recommendations with respect to timing of transplanting, fertilizer application after transplanting, and the timing of the last irrigation (Figures 5.4A - 5.4C). This result was surprising given the emphasis in the perimeter on research and technical assistance programs.

d) The low R^2 even for the farm-level equation (Equation V, Table 5.8) revealed the likeliness of other factors besides basic household characteristics and management practices affecting farm efficiency. One major factor that influences efficiency and is mentioned throughout this study is the role of institutions. Institutional constraints imposed by the irrigation agency or the pulp-processing firm are discussed as influencing efficiency but are not included in the empirical estimations. If data were available on the role of institutions on farm-level efficiency (e.g., number of contacts of farmers with extension agents, access to credit, variations in firm contracts), then maybe more of the across-farm variation in efficiency could be explained.

6.2 Limitations

The analysis presented in this study is subject to limitations and the results should therefore be considered in light of them. Most of the limitations in this study relate to the availability and nature of the data used. The most limiting data concerns the sample size, soil quality variable, management variables, and the fertilizer and pesticide indices. The study is also limited by omitted variables, including the health of farmers and their families and year-based variables.

Perhaps the greatest limitation to this study is the small sample size. There are over 1,700 small farmers in the irrigation perimeter, most of which have at one time or another produced tomatoes. The twenty-four farmers used in this study, though carefully selected by EMBRAPA, cannot be expected to represent the population of small tomato-producing farmers.

Another important limitation of the data is the variable used to represent soil quality. Soil-quality data were available on a farm-level basis and were assumed constant for all the subfields within each farm. Though most of the subfields in the same farm are expected to the same soil quality, given that the farms in the sample have at least 80% of the area belonging to a single soil group (see Appendix E), there are likely many instances where subfields do not share the same soil quality. Variations in soil quality within farm could explain some of the within-farm variations in efficiency level. Moreover, variations in soil quality could also justify the timing of input-use by farmers.

The management variables used to represent the farmer's management practices may not be the most influential ones in terms of efficiency. There are many other practices that are likely even more important in influencing efficiency level, like fertilizer application on the seedbed, the application of preventive pesticides and fungicides, the timing of irrigation during the critical growing stages of the tomato. DTRAN, DFERT, and DIRRI were used because of their availability for all subfields.

Another input-based limitation is the constraint in using fertilizers and pesticides as aggregate indices in the production frontier. There are over sixty different pesticides, fungicides, and herbicides used by the sample farmers in the production of tomatoes and aggregating them all into one index veils the impact of any one particular chemical. Given the relative importance of particular chemicals in the production of tomatoes, especially those aimed at important pests like the *traça*, data on the most important principle agents found in these pesticides would be desirable. The same rationale can be used for the fertilizer index. There are about seven different fertilizers used by the farmers, yet the index does not allow any one particular fertilizer to be more influential for efficiency than another. The limitations for fertilizer go along with limitations in soil quality data. Knowing the soil quality on each subfield would allow analysis of fertilizer use based on the needs of each subfield.

In addition to the input-based limitations, this study is also limited by the variables it did not consider, including measures of the farmers' health and year-based variables. Farmers' health is emphasized as a possible determinant of farm efficiency because of the high incidence of chemical intoxication among the small farmers (O Povo 1996). Several of the farmers interviewed mentioned health effects from using highly toxic chemicals, including dizziness and headaches. Though these side-effects may pose no immediate threat to a farmer's ability to work, it is expected that continuous contact with these chemicals over several years can have a more debilitating impact.

Another serious limitation of this study is that I did not account for any year-based events, such as yearly climate variability. Changes in precipitation level from year to year in the Petrolina/Juazeiro region do not affect the amount of water available to the farmer because only a small amount of the river's total capacity is used in the irrigation projects. Regardless of precipitation, the farmers always have access to water. Oscillations in yearly and seasonal rainfall, however, can lead to oversaturation of crops and variation in irrigation timing in particular years.

Another year-based factor not considered was the impact of the economic reforms contained in the Real Plan in July of 1994. The Plan might have had some influence on the input-use trend presented in Figure 4.3, but I did not research possible direct relationship between changes in prices resulting from the Real Plan and farmer efficiency.

Even if I did have access to data on hundreds of farmers and accounted for the omitted variables above mentioned, results obtained using the method described above may not explain all the variation in efficiency. There likely exist several nonmeasurable variables that affect farm efficiency -- variables relating to the attitude of the farmer, his objectives in farming, and his administrative capacity. So there is an inherent limitation in trying to narrow down the determinants of efficiency to basic household characteristics and management practices.

