AN ABSTRACT OF THE THESIS OF

Ariel Cajina for the degree of Master of Science in Agricultural and Resource Economics presented on April 29, 1981

Title: The Ex-ante Introduction of a Chemical Weed Mulch Weed Control System in the Atlantic Plain of Nicaragua

Abstract approved: Stanley F. Miller

The South Atlantic Region of Nicaragua, similar to the North Atlantic Region of Costa Rica, is an alluvial plain, with fairly good soils and an extremely wet and warm climate. The physical and climatic characteristics of the zone cause serious control problems with weeds.

The International Plant Protection Center (IPPC) of Oregon State University has been working in the North Atlantic Region of Costa Rica since 1976 developing alternative methods of weed control. From its research, IPPC is recommending a chemical mulch to control weeds for small farmers. In an attempt to determine the boundaries of acceptability for the new control procedure, IPPC is evaluating the technology in two different environments. The first is an environment which is ecologically different (same economic setting but much drier) than the North Atlantic Zone of Costa Rica. The second is a zone which is economically different (same ecological environment but a different economic setting). This study reports on the second effort.

A survey was conducted in the South Atlantic Region of Nicaragua (PRICA) in August of 1980. A stratified sample of 42 farmers were interviewed. Information was obtained about the input-output relationships of corn production, economic resource availability, crop income,

off-farm income, size of the family, consumption characteristics of the family, and different techniques used by farmers to control weeds in corn. Secondary data were obtained from private and government Nicaraguan institutions as well as from several manuscripts that describe the research done by IPPC in the North Atlantic Region of Costa Rica.

The quantitative information from the South Atlantic Region of Nicaragua survey was tabulated and stratified in three groups according to the post plant weed control methods practiced by the farmers. Each group represents a major traditional weed control technology.

The author obtained quantitative information from IPPC experience on the new weed control technologies in the North Atlantic Zone of Costa Rica. This information was assumed to represent the new weed control technology if it were introduced into the South Atlantic Zone of Nicaragua.

The four weed control technologies were evaluated under different availabilities of farm resources, by use of a linear programming production function convex-approximation model.

To establish the base for comparison, optimal plans of corn production were obtained by using traditional weed control technologies. Then, the new weed control technology was incorporated into the model, and optimal plans obtained. Finally, both plans--traditional and traditional with new weed control technology under similar resource availabilities are compared by several performance measure use intensities.

It was found that the new weed control technologies are potentially beneficial to PRICA corn growers. Net farm income and net cash income as predicted by the model is increased with the adoption of the new technology. When capital is a production constraint and there is only one family worker, the adoption of the new technology will greatly reduce the use of hired labor but this adverse effect is mitigated through the use of more capital in production. When two or three family workers are available on the farm and capital is a constraint, the adoption of the new weed control technology will induce the use of more family labor. When the capital constraint is released, even more family labor is used. No major changes in hired labor occur since an adequate supply of labor already exists on the farm.

Risk aversion as used in the model has a substantial effect on the results. Its influence was more marked when only traditional control technologies were considered than when both traditional and new technologies were evaluated.

The Ex-Ante Introduction of a Chemical Weed Mulch Weed Control System in the Atlantic Plain of Nicaragua

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THE EX-ANTE INTRODUCTION OF A CHEMICAL WEED MULCH WEED CONTROL SYSTEM IN THE ATLANTIC PLAIN OF NICARAGUA

I. INTRODUCTION

An increasingly widening disequilibrium exists in the welfare of the rural populations between and within rich and poor countries. Output per hectare in lesser developed countries has increased slightly but output per worker has experienced no measurable change in decades. The result has been that food output per person in many areas is little changed from that of 50 years ago. This is especially true for small farmers in many parts of Central America.

In order to overcome the low productivity of small farm agriculture in Central America, it is imperative that more effective agricultural production technology be developed. Improved weed control has been suggested as such a technology. This has often taken the form of substitution of herbicides for traditional weed control techniques.

But the introduction of new weed control technology in the form of herbicides on small farms in developing countries is the subject of considerable controversy. On one hand, herbicides possess the physical characteristic of being size neutral (easily divisible), with the possibility of decreasing the costs of production, and in some cases increasing total output. On the other hand, the use of herbicides is potentially one of the most labor-saving innovations in agriculture, with the attendant possibility for causing severe social dislocations in labor surplus economics.

Previous studies have suggested that in labor abundant areas with few employment alternatives and poor ecological conditions for plant growth, agricultural scientists should stress the development of labor, using yield increasing types of technology, i.e. varieties, low cost irrigation, techniques, improved manual and animal powered weed control techniques. Less attention they report, should be given to developing and promoting labor displacing technologies such as herbicides.

Not all the developing world, however, is so deprived. There are many areas with a large apparent untapped agronomic potential. And in certain areas this is coupled with increasing labor shortages, especially during certain peak periods. One such area is the North Atlantic Zone of Costa Rica (NAZ)

Work conducted since 1976[1/] by the International Plant Protection Center (IPPC) suggests that in the North Atlantic Zone of Costa Rica the use of herbicides in a no-till, chemical mulch, weed control system for corn is likely to be adopted. The no-till system is not only economically efficient in the use of agricultural inputs, but is also ecologically compatible with the steep tropical soils on which a considerable amount of production occurs in Central America. Erosion control is greatly enhanced by use of the system in comparison to the slash and burn or tilled production systems presently utilized.

While the system appears promising on the North Atlantic Zone of

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1/ In June 1976, an agreement was signed between CATIE (Centro Agronomico Tropical de Investigacion y Ensenanza) and IPPC in which Oregon State University and CATIE agreed to work cooperatively in developing cropping systems for small farmers. The principal objectives of IPPC's research programs were:

1. Compare weed management practices now used by farmers with newly developed techniques to assess: (a) the economic feasibility and returns to small and medium sized farmers, and (b) the incentives for adoption of the techniques.
2. Evaluate the probable socioeconomic effects of new weed management systems which are estimated to be more economically efficient than existing practices, by comparing economic efficiency gains or losses involving rural employment and redistribution of income.

Costa Rica, it may not be acceptable in different ecological or economic settings. Therefore, the technology is now being tested in two different zones: one which is ecologically different (same economic setting but much drier) and the second which is economically different (same ecological environment but a different economic setting). This study reports on the second effort.

Objectives of This Study

Specifically, the purposes of this study are:

1. To determine the existing weed control techniques for corn in the Atlantic Plain of Nicaragua.
2. To evaluate the likelihood of adoption of weed control technology for corn by small farmers on the Atlantic Plain of Nicaragua.

Since risk aversion is thought to be a characteristic of small farmers, the role it plays in technology adoption is important. Therefore, an additional objective is:

3. To determine the effect of risk aversion upon the likelihood of acceptance of the proposed weed control technology.

Outline of This Report

Selected literature on the efficiency of traditional agriculture, the necessity of introducing new, more productive technologies as viable ways to increase productivity of traditional agriculture, the nature of such new technologies, and the welfare impacts caused by the adoption of such technologies with emphasis in weed management studies carried in lesser income countries are presented in Chapter II.

Chapter III provides the historical development and discussion of the proposed new weed control technology developed by the International Plant Protection Center for the North Atlantic Zone of Costa Rica.

The data bases used in this study are given in four main sections in Chapter IV. The first section summarizes the survey procedures at Projecto Rigoberto Cabezas (PRICA) and the different data sources. The second section shows a general comparison of the physical, climatic, economic, and social characteristics of the two study areas in Costa Rica (NAZ) and Nicaragua (PRICA). The third section summarizes the information about corn production obtained in the PRICA survey. To some extent, this information is also compared with the respective one of NAZ. The fourth section presents additional assumptions and technical coefficients used in formulating the empirical linear programming model used in this study.

The structure of the linear programming model used in this study are given in Chapter V. Model validation and study results both under traditional and improved methods of weed control are presented in Chapter VI. The limitations of this study and some suggestions for further analysis are stated in Chapter VII. Finally, Chapter VIII presents the summary and conclusions of this study and some implications for further studies.

II. LITERATURE REVIEW

Fundamental economic issues dealing with technological change are reviewed in this chapter. Technological change, it will be argued, is a predecessor of economic development for traditional agriculture. In this chapter, some characteristics of the traditional sector are discussed. Then, a description of alternative paths of technological development based upon the induced innovation model is presented. Further, the causes and welfare impacts of technological change are discussed. Finally, the role of risk in selecting appropriate technologies is presented.

Characteristics of the Traditional Sector

In explaining the nature of traditional agriculture, the hypothesis that "small farmers in traditional agriculture are economically efficient in allocating the factors of production" has been controversial. On one hand, some economists (Heady and Dillon, 1961; Randhawa and Heady, 1964) have postulated that farmers could increase their income by combining their resources differently. That is, too many farmers combine factors of production on the basis of tradition rather than economic efficiency. A realignment could lead to increased production, they argue.

On the other hand, other economists (Hopper, 1965; Shultz, 1964; Hayami and Ruttan, 1971; Binswanger et. al., 1978) have argued that traditional farmers are good decision makers, given their knowledge and resources. Hence, this group of economists have hypothesized that reallocation of the factors would not appreciably increase income. They have already combined the factors of production so that the marginal value product of resources are equal in different enterprises and are equal to their marginal cost. This second position is now more widely accepted than the former (Mellor, 1969) and recently has been supported by the research of Hayami and Ruttan (1971), Stevens et. al. (1972) and Binswanger et. al. (1978).

Some empirical evidences that supports the hypothesis that farmers are good decision makers exist. Examples are: (1) several Extension Service and community development programs which have been undertaken to help farmers make the "right production decisions" have failed to increase production and, hence, have been abandoned after several years of implementation (Shultz, 1964) and (2) credit programs undertaken to combat capital shortages in traditional farming have resulted, to a large extent, in low repayment rates (20 to 70 percent) (Stevens et. al., 1977).

Accepting the hypothesis that traditional farmers are good decision makers, and that simple recombination of factor of production will not result in appreciable income increase, a strategy has been suggested for the development of traditional agriculture. It focuses on making economic, social, technical and institutional changes based on the development of locally tested agricultural technologies which are more profitable to small farmers and provide higher rates of return to investment in agriculture (Shultz, 1964; Hayami and Ruttan, 1971; Ruttan, 1976; Binswanger et. al., 1978). To do so, several development strategies[1/] have been proposed. Among them, "the induced innovation model" proposed by Hayami and Ruttan (1971) appears to be the most consistent with the actual situation of the lesser income countries.

[1/] Such development strategies are known as: (1) the frontier, (2) the conservation, (3) the urban industrial impact, (4) the diffusion, and (5) the high payoff input model.

Induced Innovation Model

The "induced innovation model" is a model of agricultural development in which technical change is treated as endogenous to the development process, rather than as an exogenous factor that operates independently (Hayami and Ruttan, 1971). In the "induced innovation model", an efficient new technology will facilitate the substitution of relatively abundant factors for relatively scarce factors of production. Such technology-embodied in new crop varieties, new equipment, or new production practices, in some cases, may not substitute for factors of production by themselves, but rather serve as catalysts to facilitate the substitution of the relative factors (Ruttan, 1976).

Alternative Paths of Technological Development

Relatively speaking, technologies may be labor-saving, land saving, or capital saving (Bier et. al., 1972; Donalson and McSnerney, 1973; Gotsh, 1972; Hayami and Buttan, 1971; Ruttan, 1976). Which is concerned is a function of which resources are the most plentiful. The most plentiful, economically speaking, should be used while conserving the most scarce. A technology to be adopted must: (1) reduce cost while maintaining output, (2) increase total output while maintaining costs, or (3) increase both costs and output but output (gross income) increasing at a faster rate.

According to Ruttan, there are basically two kinds of new, improved technology generally available to agriculture: mechanical technology which is by and large labor-saving and biological technology which is land-saving (Ruttan, 1973). The primary effect of the adoption of mechanical technology is to facilitate the substitution of mechanical or animal power for human labor, allows each worker to extend his efforts over a larger land area. The primary effect of adoption of biological technology is to facilitate the substitution of labor and industrial inputs for land. Price, of course, is the motivation for change. In the United States, the wage rates, relative to the price of land and machinery, encourage the substitution of land and power for labor. While in Japan, the supply of land was inelastic and its price was much more expensive relative to wages than to other commodities. It was not therefore profitable to substitute power for labor.

Instead, the opportunities were to develop a new biological technology which constituted varietal improvement toward the selection and breeding of more fertilizer-responsive varieties of rice. "The enormous change in fertilizer input per hectare that occurred in Japan since 1880 reflects not only the effect of the response by farmers to lower fertilizer prices, but the development by the Japanese agricultural research system of fertilizing consuming rice varieties in order to take advantage of a decline in the real price of fertilizer" (Ruttan, 1976).

Labor-Saving Technologies

If the ratio of capital to labor employed in production rises when a new technology is introduced, it is called a labor-saving/capital-using technology.

The above arguments can be seen in Figure II-1. In Figure II-1, the isoquant Y_0 represents the corn output of a typical small family farm under "traditional weed control technologies". Given the prices (opportunity costs) of labor and capital, the equilibrium production position with respect to weed control capital and labor inputs is shown at a. Assume a "labor-saving" technological change in the form of herbicides represented by the isoquant where $Y_1 = Y_o$ then the most efficient capital/labor combination shifts to b. The economic incentive for this new technology to be adopted is apparent by the lowered production costs. At the equilibrium point b, $M_2 - M_1$ units of labor are released and $T_1 - T_2$ units of capital are increased to produce the same level of output. However, if labor is a production constraint, and more land and capital are available for production, it is possible to get a higher isoquant (Y_2) by utilizing the released labor units to expand production. To move from b to c, in Figure II-1, implies that the usage of other factors of production which are not included in the discussion have to be increased, i.e., land. As a consequence, a labor-saving technology per unit of land may actually use more total labor if the size of the farm can be increased.

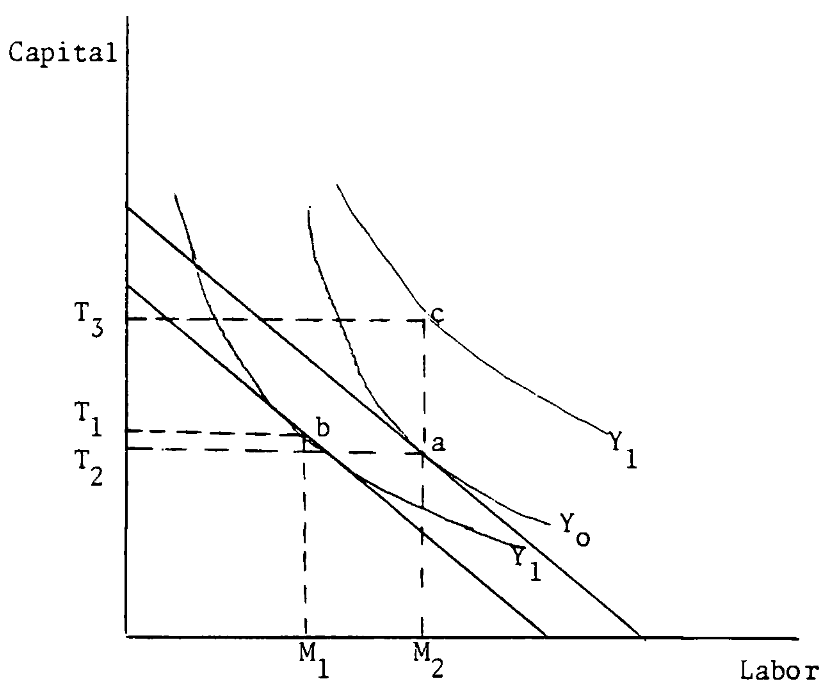

Figure II-1. Incentive to the adoption of a labor-saving technology.

Land-Saving Technologies

In contrast to labor-saving technologies which substitute capital for labor but does not change the physiological outcome of the plants or animals to which "it was applied", land-saving technologies embodied in biological innovations increases both total output and total costs (per unit of land)(Bieri et. al., 1972; Donalson and McInerney, 1973).

As total output per unit of land increases, the output/land ratio will increase. As a consequence, to produce a specified level of output, less land will be required. In order to achieve higher levels of output per unit of land, the usage of other variable inputs such as fertilizer, new seeds and breeds, pesticides and insecticides, irrigation, etc. has to be increased. In addition, the application of such inputs will induce the usage of more labor, so that the effects of biological inputs are likely to be land-saving, and labor-using.

Market Distortions

The path of development for which a new efficient technology has been developed can be easily changed due to market distortions and government policy. Hence, it will be considered here.

Factor price distortions, or other forms of government interventions influence the private profitability of a new technique which may not be socially efficient when evaluated at the true social values of the utilized resources (Miller, 1977). For instance, it is shown in Figure II-2 that market distortions lead to different input usage than would be socially desirable to produce a given level of output. In the hypothetical relationships, isoquant Y_0 represents a frontier of technically efficient capital - labor combinations used to produce a

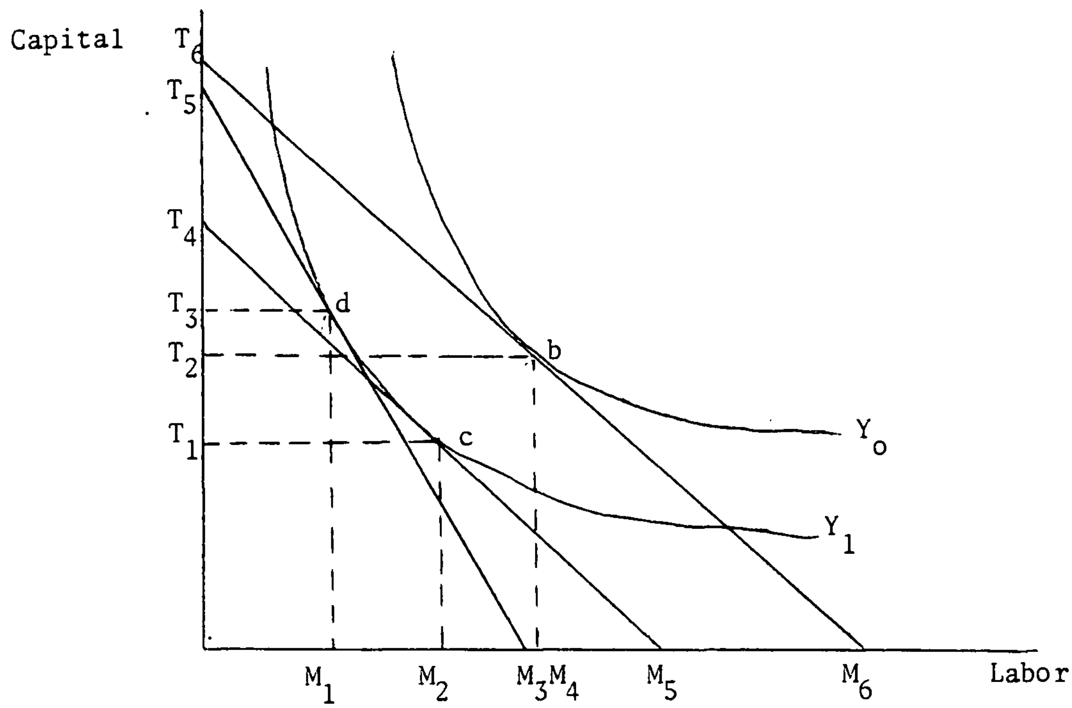

Figure II-2. Market distortions as cause of technological change.

given level of output with a given technology. The capital/labor social price ratio is reflected by isocost line T_6 M_6, which reveals that M_4 units of labor and T_2 units of capital is the most efficient combination of inputs required to produce Y_o from the perspective of the entrepreneur and society. If a factor neutral technology[2/] is introduced to produce the same level of output (Y_1) but using less inputs, T_1 units of capital and M_2 units of labor will be required if the capital/labor price relation remains as above. On the other hand, if the government subsidizes capital inputs, the isocost line increases its slope. Then, M_1 units of labor and T_3 units of capital will be required to produce the same Y_1 units of output. In other words, $\frac{OT_3}{OM_1} > \frac{OT_1}{OM_2}$. Thus, government interventions can transform neutral technologies into non-neutral technologies. The effects could be efficiency losses for society and are discussed in the following section.

[2/] A new technology is factor neutral only if it does not impinge differentially on the productivities of different factors.

Welfare Impacts of Technological Change

Welfare impacts associated with types of technological change can be either efficiency or distributional changes (Miller, 1977).

Efficiency Changes

Changes in efficiency are reflected in the resource cost of producing a given output to society. In measuring efficiency changes from technological change, two different approaches have been used by researchers. They are: (1) the research cost and social return obtained from the introduction of a new technology in production (Griliches, 1958; Ayer, 1972), and (2) the margin between the private and social costs of producing a given level of output, such margin is usually called "welfare efficiency losses".

Lowering of production costs benefits society--either consumers, producers or both. The diffusion pattern of a new technology determines the distribution of the Schumpeterian profits[3/] or losses within the farm sector (Bieri et. al., 1972). Namely, early adopters of new technologies have been principally large farmers and comparatively wealthy entrepreneurs. Large farmers tend to have easier access to capital markets, information, and education--particularly in less developed countries where these three factors typically are in limited supply, and hence, are not allocated among firms through market forces. This permits large farmers to reap profits by using new technologies and in some cases, by buying more land and displacing less favored farmers.

[3/] Schumpeter says that profits, in a dynamic framework, are obtained for monopolistic positions which are temporarily obtained by early adopters of a new technology.

Welfare Efficiency

Welfare efficiencies are generally related to the margin created between social and private costs due to the presence of market distortions. Exogenous market forces that increase the efficiency of a new agricultural technology have affected the distributions of welfare gains both within the farm sector and among the related sectors of the economy (Miller, 1977). For instance, in Figure IV-2, the government subsidies will waste $T_3 - T_1$ units of capital, and will withdraw $M_2 - M_1$ units of labor from production.

Fonollera (1977), using a linear programming model to evaluate market distortion effects in weed control technology adoption in El Salvador, found that correcting input-output price for market distortions was not sufficient to induce change in weed control technology in small and medium farm enterprises. The privately efficient and socially efficient system for all selected enterprises was the same (manual control). However, Fonollera, in the same study, found that the capital-labor substitution on the large farms was sensitive to distorted wage rates and to direct and indirect government subsidies on capital inputs. To a certain extent, these results confirm the framework stated by Bieri et. al., that market imperfections favor primarily large farmers, who also are the earlier adopters of new technologies.