6.3 Further Research

From my experience in conducting this study, further research in trying to better understand the determinants of technical efficiency among small tomato producers should focus primarily on the role of institutions in influencing farmer behavior. The impact of the household characteristics and management practices considered in this study are interesting, but provide limited insights on factors affecting farmer efficiency. Understanding farmer perceptions of the technical assistance and the pulp-processing firm would provide better indication of what influences farmer behavior and consequently, what determines his efficiency level.

From the limited analysis of the farmers' management practices, it was observed that generally, many farmers do not follow the practices recommended by EMBRAPA and the District. This result may indicate that these agencies recommend practices that are optimal, on average, for farms in the perimeter, yet may not be the best practices for all farms. Moreover, farmers may be aware of the limitations of the recommended practices and adapt them to their particular farm characteristics. On the other hand, it could be that farmers do not follow the recommended practices based on misconceptions about the technical assistance service and extensionists. Government agencies are usually not seen as providers of goods, but rather as exploiters (Salmen 1994) Several of the farmers interviewed revealed limited trust on the technical assistance agents; these farmers showed greater confidence in their own knowledge and experience than in the advice given to them by the agents.

During the field interview, some variation in the farmers' perceptions of the pulp-processing firms were noted. While many seemed favorable to the firms, others showed some dismay regarding the prices set by the firm and their timing of input delivery. In the present study, it was assumed that the role of the processing firm was constant for all the producers and that farmers faced the same constraints concerning input prices and delivery of inputs. While the assumption on fixed prices may hold, the same cannot be said about the delivery of inputs. It is unlikely that firms deliver all the inputs to the farmers on the same dates.

In addition to input constraints imposed by the firms, the relationship between the farmer and the processing firm also may have implications for farm efficiency. The efficiency of producers that respect the firms as their contractors and abide by the established contract is likely to be different from the efficiency of those producers who work under contract just to take advantage of the inputs supplied by the firm. In this case, an example is those producers who, upon receiving the inputs from the firms, either sell these inputs in the market or use them for crops other than tomatoes.

Questions which address farmer perceptions of the agencies involved in the perimeter and which may provide insights into institutional constraints influencing farm-level efficiency can be made regarding the technical assistance and the pulp-processing firms.

Questions concerning the role of the technical assistance may include the following:

- How often, and under what circumstances, do farmers seek technical assistance? What determines their trust in the recommendations given by the technical assistance? Do they understand the importance in following the recommended practices in terms of pest prevention, adequate fertilizers, appropriate irrigation, and consequently increased yields? How does the technical assistance provided by the District and EMBRAPA compare with that provide by the processing firms?

Researching these questions may explain why some small farmers are not following the recommended management practices and also explain what drives their management decisions. As explained by Salmen (1994), many of the services offered to the farmers are only as good as they are percieved by the users.

The farmer's perception about the pulp-processing firm may also affect the farmer's attitude, and consequently his efficiency. Questions to be considered include:

- What influences farmer decision to produce tomatoes under a firm contract? What are his incentives to sign a contract (i.e., how do firm prices for tomatoes compare with the price the farmer would get if he sold directly in the local market)? Are there any differences in the contracts offered by the different processing firms and if so, how does a farmer choose among the firms?

The complexity of decision-making by small farmers, such as those in the Senador Nilo Coelho Irrigation Perimeter, suggests that socioeconomic, management, and institutional factors must be fully understood when studying variations in resource efficiency.

APPENDIX A

Description of Water Costs for Farmers in the Irrigation Perimeter

Producers are charged for irrigation water on a monthly basis. The water fees include a variable cost, a fixed cost, and a finance charge (K1), as described below.

The variable cost (VC) accounts for the actual water use by each producer and covers the energy cost of pumping the water from the main pumping station to the field. (The cost of pumping the water from the Sobradinho Dam to the main station is borne by CODEVASF). In March of 1996, the variable cost was about R$ 18.75 per 1000 m^3, or $14.25 per 1000 yd^3.

The fixed cost (FC) is charged per irrigable hectare, regardless of how many hectares the farmer is actually using for agricultural production. The FC covers all other operation and maintenance costs of irrigation in the perimeter. In March of 1996, it was R$ 8.57 per hectare, or about $ 3.43 per acre.

The K1 accounts for the payment of the common-use infrastructure, namely the investment costs of constructing and installing the canals, water pumps, and roads. The level of the K1 is determined by the Ministry of Agriculture and Agrarian Reform. K1 payments are placed in a perimeter bank account and sums can be reinvested in the perimeter with authorization from CODEVASF Headquarters.

An average water bill in the perimeter, assuming a 6 ha plot, is presented below. This estimate is based on 3 planted hectares and an average of 1000m^3 of water per hectare.