Young (1977), studying the effects on social private costs of weed control in a sugarcane plantation in Northwest Brazil, found that when factor price distortions are introduced, the social and private costs of weed control are no longer equivalent. The social costs of weed control generally exceeded its private cost because plantations did not bear the full social cost of the subsidized chemical weed control systems. The distortions biased the choice of weed control technology away from the socially optimal pattern and consequently resulted in a greater resource expenditure to achieve the same level of weed control. These increased social expenditures are a measure of the efficiency losses attributable to the government interventions in factor markets.

Distributional Changes

Distributional changes refer to the distribution of welfare benefits and costs among different groups in society, and how these changes relate to society's broad equity goals (Miller, 1977). The distribution of welfare gains from technological change depend critically on the farm firms and the input suppliers to these firms (Bieri et. al., 1977). The distribution of personal income and power will be the result of: (1) the characteristics of the technology in the agricultural sector, (2) the distribution of institutional services, and (3) the distribution of productive assets, which together produce an estimate of the marketable surplus available from the rural community and a measure of the personal distribution of income. The latter, together with the nonwealth attributes of local customs and traditions, result in the distribution of personal income and power (Gotsch, 1972). Then, personal income is fedback to further capital accumulation and better institutions that serve rural communities.

As a result, the availability of savings for acquisition of additional assets depends upon the absolute surplur of the larger farmers and not of their relative position. Hence, large farmers will tend to acquire scarce resources, particularly land, even though the new technology was perfectly divisible and labor-saving. Additionally, if the distribution of income is affected by technological change, a conflict will be created between those who have and do not have access to the technology. If the latter try to create new institutions, they will be opposed by those currently in power (Gotsch, 1972).

Finally, one cannot say whether technological change, regardless of the sector in which it occurs, is beneficial or detrimental to society. All can be made better off only if appropriate redistribution policies are implemented (Bieri et. al., 1972).

The Role of Risk in Selecting a New Technology

There is strong evidence to suggest that farmers are rational when confronted with economic choices, i.e., they tend to accept the economically superior alternative. Unfortunately, too often new technologies lack sufficient economic incentives for farmers to adopt them. The identification of economically viable technologies is a long and arduous task.

The slow process of adopting supposedly superior technologies by small farmers can often be traced to the basic fact that there was insufficient incentive for adoption. The question of how much better a technology must be before farmers adopt it has received insufficient research and remains unanswered.

But another factor must be considered in assessing the appropriateness of technology-risk. Under perfect knowledge, profit is the difference between total revenue and total costs. But perfect knowledge is seldom available. Small farmers' decisions, some have argued, are based upon expectations of occurrences[4/]. The decision making

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4/ A number of anthropologists question whether farmers can effectively use probabilities. They argue that risk does not constitute a major factor to technology adoption. Failure to understand non-monetary values, they argue, is the basis of failure of many technologies.

space is bounded by results which are subject to probability of occurrences which are, in turn, translated by producers into probabilities of loss (Escobar, 1978). In this view, the profit maximization level of production is unknown and hence resources must be allocated according to producer's perception of expected revenue. Therefore, risk associated with production not only will alter the producer decision making process, but also the producer objective function, which dictates all decisions regarding production activities (Escobar, 1978).

This is a very important point when one analyzes small farmer's economic rationality. Several studies have concluded that the adoption of a new more efficient production technique by small farmers may be impeded by risk aversion (Brink and McCarl, 1978; Goodwin et. al., 1980).

There are many sources of risk, but the following are likely to be the most relevant:

(1) Farmers have difficulties in estimating the return from new alternatives. This happens because farmers do not know the return of a given new alternative under different states of nature, i.e., variation in weather, pest population, etc.

(2) Lack of information about the proper use of a new technology. Additionally, new technologies, intrinsically, involve uncertainty since they represent change which needs to be inserted into the production process. Farmers may wrongly perceive the distribution of the returns for new alternatives. Therefore, risk aversion and risk misperception are both potentially important in the acceptance of a new technology (Goodwin et. al., 1980). The institutional sector, experimental stations and government institutions play important roles in the process of adoption by reducing risk misperception at the farm level.

Summary

It has been shown that economic development can occur through induced technological change. But such technologies are not neutral in terms of factor usage nor in terms of government policy. Each potential technology must be carefully assessed to identify real gains and losses. Such an assessment tends to be more complete when risk is endogenously considered in the analysis.

III. DEVELOPMENT OF A PROPOSED WEED CONTROL SYSTEM IN COSTA RICA

In this chapter, first, a brief description of the origin and objectives of IPPC research in the North Atlantic Zone of Costa Rica is presented. This is followed by a justification for doing research in weed control techniques are presented. Further, a description of IPPC recommended weed strategy adequate for controlling the types of weeds which are more frequent in PRICA corn plots is presented. Finally, the plans for further adoption of the recommended IPPC weed control technologies under different situations is presented.

Origin and Objectives

The International Plant Protection Center (IPPC) of Oregon State University was invited to participate in the Small Farmer Cropping System Program of the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE) in Costa Rica in 1976. The program had as an objective the development of alternative cropping systems for traditional farmers in Central America. The specific mandate of IPPC in the program was to identify alternative weed management systems for the major food crops, and to evaluate the proposed technologies in terms of projected adoption potential, rural employment, and distribution of income effects. The project work area selected for the initial studies by IPPC and CATIE was the North Atlantic Zone of Costa Rica.

Site and Justification

The North Atlantic Zone of Costa Rica is part of the "llanos del Atlantico" (Atlantic Plain) which extends from Northern Nicaragua to

Southern Costa Rica, all along the Atlantic Coast. It has a warm, humid climate with high annual rainfall (3 to 4 meters) and relatively good soils. Since the physical and ecological characteristics are common all along the Atlantic Plain, a complete description of these characteristics will be reserved for Chapter III.

Agronomists and economists working jointly in Costa Rica accumulated a large amount of survey and experimental data. They learned that corn is the primary food crop and is a staple as well as being sold in the market. Weeds constitute a major production problem in corn. A zero or minimum tillage system of production is generally employed by small-scale farmers, often the traditional slash and burn system. But an unexpected high percentage of the farmers in the North Atlantic Zone use herbicides to kill existing vegetation, which is followed by planting with a dibble stick.

Further, they learned that weed control constitutes up to 60 percent of cash costs. The higher percentages were where aggressive perennial weeds predominate. Furthermore, more than 50 percent of the total weed control costs occurred prior to planting as land is cleared.

The weed complex can change over time, which in turn affects the costs of land preparation. On new land after the original clearing of marketable timber, broadleaf weed species predominate, but grasses soon follow. The high annual rainfall and high temperature favor the establishment of aggressive species, perennials such as *Panicum maximum*, *Paspalum fasciculatum*, *Paspalum paniculatum*, and annuals such as *Rottboellia exaltata* and *Digitaria* sp.

Weeds generally are cut three times by hand with a machete during the corn growing season with the residue left on the ground as a permanent mulch. The first cutting of standing weeds (in preparation for planting) is 10 to 13 cm. Then, corn is planted in rows through the mulch layer with the aid of an "espeque" or jab planter which pokes holes through the mulch and into the soil, into which the seed kernels are dropped and covered by foot. Weeds are cut a second time during the corn growing season so corn plants can stay above the weeds. A third cutting occurs just prior to or during the "doubling" of corn stalks at harvest time (doubling simultaneously dries and provides storage). Doubling minimizes disease and insect infestation in the corn ears and facilitates field drying (McCarty, 1979).

Many of the farmers experiment with herbicides in an attempt to improve weed control costs. They apply small amounts of apparently random mixtures of paraquat, diuron and 2,4-D. This experimentation, it is believed, stems from the rather general use of these chemicals in banana, coffee, and sugarcane plantations to control weeds. A few farmers also hire custom plowing and use fertilizer.

After reviewing the accumulated data, the IPPC team focused on zero or minimum tillage systems in an attempt to relieve the land preparation bottleneck. A series of experiments were conducted during the period 1976 to 1980 which led to several weed control recommendations that appeared to be both agronomically and economically sound.

The IPPC weed control recommendations were modified depending upon the weed populations and the availability of mechanical power. Since mechanical power is not available in the study area and annual weed species predominated in the corn area, two IPPC recommendations, it was believed, are appropriate for PRICA. The following summarizes these recommendations.

Alternative 1: At planting, cut weeds to ground level. From 20 to 25 DAP[1/] apply paraquat directed with shield (0.2 kg/ha).

This treatment eliminates "effective weed competition". Weeds germinating after 20 to 25 DAP will not affect yield. However, in case of significant regrowth, a second application 40 to 45 DAP will improve the aesthetic aspects of the field and leave it in better condition for harvest and planting the following crop. Manual weedings can replace paraquat if labor is available.

Alternative 2: Apply paraquat (0.4 kg/ha) over the standing vegetation one to two days before planting. A second application of paraquat (0.2 kg/ha) 20 to 25 DAP is made using a spray shield.

Manual weeding can be used if available, but experience has shown that this results in the germination of more weeds than when paraquat is used.

Plans for Further Adoption

An attempt is presently being made in Costa Rica to monitor the adoption of the new weed control technologies. Selected farmers will be taught the systems and provided needed inputs for demonstration trials on their lands. Three treatments will be tested: (1) the farmer's weed control practice, (2) the proposed weed control technology, and (3) the proposed weed control technology plus CATIE recommendations on fertilizer use and insect control.

Farm records will be maintained on a bi-weekly basis for all farm and household activities and consumption. After the first season these farmers will determine for themselves the appropriateness of the

[1/] Days After Planting.

technology. During the second season, through farm visits, a record will be obtained of their unsubsidized acceptance, rejection, or modification of the technology.

The question of whether the proposed weed control technologies introduced in Costa Rica might be adopted for different economic environments led to this study in Nicaragua. While the Atlantic Plain is ecologically homogeneous, it is divided into two countries with different rates of economic development--Costa Rica and Nicaragua (see Table IV-1). Prices both for agricultural products and inputs, including corn and labor, are considerably higher in Costa Rica than in Nicaragua. While cereal yield increased during the period 1969 to 1971 compared to the period 1975 to 1977 by an annual percentage of 2.8 in Costa Rica, it declined over the same period in Nicaragua by 0.1 percent. Thus, the acceptability of the new weed control technologies in the Nicaragua setting was not immediately apparent.

Table IV-1. Selected Economic Indications for Costa Rica and Nicaragua.

Population (millions) 1979	2.2	2.5
Population in Agriculture (%) 1977	37	45
GNP per capita ($) 1976	1.130	770
GNP growth (%/yr) 1970-76	3.0	2.5
Cereal yield (t/ha) Aug. 1975-77	1.8	1.1
Annual change: cereal yield (%) Ave. 1969-71 vs 1975-77	2.8	-0.1
Fertilizer Consumption (kg/ha) 1976	114	30
Tractor density (number/1000 ha) 1976	12	0.9

Source: International Agricultural Development Services.

IV. THE STUDY AREA: BACKGROUND, DATA BASE AND GENERAL ASSUMPTIONS UNDERTAKEN TO FORMULATE THE LINEAR PROGRAMMING MODEL

In the two previous chapters, the theoretical framework and the development of the improved weed control technology used in this study as more efficient technological process were presented. In this chapter, a general description of the areas involved in this study, the data base-information obtained in the survey about corn production and assumptions undertaken to formulate the linear programming model are given. Before proceeding, the sample procedures and data sources used for this study are discussed.

Sample Procedures and Data Sources

To realize the objectives of this study, an ecologically similar area to the NAZ was needed. It was hoped also that such an area would have a different economic environment, and previously limited exposure to modern weed control techniques. The Atlantic Plain of Nicaragua was identified as having the desired characteristics. The Rigoberto Cabezas Project (PRICA) within the Atlantic Plain became the specific study area.

A cross-sectional survey of farmers together with secondary data from government and private institutions, constitutes the Nicaraguan data. This is compared to IPPC data from NAZ.

Primary Data

A cross-sectional survey of 42 small farmers was taken in the PRICA area. The questionnaire used was designed to obtain information about input-output relationships of corn production, economic resource availability, crop income, off-farm income, size of the family, period of residence of the farmer in the PRICA area, and different techniques used by the farmers to control weeds in corn.

The survey was conducted during August and September of 1980. Farmers were interviewed in 14 of the 27 different colonies on the project.

Selection of the Sample Farmers

Cluster sampling was employed in the collection of the data. It was hoped at the outset of the study to obtain interviews with three to four farmers in each of the PRICA colonies that are accessible by vehicle during the rainy season. However, this was not totally possible since several farmers interviewed in one colony had their plots of land in nearby colonies. Also, because of time and transportation constraints, only one day was allowed to each colony. It was impossible to return if insufficient numbers of farmers were available during the alloted time.

Travel to the farmers was by public transportation to Nueva Guinea. Instituto Nacional de Tecnologia Agropecuaria (INTA), through its experimental station at Nueva Guinea, provided transportation facilities to survey the more distant colonies and to collect some surveys along the different roads.

On an average survey day, one farmer was interviewed early in the morning (when the farmers were preparing to go to their plots). Another farmer was interviewed between 9:00 am and 3:00 pm (it was difficult to find farmers at home at this time since most of them were out working). And, two farmers were interviewed after 3:00 pm (after they had returned from work).

Farmer interviews were in Spanish. From the 42 interviewed farmers, only two had written records of production. The remaining farmers (40) provided information by recall. Since the farmers expressed high interest in the survey, it is assumed that the data obtained from them are reliable and adequate for this study.

Location of the Sample Farmers

Forty-two small farmers were interviewed in 14 colonies of the PRICA project. Three farmers were interviewed in Yolaina, four farmers in Serrano, one farmer in Carlos Fonseca, three farmers in Verdum, two farmers in Nueva Guinea, two farmers in Los Angeles, three farmers in Nuevo Leon, four farmers in La Esperanza, four farmers in Ruben Dario, four farmers in Benito Escobar, four farmers in Providencia, three farmers in Blanca Sandino, three farmers in San Antonio and three farmers in Jersalen.

Secondary Data

Since no experimental research results on new weed control technologies were available in the area, experimental results from the NAZ were used to estimate the production and cost effects of the new technology.

As stated in Chapter III, agronomists and economists worked jointly in the NAZ of Costa Rica. Several manuscripts are available describing this work. The most important, as far as this study is concerned, is a Master of Science thesis written by Thomas V. McCarty, "The Agronomic, Economic, and Social Effects of the Availability of New Weed Control Treatments to Small Corn Farmers in the North Atlantic Zone of Costa Rica". It is used to establish the NAZ base to compare agronomic and institutional characteristics of PRICA and NAZ.

Other sources of secondary data are the following: Prices for different types of herbicides used in the NAZ and available in the Nicaraguan market were obtained from private institutions. Data concerning corn prices, soil and climatic characteristics of the area, credit availability and general information about the PRICA project were obtained directly from the Government of Nicaragua (GON) institutions. PRICA farmers provided information about farm gate prices and ENABAS (Empresa Nicaraguense de Alimentos Basicos) quoted current corn prices at the retail level. The credit situation of the surveyed farmers was obtained from BND (Banco Nacional de Desarrollo). Soil and climatic characteristics of the region were obtained from an INTA experimental station at Nueva Guinea and general information about the PRICA project was obtained from INRA (Instituto Nacional de Reforma Agraria).

Background of the Areas Involved in this Study

In this section, the general characteristics of the study area, PRICA, are presented, with a comparison of these characteristics with those of NAZ. It is presented to show the comparability of the two areas and thus support the hypothesis of direct transfer of IPPC technology.

General Information

The PRICA is located in the south of the Atlantic Plain of Nicaragua, about 200 kms southeast of Managua. It was established in 1965 by the GON as a small farmer resettlement project. Fifteen small farmers with their families were transferred from other regions of the country to an area of public lands located in the wooded Atlantic Region.

Shortly after transfer of the first peasants, there was a major migration of landless peasants and small farmers to the area. The migration forced the GON to develop a method of handling the unplanned growth. A feasibility study for the settlement of small farmers in the original area of 397,682 (has) was conducted by the GON with financial support of the International Bank of Development.

From the information gathered in the feasibility study, it was decided to implement the project in several phases with first two sites being PRICA I and PRICA II (January 1968). The land was distributed by site as follows:

	Area (has)	Percent
Phase I (PRICA I)	55,634	14
Phase II (PRICA II)	76,972	19.6
Other Phases	265,076	66.4
Total	397,682	100.0

Now after 15 years, there are more than 3,000 farm families living in the entire project, distributed in 27 colonies (INRA, 1980).

The small farmer sector of NAZ has a similar origin to PRICA. The majority of small farmers who are farming in the NAZ have moved to the region from other parts of Costa Rica as a result of a government program that provides 20 hectare plots for homesteading (McCarty, 1979).

Population

The total population of PRICA is calculated to be 15,000 inhabitants, and the population density is 15.6 inhabitants per km^2 (INRA, 1980). The people live within the villages of the different colonies. Each farmer has a plot of land near the village where he lives. Rarely do farmers live on their land. Each colony village is five to 15 km

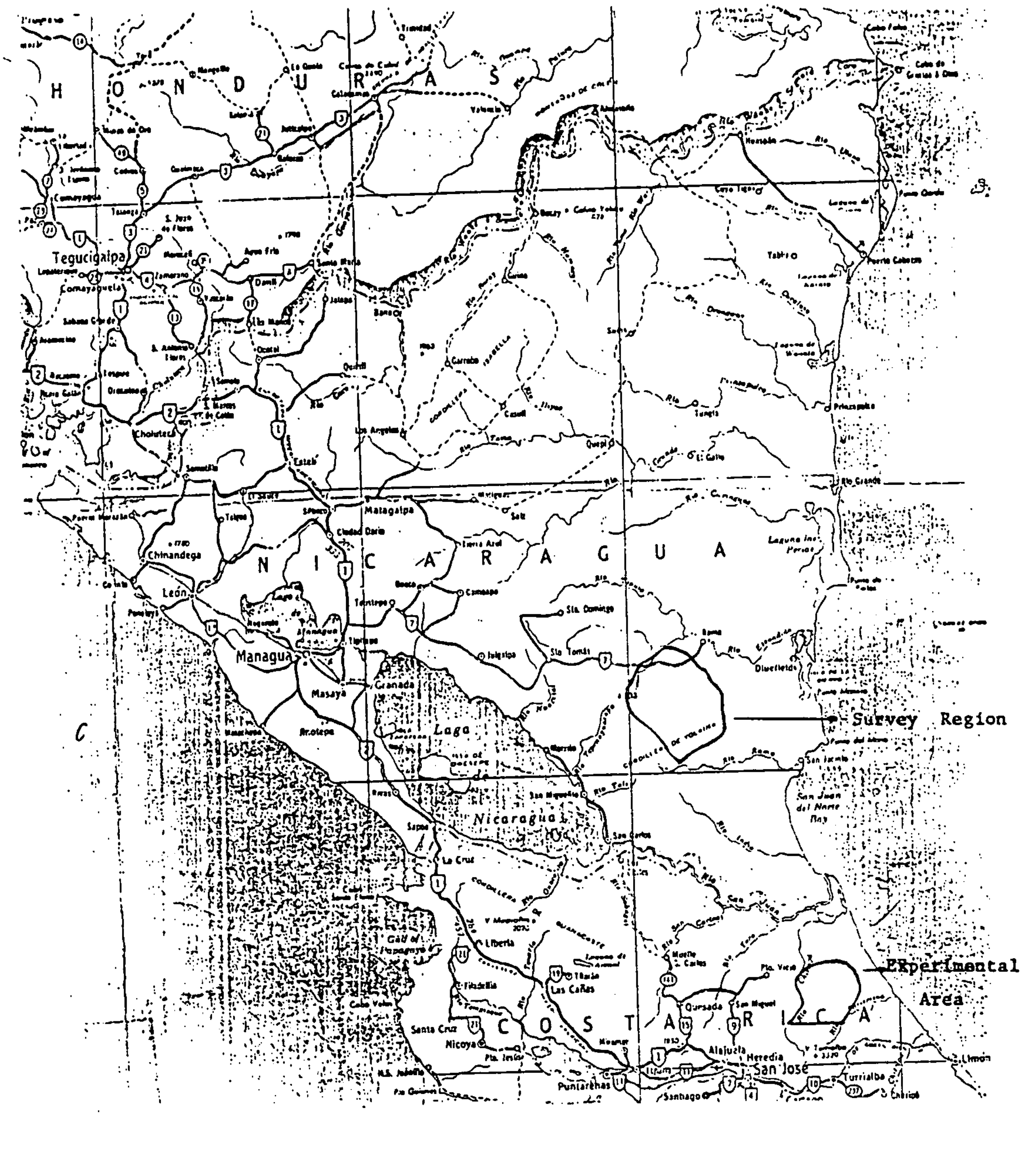

Figure IV.1 Size and position of the survey region with respect to the whole Nicaragua and experimental area in Costa Rica.

from the neighboring colony and has approximately 100 families. The total population of the NAZ is 36,000 people with a density of 42 inhabitants per km^2.

In the sample of 42 farmers, the household includes an average of 7.6 persons, 2.2 of whom are workers at the farm unit. The smallest household includes three persons and the largest 13. In the NAZ, the average household includes about eight persons, two of whom did the farm work. The smallest household includes two members and the largest 16 persons (McCarty, 1979).

Organization of the PRICA

The project has been reorganized several times by controlling government institutions. The last one was in June 1980. It combined the colonies in four sub-seats, mainly to facilitate the process of providing technical advice to farmers (see Table IV-1).

General Infrastructure

An all-weather road connects PRICA with the Nicaraguan capital, Managua, and subsequently with the rest of the country. Within PRICA's area there are approximately 150 km of dirt road, passable during most of the year, and 300 kms of roads usable only in the dry season. The colonies which have access to all weather roads are identified in Table IV-2. Also, there is a hospital, three schools in Nueva Guinea (the main colony village) and one school in each of the other colonies.

School and health facilities are equally available in the NAZ. The Costa Rican Institute for Lands and Homesteading (ITCO) has been selling subsidized hectare homesteads to Costa Rican citizens since 1965 (McCarty, 1979). No downpayment is required and no interest is charged.

Table IV-2. Actual Organization of the PRICA Project and Characteristics of the Different Colonies.