APPENDIX A - *Continued*

A Representative Water Bill for Farmers in the Irrigation Perimeter, 1996

Item	Unit Price (R$)	Total
Total irrigable land in farm: 6 hectares		
Total area planted: 3 hectares		
Variable cost	18.75 per 1000 m3 of water	56.25
Fixed Cost	8.57 per irrigable hectare	51.42
K1	3.58 per irrigable hectare	21.48
Total		129.15

Source: Janebro 1996

APPENDIX B

Input Package Provided by Firm Contract with Tomato Producers

Product	Unit	Price (R$)	Equivalent in tomato (kg)
Bac Control	kg	9.37	161.55
Oleo Vegetal		2.11	36.38
Vertimac	l	97.25	1676.72
Ortho Hamidoph (Tamaron)	l	9.48	163.45
Pounce	l	38.81	669.14
Nomolt	l	146.07	2518.45
Oxicloreto de Cobre	kg	3.31	57.07
Cantap	l	16.41	282.93
Elsan	l	18.66	321.72
Podium	l	27.54	474.83
Adubo 6-24-12	ton	279.44	4.82
Ureia	ton	321.65	5.55

Source: Janebro 1996

APPENDIX C

Sample Spreadsheet with Productive Inputs from the EMBRAPA Database

AVALIACAO ECONOMICA DE CULTURAS IRRIGADAS - POR AREA DE PRODUCAO
PLANILHA DE ACOMPANHAMENTO DAS DESPESAS VALORES EM DOLAR

Pagina: 0001
Data: 30/07/95

PROJETO: 01 SENADOR NILO COELHO
LOTE: 289 JOSE ARNALDO BEZERRA
CAMPO: 02
SUBCAMPO: 07 PRECO INDUSTRIA
OBSERVACOES:

NUCLEO.....: 03 NUCLEO - 3
CULTURA....: 12 TOMATE
VARIEDADE : IPA-05
ESPACAMENTO: 0,7 X 0,2M
DATA IMPLAT:03/94

AREA: 2,50Ha

ITEM	UNI-DADE	QUANT. TOTAL	VALOR TOTAL US$ (PAGO)	VALOR TOTAL US$(CORRIGIDO)	VALOR TOTAL US$ (MERCADO)	VALOR TOTAL US$ (POR Ha)
1. DESPESAS DE OPERACAO						
1.1. Maquinas e Implementos						
ARACAO	H/M	7,000	0,05	0,05	186,17	74,47
GRADAGEM	H/M	3,500	0,02	0,02	93,07	37,23
SULCAMENTO	H/M	1,500	0,01	0,01	39,90	15,96
CULTIVO ANIMAL	D/A	6,500	0,01	0,01	103,72	41,49
Total Maquinas e Implementos			0,09	0,09	422,87	169,15
1.2. Insumos						
DIPEL	L	8,800	0,04	0,04	121,70	48,68
KARATE 50 CE	L	1,300	0,02	0,02	49,77	19,91
RECONIL	KG	2,300	0,00	0,00	12,55	5,02
VERTIMEC 18 CE	L	1,150	0,06	0,05	172,61	69,04
TRIFURALINA	L	5,000	0,01	0,01	58,40	23,36
AGRIL	L	0,330	0,00	0,00	0,70	0,28
FUNGURAN	KG	1,002	0,00	0,00	4,26	1,71
STRON	L	1,600	0,01	0,01	17,02	6,81
AGUA	M3	11.350,000	0,03	0,03	120,74	48,30
UREIA	KG	250,000	0,02	0,02	63,83	25,53
6-24-12	KG	2.250,000	0,15	0,15	574,47	229,79
Total Insumos			0,39	0,39	1.196,09	478,43
1.3. Mao-de-obra						
IRRIGACAO	D/H	22,000	0,03	0,03	140,43	56,17
PULVERIZACAO	D/H	28,500	0,05	0,05	227,39	90,96
CAPINA MANUAL	D/H	27,000	9,04	0,04	185,11	74,04
ADUBACAO	D/H	4,000	0,01	0,01	25,53	10,21
TRANSPLANTIO	D/H	20,000	0,03	0,03	127,66	51,06
COLHEITA	D/H	345,000	1.497,61	1.497,61	2.202,13	880,85
Encargos Sociais			502,24	502,24	2.472,00	988,80
Total Mao-de-obra			2.270,82	2.270,82	5.380,25	2.152,10
TOTAL DESPESAS DE OPERACAO			2.771,35	2.771,35	6.999,21	2.799,68

Fonte: SISTEMA DE PRODUCAO - PNP - EMBRAPA/CPATSA - PREF. MUN. PETROLINA
1. Valores Corrigidos Pelo IGP-M (FGV)
2. Valor Corrigido e Valor de Mercado em: 08/95

Source: EMBRAPA/CPATSA 1996.

APPENDIX D

Calculation of Aggregate Indices for Fertilizers and Pesticides

An aggregation index was used as a proxy for fertilizers and pesticides in the estimation of the production frontier for the following reasons: a) the data obtained on fertilizer and pesticide use were given in several measuring units, making it impossible to use a single variable for fertilizer and another for pesticide. Even if these inputs were given in equivalent units, aggregating them would be senseless given their varying degrees of strength (e.g. 3 kgs. of one particular fertilizer may be more effective than 15 kgs. of another fertilizer); b) not every fertilizer and pesticide were used in all the subfields; and c) there were no data available on fertilizer and pesticide given by their active agents.

Given cross-sectional data on prices and quantities of fertilizers and pesticides for all 94 subfields, a price and quantity index is calculated for aggregate input for each subfield.

Let P_{ij} be the price of the i^{th} input for the j^{th} subfield and Q_{ij} be the quantity of the i^{th} input for the j^{th} subfield, where i = 1- n, where n is the number of fertilizers or pesticides, and j = 1-94. We want to aggregate this data over i to get P_j and Q_j, such that

$$P_jQ_j = \sum_{i=1}^{n} P_{ij}Q_{ij} \quad \text{for all j}$$

Then $$P_j = \sum_{i=1}^{n} S_{ij} \bullet (P_{ij}/P_i^*) \quad \text{and} \quad Q_j = \frac{\sum_{i=1}^{n} P_{ij}Q_{ij}}{P_j}$$

where $P_i^* = \frac{1}{N} \sum_{j=1}^{94} P_{ij}$ is the average price for the jth product and

$$S_{ij} = \frac{P_{ij}\,Q_{ij}}{\sum_{i=1}^{n} P_{ij}Q_{ij}}$$

is the share of the ith product in total value of all products for the jth subfield.

APPENDIX E

Selection Process of Colonos in the EMBRAPA Database

The sample of farmers used in this study was obtained from previous research carried out by CPATSA/EMBRAPA. Specifically, the 24 farmers examined were among the 25 tomato-producing farmers in the 1993-1995 CPATSA database. Observations from one farmer were discarded because of incomplete data. CPATSA considered two main criteria in selection the farmers to be included in the database: the economic situation of the colono and the soil quality of his farm.

To look at the socioeconomic condition of the farmers, CPATSA first surveyed 272 colonos in Nuclei 1 through 5. Data were collected on ownership of property and farm animals; non-agricultural activities; total area of farm; irrigated area; availability of family, permanent and temporary labor; availability of machinery for soil preparation; area planted with annual and temporary crops; and area rented or sharecropped.

CPATSA then identified three main types of colonos based on the follow classification:

- Type A - Good economic situation.

  Farmers in this group have a relatively high investment capacity and an average of 4.5 hired laborers. They use all of the farm for annual crops, especially high-investment crops like grapes and mangoes. Farmers in this category usually have cattle and off-farm income, and many own several farms in the perimeter.

- Type B - Average economic situation.

  Farmer have an average investment capacity, live in the village and depend primarily on family labor. Temporary labor is hired for planting and harvesting. Farmers in this group are slowly introducing annual crops, yet over half of the farm is still used for temporary crops, including tomatoes, onions, and watermelons. These farmers are highly dependent on farm generated income.

- Type C - Low economic situation.

  Farmers in this group do not have any investment capacity. They usually have been in the perimeter for over five years and use only family labor. Farmers only produce low income crops, like corn and beans, and usually do not use all of their farmland. They constantly depend on firm contracts (tomatoes, green peppers, tobacco) and are usually late in paying their water fees.

The soil quality of each farm was based on information on soil type, soil depth, and soil texture. This information was used to generate a soil classification index for each farm, ranging from good drainage and soil quality, to poor drainage and soil quality. Only farms with over 80% of a particular soil class were considered for the study.

The socioeconomic groups (A, B, C) and the soil classes (good, average, poor) were used to generate a 3 by 3 factorial. Four repetitions were made and 36 farms were identified for the EMBRAPA study.