Colony	Number of families	Area[a/] Total	Area[a/] planted of corn	Original phase that belonged to Prica I	Original phase that belonged to Prica II	Access to year-around road	Surveyed farmers
Sub-seat I							
Yolaina	132	4042	115.2	x		x	3
Serrano	171	5160	267.0	x		x	4
Carlos Fonseca	153	5772	281.1	x		x	1
Verdum	119	3640	212.8	x		x	3
Nueva Guinea	295	5418	179.2	x		x	2
Los Angeles	152	5320	189.7	x		x	2
Subtotal	1022	29351	1245.7				15
Sub-seat II							
Nuevo Leon	93	2965	204.1		x	x	3
La Esperanza	142	4643	182.9	x		x	4
Ruben Dario	77	2103	146.3		x	x	4
Benito Escobar	167	5226	206.7		x	x	4
Providencia	172	6020	215.6		x		
Nuevos Horizontes	152	3479	149.1		x		
German Pomares	194	3076	149.1		x		
19 de Julio	142	2930	149.1		x		
Subtotal	1139	31440	1402.8				19
Sub-seat III							
Talolinga	100	3837	91.7		x		
Kuringuas	99	3036	115.5		x		
San Jose	120	4690	73.5		x		
San Martin	121	3518	202.3		x		
Jacinto Baca Jerez	105	2657	60.7		x		
Los Laureles	69	2302	150.5		x	x	
Subtotal	614	20047	694.2				-

-continued next page-

Table IV-2., Continued

Colony	Number of families	Area[a/] Total	Area[a/] Planted of corn	Original phase that belonged to Prica I	Original phase that belonged to Prica II	Access to year-around road	Surveyed farmers
Sub-seat IV							
Blanca Sandino	72	3182	151.6	x		x	3
San Antonio	133	4553	207.6		x	x	3
San Miguel	140	5040	347.9		x		
San Ramon	113	3266	160.7		x		
Jerusalen	116	5218	241.2	x		x	3
Caracito	57	2446	79.8	x		x	
Rio Rama	149	2222	377.3	x		x	
Subtotal	780	25926	1565.9				9
TOTAL	3555	106765	4980.6				42

a/ Hectares.

Source: INRA, 1980.

Physical and Climatic Conditions

In the PRICA region, the soils are predominantly deep and will drain clays with an average pH of 5.3. The NAZ has generally the same types of soils, however, they are slightly less acidic (pH of 5.5). In both zones, the topography is flat to gently rolling. PRICA altitudes range from 100 meters above sea level (m.a.s.l.) to 467 m.a.s.l. with the mode being between 186 and 200 m.a.s.l.

Measured by its agricultural potential, 33 percent of the PRICA area is of general use, 21 percent is of limited use, 38 percent is of very limited use, and three percent is for restricted use only. Thirty-three percent of the total area is fit for the production of annual crops and 59 percent fit for livestock production (IAM, 1968).

While the average annual rainfall in the NAZ is 3.5 meters, in the PRICA area it is 2.5 meters. In the PRICA area, the wet season starts in May and ends in February or March followed by a short (1 to 2 months) dry season; however, it is often wet through the entire year. As shown in Figure IV-2, the months of the lowest precipitation in the PRICA are February, March and April. Figure IV-3 shows a similar record for NAZ. In the NAZ, there is also a short period of low precipitation in the middle of the wet season (September). This period does not occur in the PRICA.

The temperature is relatively constant in both areas. In the NAZ, the average temperature is 26°C, in the PRICA it is 24.42°C. The minimum in PRICA is 23.36°C in January and the maximum is 25.67°C in May. Corresponding figures for NAZ are 23°C in January and 26°C in September. The average monthly humidity is 87.61 percent with the minimum being 80.29 percent in April, and the maximum being 91.63 percent in December (INTA, 1980). The humidity is equally as high for NAZ.

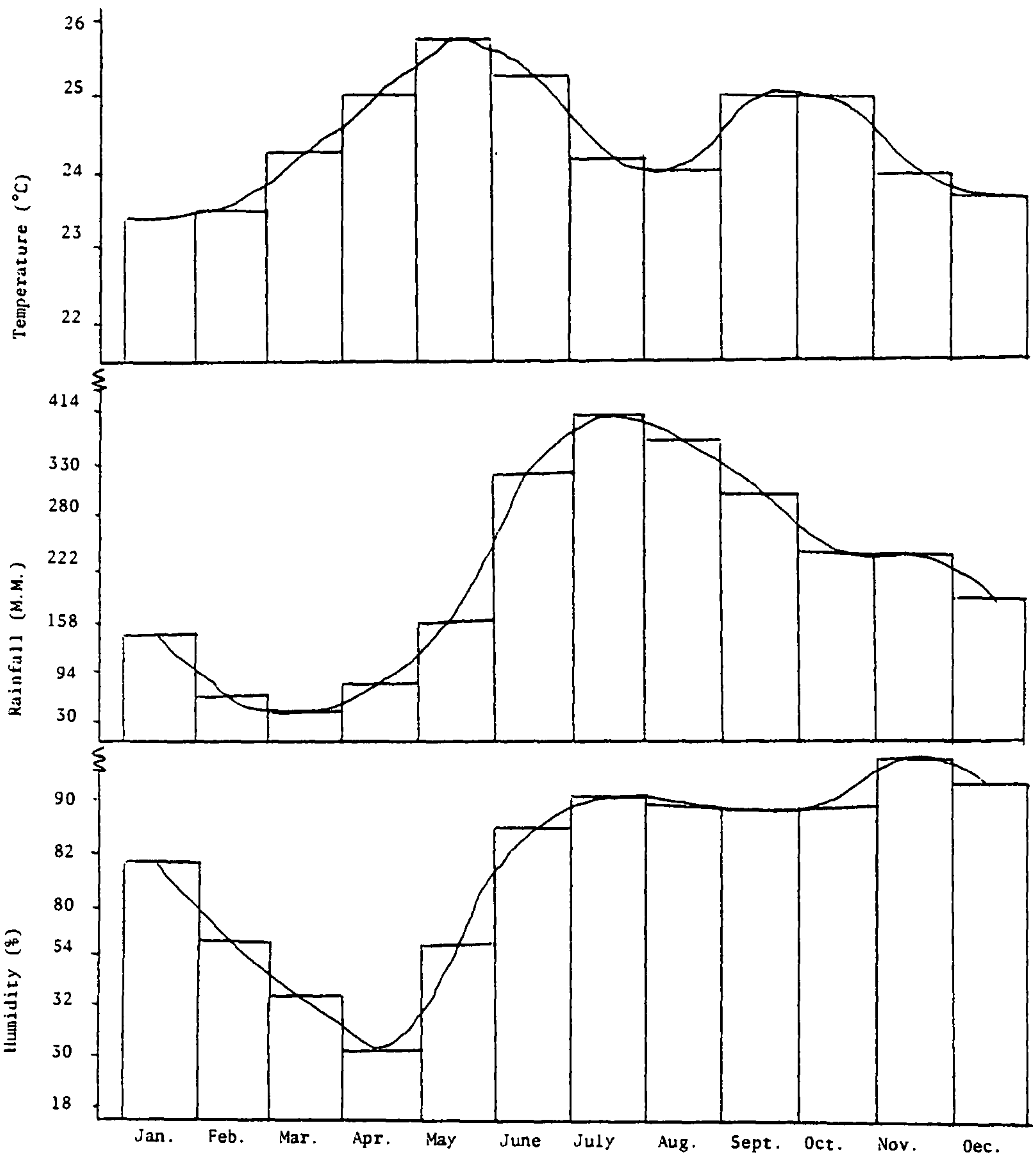

Figure IV-2. Mean monthly temperature, rainfall, and humidity at Oean Pagget Station, Nueva Guinea, nine years (1970-1978). Source: INTA, 1980

Farm Size and Tenure

Most of the farm units in the PRICA area are uniform in size. Of the total 27 colonies of the project, 24 have an average farm size of 35 hectares. Only in Nueva Guinea and Verdum are there large farms (50 has). In Jerusalen there are a few farms of 10 to 25 (has). Additionally, scattered within the project area, there are a few big farms (55 to 175 has) which belong to farmers who were residents in the region before the project was founded (INRA, 1980).

In the NAZ, 65 percent of the farms have 20 hectares or less (McCarty, 1979). There are a number of large farms, however. In contrast to the NAZ, small farmers on the PRICA area are not making the required land payments to the government. This may arise from the political unrest which has characterized Nicaragua in recent years as well as question their ability to pay.

Verdum and Nueva Guinea farmers have title to their land, while farmers of the rest of the colonies have "title of possession". Title of possession prohibits them from selling or trading their land. The land tenure status was changed (Verdum and Nueva Guinea) after a few years of project implementation since farmers were trading or selling their land and the infrastructure invested by the government in their farms (INRA, 1980).

There are landless peasants in both regions. However, it is not difficult for them to have access to a piece of land and raise crops. Often, it is free, but in some cases, land is rented (up to $140.00[1/] cordobas per hectare in PRICA and ¢40[2/] colones to 128 in NAZ, depending upon the availability and class of land).

[1/] The currency of Nicaragua is the Cordoba. One cordoba is equal to 0.1 dollars. The currency of Costa Rica is the colon. One colon is equal to .12 dollars.

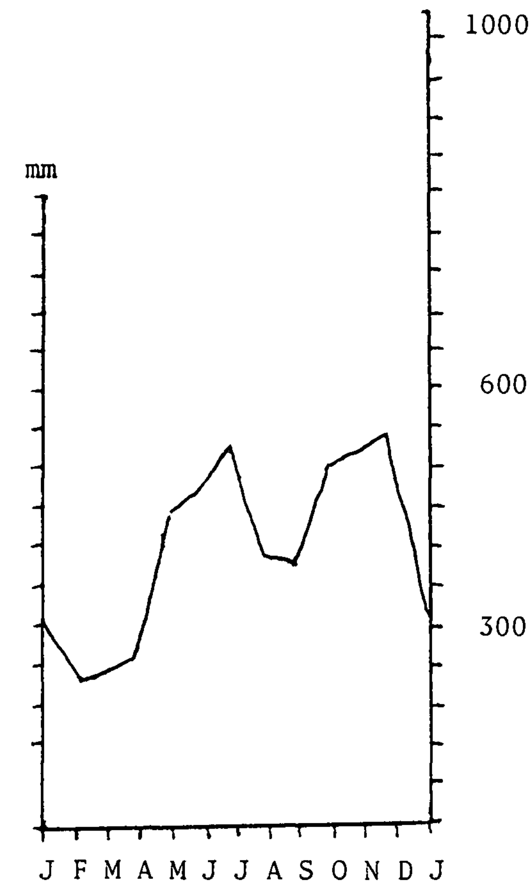

Figure IV-3. Average rainfall by month, 1952-65, Los Diamantes, North Atlantic Zone, Costa Rica.

Labor Use and Wage

The standard, legal workday for agriculture in the PRICA is 8 hours but the length of the actual workday varies, depending upon the workers themselves, the type of labor involved, the employer and the type of cultural practice being performed. Family members usually follow a regular schedule of work. They work from sunrise to 2:00 or 3:00 pm.

In contrast, hired labor is supplied in two forms: (1) through the standard -hour workday, and (2) more commonly through custom contracts in which the farmers specify the piece of work to be done and the hired labor receives a payment based on his assessment of the time requirement. This form of work is preferred by the hired laborer because of its flexibility. The labor suppliers can simultaneously work outside or on their own farms. In addition, this type of arrangement allows the landless workers to raise their own crop on rented land while they work for other farmers.

Employers also influence the length of the normal workday. Some prefer to hire under the 8-hour workday schedule, while others prefer the contract system. Moreover, there are some government institutions which hire labor under the 8-hour workday, but there are others that prefer a 9-1/2-hour workday giving Saturday free to the workers .

The type of cultural practice also influences the workday. For instance, in the planting of corn, farmers prefer to hire labor under the 8-hour system since the contract system does not easily allow the farmers to monitor the assignment. Additionally, during planting, there is a high demand for corn planters, so farmers are exposed to losses if planting is not done on time.