APPENDIX F

Sample Log of Production Activities

ACOMPANHAMENTO DIARIO Data: 30/09/95

01 01 1569 10 01 12

DATA	PRODUTO	UNID	QUANT
15/03/95	302 LIMPEZA	D/H	3.000
16/03/95	308 ADUBACAO	D/H	1.000
16/03/95	307 PREPARO DE BANCADA	D/H	3.000
16/03/95	46 ESTERCO	M3	0.200
16/03/95	530 10-13-20	KG	4.000
17/03/95	302 PLANTIO	D/H	2.000
18/03/95	217 TOMATE	KG	1.000
18/03/95	303 IRRIGACAO	D/H	0.500
24/03/95	303 IRRIGACAO	D/H	0.500
27/03/95	169 RIDOMIL MANCOZEB BR	KG	0.040
27/03/95	304 PULVERIZACAO	D/H	0.040
27/03/95	541 GRADE ARADURA	H/M	1.400
28/03/95	520 ESCARIFICACAO	D/H	1.500
01/04/95	303 IRRIGACAO	D/H	0.120
03/04/95	300 ARACAO	H/M	2.500
03/04/95	320 SULCAMENTO	H/M	1.000
07/04/95	303 IRRIGACAO	D/H	0.120
16/04/95	303 IRRIGACAO	D/H	0.120
21/04/95	303 IRRIGACAO	D/H	0.200
30/04/95	352 AGUA	M3	830.000
03/05/95	303 IRRIGACAO	D/H	1.710
03/05/95	330 TRANSPLANTIO	D/H	5.000
14/05/95	303 IRRIGACAO	D/H	0.720
14/05/95	306 CAPINA MANUAL	D/H	5.000
14/05/95	308 ADUBACAO	D/H	1.000
14/05/95	369 CAPINA ANIMAL	D/A	1.000
14/05/95	57 6-24-12	KG	300.000
21/05/95	125 DIPEL	L	0.590
21/05/95	142 KARATE 50 CE	L	0.100
21/05/95	303 IRRIGACAO	D/H	0.900
21/05/95	304 PULVERIZACAO	D/H	1.000
28/05/95	304 PULVERIZACAO	D/H	1.000
28/05/95	521 ORTHENE	KG	0.500
30/05/95	352 AGUA	M3	580.000
04/06/95	303 IRRIGACAO	D/H	0.670
11/06/95	303 IRRIGACAO	D/H	0.335
18/06/95	177 TAMARON BR	L	0.250
18/06/95	303 IRRIGACAO	D/H	0.335
18/06/95	304 PULVERIZACAO	D/H	1.000
25/06/95	303 IRRIGACAO	D/H	0.335
30/06/95	352 AGUA	M3	340.000
02/07/95	303 IRRIGACAO	D/H	0.460
05/07/95	303 IRRIGACAO	D/H	0.335
09/07/95	303 IRRIGACAO	D/H	0.460
09/07/95	308 ADUBACAO	D/H	0.400
09/07/95	64 UREIA	KG	100.000
10/07/95	303 IRRIGACAO	D/H	0.335
30/07/95	352 AGUA	M3	397.500
06/08/95	374 TOMATE-INDUSTRIA	KG	12000.000
06/08/95	9999 COLHEITA	D/H	24.000
20/08/95	374 TOMATE-INDUSTRIA	KG	4340.000
20/08/95	9999 COLHEITA	D/H	11.400

Source: EMBRAPA/CPATSA 1996.

APPENDIX G

Producer Survey

Informações Gerais sobre o Manejo dos Unidades de Produção dos Produtures de Tomate do Perimetro de Irrigação Senador Nilo Coelho

IDENTIFICAÇÃO

Data:
Hora:

Nome do produtor (x001) ____________________________

Núcleo____ (x002) Lote _______ (x003) Área total ______ha Dependentes no lote______ (x005)

Área irrigada:_____ha (x004i) Área de sequeiro:______ha (x004s)

Estrutura Familiar

Parentesco	Idade	Escolaridade

1. SITUAÇÃO ECONÔMICA

x006 **Reside na área do Projeto com a família?**
( ) 1 Sim ( ) 0 Não ( )

x007 **Há quanto tempo trabalha com o lote que possui?** ______anos

x008 **O senhor está atualmente pagando as parcelas para ser dono deste lote?**
( ) 1 Sim ( ) 0 Não ( )

Bens possuídos: **Descrição** (nº, fabricante, modelo, ano)

x009 ( ) 1 Propriedades agrícolas (o lote)________________________
x010 ( ) 1 Imóveis na cidade ________________________
x011 ( ) 1 Estabelecimento comerical ________________________
x012 ( ) 1 Veículos ________________________
x013 ( ) 1 Máquinas agrícolas ________________________
x014 ( ) Animais de serviço ________________________

x015p **Quantos trabalhadores permanentes tem no seu lote?** _____H.U.
x015f **Quantos trabalhadores familiares no seu lote?** _____U.H.

x016 **Contrata trabalhadores temporários?** Quantos:______ D/H

x017 **Desenvolve alguma atividade pecuária?**
( ) 1 Sim ( ) 0 Não ( )

Caso positivo, quais os animais que o senhor possui? Quantos?
x018 Bovino ___ x020 Ovino ____
x019 Caprino ___ x021 Aves ____

Quais os cultivos perenes explorados e respectivas áreas?

	Cultivo	Área (ha)
x022	manga	_______
x023	uva	_______
x024	banana	_______
x025	acerola	_______
x026	côco	_______
x027	outros	_______

x028 **O senhor tinha alguma coisa guardada para investir no lote quando chegou no projeto?**
( ) Nada
( ) Coisas específicas (vacas, vehículo, etc.):
____
____
____
____

x029 **A sua situação financeira hoje, é melhor de quando o senhor chegou no projeto?**
( ) Melhor ( ) Igual ( ) Pior

x030 **O senhor tem alguma dívida de conta d'água com o Distrito?**
( ) 1 Não ( ) 0 Sim ( )

2. CRÉDITO

O financiamento dos insumos e atividades de custeio desenvolvidas no lote é feito através de:
x031 ( ) Banco
x032 ( ) Cooperativa
x033 ( ) Recursos próprios
x034 ( ) Casa comericial (pagamento após a colheita)
x035 ( ) Indústria
x036 ( ) Parentes/amigos

3. SAÚDE

A água para consumo humano recebe que tratamento?
x037 ( ) 1 É clorada (tratemento com cloro) ( )
x038 ( ) 1 Filtrada e fervida ( )

x039 ( ) 0,5 Só filtrada ( )
x040 ( ) 0,5 Só fervida ( )

x041 **No ano passado, o senhor passou quantos dias sem trabalhar por se sentir mal?**
( ) Nenhum ( ) Menos de 5 ( ) 5 a 10 ( ) Mais de 10

4. ORIENTAÇÃO EMPRESARIAL

x042 **O sucesso na agricultura é mais uma questão de sorte.**
( ) 0 Sim ( ) 1 Não ( ) 0 Indiferente ( )

O que é necessário para obter sucesso com agricultura irrigada?
( ) Prática agrícola
( ) Conhecimento empresarial/administrativo
( ) Outros:________________________
____
____

Como você define os cultivos que vai plantar a cada ano?
x043 ( ) 0 Pela sua experiência de produtor. ( )
x044 ( ) 0 Através de troca de informações com outros colonos. ( )
x045 ( ) 1 Influenciado pela Assistência Técnica. ( )
x046 ( ) 1 Através de informações sobre o comportamento dos preços. ( )

x047 **O senhor mantém anotações dos gastos feitos com os insumos usados na produção agricola?**
( ) 1 Sim ( ) 0 Não

No caso positivo, qual o seu procedimento?
x048 ( ) 1 Faz todas as anotações ( )
x049 ( ) 0 Faz apenas dos valores mais importante ( )
x050 ( ) 1 Faz por cada cultura plantada ( )

x051 **Você prefere obter pouca renda sem risco ou muito lucro com possibilidade de perda.**
( ) 0 Pouca renda sem risco ( ) 1 Muito lucro com risco ( )

x052 **Você aplica pelo menos parte dos lucros provenientes do lote em novos investimentos na unidade de produção?**
( ) 1 Sim ( ) 0 Não ( ) 0 Indiferente ( )

5. CONHECIMENTO TECNOLÓGICO/TÉCNICO E EDUCAÇÃO

x053 **Participa normalmente das reuniões, solicitadas pela Assistência Técnica?**
( ) 2 Sempre ( ) 1 Raramente ( ) 0 Não participa ( )

x054 **Faz parte de algum grupo de interesse orientado pela Assistência Técnica?**
( ) 1 Sim Qual__________________ ( ) 0 Não ( )

x055 **Faz análise de solo para poder efetuar a adubação no cultivo de tomate?**
( ) 1 Sim ( ) 0 Não ( )

x056 **Faz calagem para o plantio do tomate?**
( ) 1 Sim ( ) 0 Não ( )

x057 **Usa adubo foliar?**
( ) 1 Sim ( ) 0 Não ( )

x058 **A adubação de fundação foi feita...**
( ) 1 antes do transplantio ( ) 0 depois do transplantio ( )

x059 **Qual a idade da muda do tomateiro usada no transplantio (dias)?**
( ) 1 Entre 20-30 dias ( ) 0 Outro ( )

x060 **Fez abacelamento?**
( ) 1 Sim ( ) 0 Não ( )

O controle das ervas daninhas foi feito através de...
x061 ( ) 0,5 Capina ( )
x062 ( ) 0,5 Herbicida ( )
x063 ( ) 1 Capina e herbicada ( )

x064 **Quantos dias, antes da colheita, você suspende a irrigação do tomateiro?** ____