For 1980, the average hired labor wage was $27.50 cordobas per day and it varied between $25.00 and $33.00. In the NAZ, ¢20.00 colones per five or six hour man-day appears to be the general method of employment and wage paid by farmers for work in annual crops (1977). Basic wage rates on large plantations are about ¢35.00 colones per 8-hour man-day.

Land Use

The sample of 42 PRICA farmers grew, in the wet season of 1980, 106 hectares of corn, 28 hectares of rice, 66.4 hectares of banana and plantain and 20.2 hectares of coffee. They also grew nine hectares of other crops which include cassava, quiquisque, pineapple and sugarcane.

Rice is a relatively new crop in the area. It has been introduced in the area in the last few years and farmers presently do not have a yield history. Coffee is also a new crop in the area. None of the plantations are presently in production. The first crop is expected in 1981.

The amount of land devoted to crop production and specified above, as well as the amount of grassland and weedy land that exists in the average PRICA farm are presented in Table IV-2.

Livestock Production

The PRICA small farmer in the sample has an average of 4.5 heads of cattle on 12.1 hectares of grassland. In contrast with the small average farmer of the NAZ who has 13 heads of cattle on nine hectares of land. Farmers in both areas also own a small number of pigs, chickens and horses.

Table IV-3. Relative Use of Land by PRICA and NAZ Farmers.

Use of land	PRICA (wet season of 1980)	NAZ (wet season of 1977)
Ave. farm (has)	34.1	19.2
Annual crops (%)		
Corn	7.4	31.1
Rice	2.0	1.0
Other		4.2
Sub-total	9.4	36.3
Perennial crops (%)	6.60	5.2
Grassland (%)	35.5	47
Weedy and Virgin Land (%)	48.5	13
Total	100	101.5

Comparatively, PRICA farmers have more unused land and less corn land than their NAZ cousins.

Credit

The GON offers loans to PRICA through the National Bank of Development (BND) which has a main office in Nueva Guinea and branch offices in Talolinga, San Antonio and La Esperanza. Generally, PRICA farmers have access to 15 different types of BND's loans which cover farm improvement, livestock, annual crops and perennial crops.

For this study, after the 42 participating farmers were interviewed, information about their credit situation was obtained directly from BND officials. Twenty-two of the farmers (52 percent of the sample) have outstanding loans. Table IV-4 presents the actual credit situation of the loan holders. The data are somewhat biased toward long-term credit since information about short-term loans for annual crops which had been used by the farmers and repaid, was not available.

Table IV-4. Types of Loans and Amount of Capital Borrowed from the BID by 22 of the 42 Surveyed Farmers.

	Interest Rate[a]		Total Loans[b]		Debit Balance[b]	
Type of Loan	1976	1978-79	Offered	Used	Total	Mature
Development:						
Fences	6	9	71,498	62,498	62,498	7,431
Tree-clearing	6	9	80,600	79,200	78,533	6,782
Grasses	6	9	86,800	84,200	82,906	8,280
Water bombs			1,400	1,130	1,130	
Other Agr. loans			27,023	6,043	6,043	4,396
Livestock:						
Mules	6	9	12,600	10,600	10,065	3,605
Bulls	6	12	23,600	21,460	20,860	4,600
Heifers	6		80,440	72,565	71,039	14,596
Annual Crops:						
Upland rice		10	6,580	1,925	1,925	1,925
Maize		10	17,580	6,793	6,793	6,793
Maize-beans		10	19,660	7,797	7,797	7,797
Beans		10	26,220	14,596	13,996	13,996
Other Crops:						
Coffee		10	180,000	94,417	94,417	
Banana & plantain		9	48,210	17,327	17,207	480
Roots & tubercles			11,290	5,219	5,219	1,319

a/ Percent.

b/ Cordobas (₡). One cordoba is equal to 0.1 dollars.

Source: Banco Nacional of Nicaragua, Sucursal Nueva Guinea.

An important observation about Table IV-3 is that the initial amount of capital which was offered by BND was not used by the farmers. That is, farmers borrowed less capital than was initially offered by BND. In the NAZ, credit is also available to small farmers. In 1977, small farmers were obtaining short-term loans (six months for corn and nine months for beans) with an interest rate of eight percent. Such loans are available at 100 percent of the assessed cost of raising the crop (McCarty, 1979).

Corn Production

In the previous section, the general characteristics of the study area and its comparability with the NAZ were discussed. In this section, the discussion is narrowed to production methods used by small farmers for corn.

Methods of Cropping and Weed Control

Land Preparation

Land preparation in the PRICA area consists of clearing the planting area of weeds and old growth vegetation. It is usually done with a machete. However, in areas of virgin land, it is cleared of trees by axe, if necessary. Since little land remains in the virgin state, this type of land preparation is relatively insignificant for PRICA farmers. Land preparation (preplant weed cutting) is similar in the NAZ. A few farmers plow their lands, however, plowing is not used in PRICA.

In the NAZ, vegetation is generally out four to five inches above the ground. The cut vegetation is left in place as a mulch. Several farmers spray herbicide mixture over the regrowth of the cut weeds before seeding (McCarty, 1979).

After cutting the vegetation, PRICA farmers burn the fields. It is believed by the farmers that this reduces the time required to seed and reduces post-plant weed control labor requirements.

Planting

Similar to methods used in the NAZ, planting is done in PRICA by making a hole in the soil with a pointed stick, dropping two to six seeds (four to nine in the NAZ) into the hole and then covering it over with the foot. The space left between rows and hills is the same in both areas--95 cm. The average amount of seed corn planted in one hectare by PRICA farmers is 14.1 kgs. None of the interviewed PRICA farmers use fertilizer for corn while only a minority of small farmers applied fertilizer to their corn crop in NAZ.

Post-Plant Weed Control

In the NAZ, some farmers hand weed their lands after planting, however, most use herbicides in addition to or in place of hand weeding. Most apply light concentrations of 2,4-D, but some directed applications of paraquat are also employed.

Three post-plant weed control technologies are currently practiced by PRICA farmers. Approximately one-third of the producers use each system. They are:

(1) One hand weeding done after planting, when the weeds are 15 to 35 cms high and the corn plants are a little higher than the weeds. This hand weeding is usually done 21 days after planting. This system is called T_1 in subsequent discussions.

(2) One hand weeding done one month after planting, when the

weeds are between 40 and 80 cms high (T_2).

(3) Two hand weedings done after planting. The first hand weeding occurs about 21 days after planting. The second hand weeding is done one month later, when the weeds have grown to 35 cms. The corn at this time is between one and one and one-half meters high (T_3).

Harvest

Farmers in the NAZ usually double the corn and cut the weeds before the corn is actually picked. This is done to prevent the weeds from reaching the doubled ears, which would result in ready access by rats and other pests. Doubling keeps water away from the mature ears allowing for field drying.

In contrast to NAZ farmers, PRICA farmers do not cut weeds before harvesting, even though they are aware of the practice in other areas. They believe that the created mulch will reduce the germination of the bean crop in the second season. (Beans are commonly broadcast in the areas where corn was raised during the first season.) PRICA farmers also do not double the corn ears. The corn is usually picked and accumulated in hills on the field. From there it is taken to storage either near the crop area, or more commonly, near the farm house.

Systems of Corn Production in the PRICA Area

Regardless of the weed control technology that is used, two traditional systems of corn production are used by PRICA farmers. The average farm has 22.0 hectares of non-forage crop, land, but only 2.52 hectares are in corn production. Deducting the hectarage of other crops leaves 16.5 hectares of rotatable land. Much of this land is presently unused, that is, it has been cleared of large trees and at some time in the past has been used for crop production but at present natural vegetation is regrowing with no current commercial production.

Production System One

System one is the most common system used by PRICA farmers. Basically, it consists of cropping a piece of land for three years and then fallowing it for an indefinite period of time before being brought back into production. The length of fallow varies according to the need for land, but it may be as much as 15 years. Preplant soil preparation labor requirements are lower than in a previously fallowed area. As a consequence, farmers prefer to crop in a previously cropped area, other factors being equal. However, the invasion of weeds and decreasing soil productivity force farmers to move to a new area every three years.

In order to maintain soil fertility and avoid the increasingly noxious weed, the farmer plants one-fourth of this corn area on previously fallowed land. Thus, in a typical year, three-fourths of his corn area is on land which previously produced corn (old land) and one-fourth of his land is on previously fallowed land (new land). The average amount of old land on PRICA farms is 2.52 hectares.

For the moment, production system two will be skipped. It will be discussed when the new weed control technologies are presented.

Production System Three

System three is similar to system one in that a particular area is cropped and then fallowed. In contrast with system one where the farmers maximize the use of old land to reduce labor usage in land clearing, farmers in system three produce each year on new land. New land (prevously fallowed land) generally yields about 10 percent more corn than the average of an area which is used for three years, but requires more time for preplant land preparation. This amounts to an increase of two days per hectare in soil preparation.

Schedule of Activities

Farmers of the PRICA area generally grow corn as the main crop during the wet season of the year and beans during the dry season. However, corn is often grown in the dry season as well.

The timing for cultural practices for wet season corn for the two areas is shown in Table IV-5. As can be seen, the PRICA area is about one month in advance of NAZ. The precise reason for the difference is not known.

Planting extends from the middle of May to early June in PRICA, and through July in the NAZ. However, it is assumed that NAZ farmers attempt to take advantage of the reduced rainfall occurring in August in the North Atlantic Zone.

Table IV-5. Timing of Cultural Practices in Wet Season Corn Production, PRICA and NAZ.

Practice	PRICA	NAZ
Land clearing	March-April	June
Field burning	Late April	--
Planting	May-June	July
Hand weeding	June/July/August	July-August
Herbicide application	--	July
Preharvest weeding	--	October
Harvest	October	November

Marketing

PRICA farmers raise corn for family needs, but they do sell part of the total production. In determining the amount to be sold, the farmers behave in one of two ways: (1) some farmers prefer to sell most of the production, storing only family needs for two to three months and buying corn thereafter. They believe that the losses caused by insects and disease in farm storage are so high that it is not feasible to store corn for the six-month period until the next harvest. (2) Other farmers prefer to store enough corn for family consumption. They recognize that storage losses will be high, but prefer the security of physically owning the food. They prefer to suffer high storage losses rather than being forced to buy the corn on future markets when corn is sometimes hard to find.

The prices of grain crops both at the farm gate and at the retail price in the region are controlled by the GON through ENABAS. The prices are the same as exist in the rest of the country minus transportation costs. ENABAS provides the bags for transportation. ENABAS does not penalize for corn moisture but it does for foreign material. The price paid farmers for corn by ENABAS in 1980 was $1.64 cordobas per kilo of corn.

Most corn growers in NAZ sell their corn either to commercial buyers or the National Council of Production (NCP). Only eight percent of the corn is kept for home consumption. The retail price of corn in Costa Rica is the highest in Central America (₡1,808 colones per metric ton of clean, shelled corn at 14 percent moisture, 1978). A charge of ₡141 colones per metric ton was deducted for transportation to San Jose, the central market.

Yields

When the PRICA survey was taken, corn had not been harvested. Yields, therefore, were estimated by farmers.

The average yield estimated by PRICA farmers for the wet season of 1980 was 832.2 kgs per hectare. NAZ farmers produced an average of 870 kgs per hectare in the wet season of 1977 (McCarty, 1979). Table IV-5 contains the average yields estimated by PRICA farmers according to the post-plant weed control strategy that they were using. The standard deviation of yield is also given by technology.

Table IV-6. Actual Yield Obtained by PRICA Farmers in the First Season of 1980 for Three Different Types of Weed Control and a Yield Estimate for the Improved Technology.

	T_1	T_2	T_3	T_4
Yield (kgs)	783	753	981	1109
Standard deviation	212	444	470	222

Yields vary considerably by technology. Of the traditional technologies, T_3 is the highest. Since it includes both an early and a second weeding it would be expected to be higher than either T_1 (one early weeding) or T_2 (one late hand weeding). Between T_1 and T_2, T_2 is the lowest. This is reasonable, since late weeded plots generally yield less than early weeded plots.

The new weed technology T_4 will be discussed in the next section. However, the high yield reflects recent results reported by IPPC researchers which show increases in yield of 13 percent associated with the new technology (Shenk, 1980).

The standard deviations are about the same for T_1 and T_4, and T_2

and T_3. The low standard deviation in T_1 and T_4 reflect the proper employment of hand weeding and chemicals. A high degree of variability in yield is a natural consequence of the late hand weeding in T_2. Since T_3 has two hand weedings, its high standard deviation possibly reflects that on the part of at least some of the producers, the second weeding was required because the first was not done well. While the above is conjecture, it would explain the high average yield and the associated high standard deviation.

These yields and standard deviations were used as estimates in production System I. However, in production System III, the yields and their standard deviations were increased by 15 percent. The increase is justified by the exclusive use of new land on production System III.

As will be explained later, the yields of production System II are the same as those of production System I.

Improved or Modern Technolcgies

Improved or modern technologies are introduced into the analysis by adding a new weed control technology to production Systems I and III. Additionally, a third production system, System II, is added.

Labor Use in Corn Production

Under the traditional systems of corn production in both areas, most of the expenses are for labor. Ninety-six percent of total production costs come from family and hired labor costs for the average PRICA farmer.

In the average PRICA farm, the farmer family supplies 74 percent of the total labor and hired labor supplies the rest (26 percent). In the NAZ, the farmer and his family supply 63 percent of the total labor and hired labor supplies 33 percent of the total labor use. In both areas, farmers hire the highest percentages of labor for land preparation. PRICA farmers hire 43 percent and NAZ farmers hire 46 percent.

Table IV-7 shows the average man-days of labor per hectare used by PRICA and NAZ farmers to perform the different activities in the process of raising corn. As PRICA farmers commonly use three different methods for controlling post-plant weeds, the PRICA data were also stratified according to the three methods of post-plant weed control.

Table IV-7. Labor Requirements and Variable Costs of the Proposed Technology, by Land Loss.

Labor Requirement (man/days/hectare)	Old Land	New Land	Old land with fertilizer
Land clearing		9.7	
Preplant herbicide appl.	2.5		2.5
Planting	4	4	4
Fertilizer application			0.25
Post-plant herbicide application	3.5	3.5	3.5
Harvest	10.0	11.5	9.5
Variable Costs (cordoba/hect.)			
Labor	55	189.2	543.1
Herbicide application	214.5	87.0	214.2
Seed	30	30	30
Fertilizer	--	--	110.0
Total variable costs	794.5	906.3	897.6

Cost of Production

The total variable costs per hectare incurred by PRICA and NAZ farmers are presented in Table IV-8. Each of the three traditional weed control technologies are given for PRICA farmers.

Generally, the cost of family labor represents the highest proportion of costs for both PRICA and NAZ farmers. For PRICA, those farmers who utilize technology T_3 have the highest variable costs. This occurs because of the larger amount of labor used for weed control.

The total variable costs are higher for NAZ than for PRICA farmers. They are higher for several reasons:

(1) NAZ farmers use more labor in weed control activities. This may arise because NAZ farmers have more problems in weed control than PRICA farmers do. The presence of noxious grasses could be the reason.

(2) NAZ farmers also use more labor in non-weed control activities. PRICA farmers in contrast to NAZ farmers do not fertilize nor apply pesticides.

(3) The costs are calculated using similar technical units but different monetary units. NAZ costs are expressed in 1977 prices while PRICA costs are expressed in 1980 prices.

(4) Labor as well as other inputs have been more expensive historically in Costa Rica than in Nicaragua.

Assumptions Undertaken to Formulate the Linear Programming Model

Assumptions used in the linear programming model, information and data obtained from the farmer survey, local sources and the agronomic

Table IV-8. Summary of Labor Use in Corn Crops by PRICA and Naz Farmers.

	PRICA			
	T_1[b/]	T_2[c/]	T_3[d/]	NAZ[a/]
Soil Preparation				
Pre-plant weed control	9.09	9.8	10.2	14.5
Herbicide application	--	--	--	0.6
Field burning	0.3	0.41	0.21	--
Planting				
Seeding	3.22	2.97	3.72	5.3
Fertilizer application	--	--	--	0.3
Pesticide application	--	--	--	0.2
Post-Plant Weeding				
First early hand weeding	5.43	--	5.3	1.5
First late hand weeding	--	4.4	--	--
Second hand weeding	--	--	4.69	--
Herbicide application	--	--	--	2.0
Pre-Harvest Weeding	--	--	--	3.8
Harvesting				
Doubling	--	--	--	3.5
Picking	8.26	7.58	9.0	15.5

a/ Source: McCarty, 1979. The coefficients of this column were transformed from a six-hour work-day to an eight-hour work-day to facilitate comparison.

b/ Technology one of weed control.

c/ Technology two of weed control.

d/ Technology three of weed control.

Table IV-9. Total Variable Costs for Corn Per Hectare, Incurred by PRICA and NAZ Farmers.

	PRICA[a/]			
	T_1[c/]	T_2[d/]	T_3[e/]	NAZ[b/]
Cost of family labor	553.6 (55.36)[h/]	445.0 (44.50)	711.7 (71.17)	925 (108.83)
Cost of hired labor	170.0 (17.00)	247.0 (24.70)	199.1 (19.91)	366.3 (43.09)
Total cost of labor	723.6 (72.36)	692.0 (69.20)	910.8 (91.08)	1291.3 (151.92)
Non-cash costs[f/]	29.1 (2.91)	31.4 (3.14)	32.9 (3.29)	28.3 (3.33)
Other cash costs[g/]	---	---	---	133.1 (15.66)
Total	752.7 (75.27)	723.4 (72.34)	943.7 (94.37)	1452.7 (170.91)

a/ The expenses of PRICA farmers are expressed in 1980 Cordobas (10 cordobas/one dollar).

b/ The expenses of NAZ farmers are expressed in 1977 Colones (8.5 colones/one dollar).

c/ Technology one of weed control.

d/ Technology two of weed control.

e/ Technology three of weed control.

f/ The opportunity cost of corn seed for planting.

g/ Dollar equivalent--no adjustment has been made for the differences in the exchange rate or rate of inflation between 1977 and 1980.

h/ Dollar equivalent--no adjustment has been made for the difference in the exchange or rate of inflation between 1977 and 1980.

weed control experiments conducted by IPPC researchers in the NAZ were used to develop the linear programming model used in this study. In this section, the specific assumptions employed in the model are presented.

Alternative Model Specifications

To evaluate the substitution effect of the proposed new systems of weed management over the traditional systems used by the PRICA farmers, optional solutions under the present systems of production with different levels of resource availability are calculated and used as the base. Then the proposed "new weed control technology" is incorporated into the model. A comparison between the solutions indicates the possible advantages or disadvantages for the PRICA farmers if introduced and adopted.

(a) Specifications of the Farm Cases

Three different family labor sizes are considered in the evaluation. Data from the PRICA farm survey are used to estimate the production coefficients are summarized in Appendix Table ______. Actually there is a little difference in the coefficients of the three except for the amount of family labor available to help in the farm enterprise.

Seven farm cases are examined (see Table IV-10), first with traditional technologies and then with both traditional and modern technologies.

In the PRICA area, approximately 33 percent of the surveyed farms have only one family farm worker. Capital is constrained to the existing available capital in case one but relaxed in case two. By so doing, a comparison between short-run and long-run results can be made. Since increased profits can be used to remove any reasonable existing capital constraint, the new weed control technologies have an economic advantage.

Case three allows consideration of the situation where no outside employment opportunities are available to the farmer. Cases four and five, and cases six and seven are the same as cases one and two except for the increase in the number of family farm workers.

Table IV-10. Alternative Model Cases.

Case	Tenure status	No. of family workers	Cost of family labor	Capital
1	owner	1	non-zero	constrained
2	owner	1	non-zero	unconstrained
3	owner	1	zero	constrained
4	owner	2	non-zero	constrained
5	owner	2	non-zero	unconstrained
6	owner	3	non-zero	constrained
7	owner	3	non-zero	unconstrained

Internal Capital

The amount of capital currently used in corn production in hiring labor plus the estimated value of the amount of corn seeds used by farmers is assumed to be the amount of internal capital available to the PRICA farmers for corn production.

When only the traditional technologies of weed control are considered in the analysis, the amount of internal capital available to the farmers is specified to be used for hiring labor and buying corn seed. Then, when the proposed new technologies in weed control are brought into the analysis, internal capital can be used for hiring labor, purchasing herbicides, fertilizer, corn seed, and paying for depreciation and maintenance of the equipment used to apply herbicide. The amount of internal capital was calculated from the survey data to be $840.00 cordetsos.

Credit

No interviewed farmers were currently using borrowed capital to grow corn, however, 52 percent of the farmers have used loans in the past from the BND (see Table IV-3) for production of corn and other crops, and for investments in farm improvements. Several farmers, when asked why they did not use production credit, stated that the low rate of return on these investments prohibited further borrowing under current systems of production. Consequently, availability of capital is not likely to be a binding constraint.

Interest Rate

In the farm cases where capital is unconstrained, the interest rate applied to the use of borrowed capital is 10 percent. This is the rate that the BND currently charges to the farmers for short-term loans.

Available Family Labor

According to the data gathered in this study, the amount of family labor available for farming in each farm unit varies between one and three family workers. Fourteen of the farmers interviewed (33 percent of the sample) reported having no additional workers in the farm units, while 11 farmers (26 percent of the sample) reported having one additional family worker, and ten farmers (24 percent of the sample) reported having two additional family workers on their farms. The family labor availability in the model is specified by multiplying the number of days in which a specific activity could be performed. Since rice production overlaps corn production, the amount of family labor available for land clearing and planting was obtained by subtracting the amount of family labor used for land clearing and planting of rice from the total amount of labor available.

The estimated length of time available to complete the different activities currently performed is given in Table IV-11.

Table IV-11. Periods in Which the Different Activities Performed by PRICA Farmers are Commonly Undertaken.

	Land clearing	Field burning	Planting	First early weeding	First late weeding	Second weeding	Harvesting
Date	Mar-Apr	Apr-May	May	Jun-Jul	Jul-Aug	Aug	Sept-Oct
Period Length (weeks)	4	2	2	2	2	2	4

Available Hired Labor

The amount of labor that can be hired is not constrained in the model. Instead, the amount of hired labor available to the farmer depends upon available capital, either internal or borrowed.

Wage Rate of Labor

The 1980 wage rate of hired labor in PRICA was $27.5 per day. In the model, the farmer is assumed to hire labor at this wage rate to perform the different activities which cannot be done with family labor.

Family labor cost varies according to the farm case. It is zero when it is assumed that the farmer has no work opportunities outside of his farm and additional labor on the farm has no value. It is the same as the hired labor wage where the family workers or the farmer have outside work opportunities or where alternative activities on the farm have a value equal to the going wage rate.