O que foi feito com os restos da cultura do tomate?
x065 ( ) 1 Incorpora de imediato ( )
x066 ( ) 1 Retira da área ( )
x067 ( ) 0 Deixa para alimento animal ( )
x068 ( ) 0 Outros ( )

x069 **Usa o mesmo tempo de irrigação para todas as culturas?**
( ) 0 Sim ( ) 1 Não ( )

x070 **O senhor muda o ponto de irrigação do tomate com que frequencia?**
( ) A cada ______ hora(s)
( ) Não sabe

x071 **Você faz a manutenção, pelo menos uma vez por ano, dos aspesores, nas válvulas e nas tubulações?**
( ) 1 Sim ( ) 0 Não ( )

x072 **Os aspersores são da mesma marca?**
( ) 1 Sim ( ) 0 Não ( )

x073 **Quando faz irrigação...**
( ) 0 Você parte do mesmo ponto em que terminou
( ) 1 Volta ao ponto original ( )

x074 **Quantos cursos você já fez sobre qualquer cultura irrigada?** ( )
( ) 0 Nenhum ( ) 0,5 Um ( ) 1 Dois ( ) 1,5 Três ( ) 2 Quatro ou mais

x075 **Tem algum técnico agrícola na família ou alguem se formando para ser técnico?**
( ) 1 Sim ( ) 0 Não ( )

No surgimento de uma doença ou praga que você não conhece e que está prejudicando a cultura que decisão você toma ?
x076 ( ) 1 Procura a Assistência Técnica ( )
x077 ( ) 0,5 Procura orientação com o vendedor das casas comerciais de agrotóxicos ( )
x078 ( ) 0 Procura orientação com o vizinho ( )
x079 ( ) 0 Usa conhecimento próprio para tratar do problema ( )

x080 **Quem faz a pulverização?**
( ) 1 mão-de-obra contratada ( ) 0 membros da família ( )

x081 **Usa roupa ou instrumentos de proteção?**
( ) 1 Sim ( ) 0 Não ( )

x082 **Obedece carencia do produto?**
( ) 1 Sim ( ) 0 Não ( )

Depois do senhor usar os agrotóxicos, onde é que coloca as embalagens?
x083 ( ) 1 Enterra ( )
x084 ( ) 0 Abandona na área do lote ( )
x085 ( ) 0 Abandona em qualquer lugar (pelo Núcleo, na estrada) ( )

x086 **Já houve intoxicação devido a uso de agrotóxicos?**
( ) 0 Sim ( ) 1 Não ( )

Há quanto tempo trabalha com agricultura irrigada?
x871 ( ) 1 10 ou mais anos ( )
x872 ( ) 0,5 5 a 10 anos ( )
x873 ( ) 0 Menos de 5 anos ( )

Antes de trabalhar com agricultura irrigada qual a sua ocupação principal?
x088 ( ) 1 Sempre trabalhou com agricultura irrigada ( )
x089 ( ) 1 Técnico em agricultura ( )
x090 ( ) 0,5 Agricultor de sequeiro ( )
x091 ( ) 0 Trabalhador em área que nada tem a ver com agricultura ( )
x092 ( ) 1 Comerciante de produtos agrícolas ( )

6. ASISTÊNCIA TÉCNICA E EXTENSÃO RURAL

x093 **Com que frequencia o senhor chama o Técnico para visitar seu lote?**
( ) 1 Uma vez por mês
( ) 0 Uma vez por ano ( )
( ) 0 Só em caso de emergencia. Por ex.:

x094 **Toda vez que o senhor chama o Técnico, ele comparece?**
( ) 1 Sim ( ) 0 Não ( )

x095 **O senhor foi a alguma reunião técnica ou dia de campo sobre tomate?**
( ) 1 Sim ( ) 0 Não ( )

Como é que o senhor classificaria os serviços da Assistência Técnica?

		Bom	Regular	Ruim
x096	Visita do técnico ao lote.	( )	( )	( )
x097	Reuniões técnicas.	( )	( )	( )
x098	Dias de campo.	( )	( )	( )

7. COMERCIALIZAÇÃO (sem índice)

Para quem que o senhor vende seus tomates?
x099 ( ) 1 Direto para a indústria.
x100 ( ) 2 Para o mercado local. ( )
x101 ( ) 3 Outro:

x102 **Nos contratos feitos com a indústria, o senhor está satisfeito com a quantidade dos produtos que recebe?**
( ) 1 Sim ( ) 0 Não ( )

x103 **Nos contratos feitos com a indústria, o senhor está satisfeito com a qualidade dos produtos que recebe?**
( ) 1 Sim ( ) 0 Não ( )

x104 **Os produtos fornecidos pela industria chegam na hora certa, de acordo com o que a indústria se compremete?**
( ) 1 Sim ( ) 0 Não ( )

x105 **Quando a indústria compra seus tomates, ela lhe paga em tempo hábil?**
( ) 1 Sim ( ) 0 Não ( )

x106 **Houve perda na colheita de tomate ano passado?**
( ) 1 Sim ( ) 0 Não ( )

Houve perdas devido a:
( ) falta de caixas na época oportuna
( ) falta de mão-de-obra para a colheita
( ) atraso no recolhimento do tomate

x107 **O senhor vai plantar tomate este ano?**
( ) 1 Sim ( ) 0 Não ( )

OBSERVAÇÕES ____

APPENDIX H

OLS Estimates of Translog Cobb-Douglas Production Function Using Subfield-Level Data

Independent Variables	Unit	Estimate
Land	hectares planted with tomatoes	1.71
		(0.357)
Labor	total man-days used in production	1.71
		(0.628)
Water	m^3	-0.840
		(-0.302)
Fertilizer	aggregate index[a]	0.736
		(0.732)
LandSQUARE		0.256
		(0.496)
LaborSQUARE		0.163
		(0.515)
WaterSQUARE		0.131
		(0.829)
FertilizerSQUARE		-0.022
		(-0.852)
Land*Labor		-0.137
		(-0.246)
Land*Water		-0.183
		(-0.381)
Land*Fertilizer		0.159
		(0.811)
Labor*Water		-0.258
		(-0.677)
Labor*Fertilizer		-0.042
		(-0.372)
Water*Fertilizer		-0.034
		(-.300)
Crop	dummy for purestand crop	0.026
	(1 = purestand, 0 = intercropped)	(0.184)
Crop*Water		-0.00
		(-0.918)
Intercept		6.074
		(0.432)
Adjusted R2		0.85
F Value		34.244*

Note: Figures in parenthesis are t-statistics. Signficance levels based on two-tailed test.

[a] Method used in calculating aggregate index is shown in Appendix D.

* Significant at 1%.

APPENDIX I

Two-Stage Least Squares

Two-stage least squares (2SLS) was used instead of ordinary least squares (OLS) in estimating Equations I, II and III because of the correlation in the system of equations. One of the assumptions in regression analysis is that the regressor variables are independent of the error term. If the assumption is violated, then parameter estimates are biased and inconsistent. A frequent cause of dependence between the error term and regressors is the determination of variables in a simultaneous equation system (Kennedy 1993; Pindyck and Rubinfeld 1991).

Equations I, II and III are defined as

$$TE_i = \alpha + \beta_1 M_1 + \beta_2 M_2 + \beta_3 M_3 + \varepsilon$$

where TE_i is the subfield-specific efficiency index, M_i (i = 1, 2, 3) are the management variables, β_i are the parameters to be estimated, and ε is the error term.

The problem of correlation arises when we consider the last part of the three-step model, in which M_i are the endogenous variables being explained by the household characteristics, as follows:

$$M_i = \alpha + \Sigma \beta_i SE_j + \varepsilon$$

where SE_j are the socioeconomic variables used to explain the variations in management variables. The M_i in Equations I, II and III are therefore endogenous variables and as such are correlated with the error term, ε.

2SLS gets around this problem by using instrumental variable in the following two-stage regression:

1. In the first stage, each endogenous variable (M_i) is regressed on all the exogenous variables in the system of equation. In the present study, we have used all the exogenous variables from the production function and the socioeconomic equation, namely

$$M_i\text{hat} = \alpha + \Sigma\, \beta_i\, x_j + \Sigma\, \beta_i\, SE_j + \varepsilon$$

where all the variables are defined above, and x_j are the input variables used in the production function.

2. In the second stage regression, the technical efficiency equation is estimated by replacing the variables M_i with the first-stage fitted variables, $M_i$hat.

$$TE_i = \alpha + \beta_1\, M_1\text{hat} + \beta_2\, M_2\text{hat} + \beta_3\, M_3\text{hat} + \varepsilon.$$

APPENDIX J

Equation II Estimates: Level of Technical Efficiency Explained by Recommended Management Practices

Variable	Estimate
DTREC	0.081
	(1.115)
DFREC	0.173
	(1.061)
DIREC	0.077
	(0.751)
Intercept	0.387*
	(8.292)
Adjusted R^2	0.012
F Value	1.377

Note: Figures in parenthesis are t-statistics.
Signficance levels based on two-tailed test.
* Significant at 1% level.

APPENDIX K

Equation III Estimates: Level of Technical Efficiency Explained by Management Practices of Farmers Relative to Management Practices of Most Efficient Farmer

Variable	Estimate
DT56	0
	(0.618)
DF56	0.016****
	(1.563)
DI56	-0.004
	(-1.136)
Intercept	0.493*
	(10.981)
Adjusted R^2	0.00
F Value	1.003

Note: Figures in parenthesis are t-statistics.
Significance level based on two-tailed test.
* Significant at 1% level.
**** Significant at 20% level.

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