Subsistence Requirement of Corn Production

The subsistence requirements of corn for the family is estimated by multiplying the family size times the number of days until the next harvest times the average daily consumption.

The national average daily consumption of corn in Nicaragua from 1960 to 1980 was estimated to be 0.6 pounds[2/]. Since urban households generally consume less corn than rural households, and are included in the average, an adjustment must be made. Bersten and Herdt (1977), in a corn production study of Belize, a region with physical and climatic conditions and corn production systems similar to those of the PRICA region, found that the average consumption of corn in that rural area was 1.2 pounds (0.547 kiograms). It is believed that their estimate is a better measurement of corn consumption of the rural PRICA population and was therefore used in this study. The estimated subsistence requirements for the different family sizes considered in this study are shown in Table IV-12.

2/ This average was estimated from tables related to corn production in "Iudicadores Economicos" edited by the Central Bank of Nicaragua.

Table IV-12. Estimated Subsistence Requirement of Farm Family by Number of Working Members.

Number of working members	Implied family size	Subsistence requirement (Kgs)
1	6.15	601.85
2	9.10	893.45
3	6.10	598.91

Storage Corn Losses

Farmers reported storage losses varying from zero to 40 percent, depending upon the period of storage and types of structure used for storage. It is assumed in this study that the storage losses of corn average 10 percent.

Systems of Production

To utilize the maximum of land available on the farm unit in corn production as well as to use properly the recommended weed control technologies, three systems of production are compared. Such systems were described in the previous section.

Herbicide Use

The creation of a chemical mulch is the basis of the new technology. The weeds most frequently present in the corn plantations of the PRICA farmers are broadleaves. In this situation, IPPC recommends two alternatives, depending upon the stage of the weeds before planting.

Herbicide Application Equipment Costs

Herbicide application equipment costs include depreciation and cost of maintenance of a backpack sprayer. Depreciation is based on a unit cost of $1,300.00 in Nicaragua and an expected life of 15 years. Maintenance consists of replacing the nozzle of the sprayer every five years. Total estimated cost is $10.50 per hectare.

Fertilizer Use

If farmers produce corn continuously in the same area, fertilizer must be used to maintain the fertility of the soil. The dosage used in the model is 28 kgs of fertilizer 15-15-15 and six kgs of urea per hectare. Such an application has a cost of $110.00 and requires one-fourth of a man-day for application per hectare.

Risk[3/]

Farmers are continually confronted with risk and uncertainty. This occurs in the form of price uncertainty, yield uncertainty, and uncertain change in technology and the government or legal framework in which farmers operate. Farmers in Nicaragua do not control prices. They are set by the GON; therefore, while the price is low, it ceases to be an unpredictable variable. The government and the legal framework are also beyond the control of the individual farmers. Technological changes and the associated investments are so slow in traditional agriculture that they are also of minimal importance. Yield uncertainty for a known or anticipated production technique is the major problem for small farmers.

Farmers want to avoid the possibility of high losses as they seek to improve their average net income. For subsistence farmers, an occasional net loss can have serious consequences. Therefore,

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3/ For some authors, nobody knows what risk is in production and prefer to call to this phenomenon: dispersion measure.

variability in yields and its effect upon net income are of great importance to them.

There are three sources of yield variability:

(1) Site-to-site variability under the same management conditions.

(2) Year-to-year variability under the same management conditions.

(3) Management level variability on a given site in a given year (Perrin et. al., 1976).

These occur because of differences between site, weather, pest infestation and management between sites of production and between years. In this study, no estimate is available for the between year variability. Similarly, differences between management are not estimated. Yield variability is restricted to the single consideration of site-to-site variability within a single year.

Individual farmers respond differently to risk. Some respond positively, others are indifferent, but most small farmers are risk averse. Underlying their attitudes are concepts of diminishing utility and nonlinear preference for gains and losses. Unfortunately, the "neoclassical theory of the firm with its assumptions of certainty and linear utility is inadequate for normative analysis of risky production where preferences for profits are nonlinear" (Anderson, 1971). Since many farmers are risk averse, they are often willing to give up some expected gain to reduce risk. A farmer is indeed fortunate if a technology can be adopted which both reduces risk and increases net income.

The standard deviation of yield multiplied by the various weed control systems when substantial from the average yield is used as the measure of yield variability in the model. The risk aversion coefficient (λ) accounts for the variability in risk preference of farmers.

As previously stated, no estimates are available of the true utility function and the associated risk aversion coefficients of the farmers in PRICA. Thus, the risk aversion coefficient is allowed in the model to range from 0.0 to 2.0. Such values of risk aversion are consistent with those of other studies (Nieuwoudt and Mathia, 1976; Hazell et. al., 1978; O'Brien, 1980; Escobar, 1980). The amount of corn available for sale and consumption, therefore, decreases as the risk aversion coefficient increases. When $\lambda = 0$, the assumption is the farmer is risk neutral and the model solution obtained corresponds to the conventional profit maximizing linear programming solution.

Summary

As stated in Chapter I, IPPC weed control technologies are now being tested in two different zones: one which is ecologically different (same economic setting but much drier) and the second which is economically different (same ecological environment but a different economic setting). Also, in Chapter I, it is stated that this study reports on the second type of technological test.

To demonstrate that this second objective is being considered, two sections of Chapter IV are devoted to present information of and comparison of the two areas involved in this study--the NAZ, where the new technology has been developed and is in process of adoption, and the PRICA, where the new technology is pretended to be introduced. In one section, the discussion is focused on general physical, climatic, social and economic characteristics. In the other section, the discussion is narrowed to traditional systems of corn production, that is, to a comparison of the timing of cultural practices, activities, technical coefficients and weed management practices in corn production.

A conclusion of these two sections is that both zones, PRICA and NAZ, are similar in physical and climatic aspects. That is, they have similar temperature, rainfall and humidity distributions around the year. Also, both zones are endowed with similar types of soils--close pH, structure and topography.

As expected, the major discrepancies between PRICA and NAZ were found in economic and social aspects. Among those characteristics, the following are considered to be more relevant for this study:

(1) The workday is longer in PRICA. It is usually eight hours. In the NAZ, the workday is five to six hours.

(2) On average, PRICA farmers have larger amounts of land than NAZ farmers. Also, PRICA farmers have larger proportions of unutilized land than NAZ farmers.

(3) Although not formally demonstrated in these sections, wages have been historically higher in Costa Rica than in Nicaragua. Hence, they have been higher in NAZ than in PRICA.

(4) Corn prices are controlled by the government of Nicaragua in PRICA as well as in the rest of the country. Such prices are likely to benefit consumers rather than producers. On the other hand, the Costa Rican government subsidizes corn prices to NAZ prodcuers to stimulate production.

The final two sections of Chapter IV describe the sample procedures and data sources, and the assumptions undertaken to specify the linear programming model.

V. MODEL SPECIFICATION

The purpose of this chapter is to present: (1) a review of both deterministic and risk programming models which are the basis of the model used in this study, and (2) the specification of the constructed model.

Linear Programming Formulations

Linear programming is a technique which has been widely used by economists and agricultural economists to solve research, Extension and operational decision making problems (McCarl and Nuthall, 1978). The more common structures which have been used in formulating conventional linear programming problems are, among others, transportation problems, assignment problems, resource allocation, equilibrium-disequilibrium, assembly, disassembly, dynamic, block diagonal, production function-convex approximation and accounting. The production function-convex approximation structure is used in this study.

Justification of the Production Function-Convex Approximation Model

The advantages of employing a production function-convex approximation linear programming model for evaluating the actual traditional weed control technologies and the impacts of adopting a new weed control treatment based on the use of herbicide in the PRICA area include the following:

(1) The model allows the evaluation of the corn crop under different traditional technologies of weed control practiced by PRICA corn producers.

(2) The model allows the incorporation of the new proposed weed control technology.

(3) The model allows the comparison of the new weed control technology with the traditional ones. Therefore, the model is capable of selecting the most profitable combination of weed control technologies.

(4) The model allows the maximum utilization of scarce resources. This feature is not captured by simple methods of analysis as budgeting.

(5) The model allows utilization of different supplies of land in corn production.

Review of Production Function-Convex Approximation

This structure is presented by McCarl (1978) to portray well behaved, convex, nonlinear functions which exhibit constant return to scale. The problem was stated as one of maximization of total income discounted for total costs, subject to a set of linear constraints. The model is the following:

(1) Maximize $C_o Y_o \quad - d_i Z_i$

(2) subject to $Y_o \quad - \sum_m Y_m \lambda_m$

(3) $\sum_m X_{im} \lambda_m \quad - Z_i \geq 0$

(4) $Z_i \geq b_i$

$Y_o, \lambda_m, Z_i \geq 0$

where

C_o is the return per unit of output Y

Y_o is the total production of Y summed over all production processes

d_i is the cost of ith input

Z_i is the total quantity of the ith input used in all production processes

Y_m is the output of Y per unit of the mth production process

λ_m is the number of units of the mth production process employed

X_{im} is the use of the ith input in one unit of the mth production process

b_i is the maximum availability of the ith input

Equation one maximizes the return to production less the cost of inputs; equation two is an accounting equation relating sales of output to supply of the output through production; equation three relates demand for the inputs to the supply of the inputs; and equation four states bounds of the maximum input availability.

In formulating the linear programming model for this study, the yield coefficients for the different technological process (Y_m's of the production function-convex approximation model) are assumed to be stochastic. There is a level of variability associated with each average yield of each technology. As a consequence, the yield coefficients are not totally predictable. This assumption, stochasticity in the yield coefficients or risk, is important to farmers when deciding how much of a particular crop to produce.

Risk Programming Formulations

Risk is an important real world phenomena to decision makers, however, it is often ignored (Hazell, 1978). Conventional linear programming models assume that all the objective, input-output coefficients and resource constraints are known with certainty. Farmers are assumed to behave in a risk neutral manner. But agricultural production, particularly in developing countries, is generally a risky process, and considerable evidence exists to suggest that farmers have a high risk aversion (Wicks and Guise, 1978). Risk is accounted in the objective function indirectly by discounting "the cost of risk" (standard deviation of yield times a risk aversion coefficient) from the total output. Output will be reduced as long as "the cost" of bearing risk increases. The higher "the cost", the less the output available for sale. A pragmatic problem exists in estimating the appropriate risk aversion coefficient.

Overview of the Production Function-Convex Approximation with Risk Consideration Model Used to Analyze PRICA Corn Production

This model focuses on the weed control decisions involved in corn production during the first production season of the year. Since production system one has eight weed control systems (four (T_1, T_2, T_3, T_4) for old land and four (T_1, T_2, T_3, T_4) for new land), production system two has one weed control system (T_4) and production system three has four weed control systems (T_1, T_2, T_3, T_4) there are 13 production processes or activities.

Expected net revenue above variable costs is maximized less the cost of bearing risk. As stated before, the standard deviation of yield times "the risk aversion coefficient", is discounted from total production summed over all production processes. Each weed control technology has a different standard deviation of yield.

Constraints on the model include: (1) the acreage of land available for corn production, (2) budget and credit limitations for purchasing labor and inputs of production as corn seeds and herbicides, and (3) available levels of family labor to perform land clearing, field burning, planting, weeding, and harvesting. The model considers the subsistence requirement for family consumption by setting a limit of the amount of corn that is required to feed the farm family until the following crop is reached.

Corn for consumption is valued at the retail price and corn for sale is valued at the farm gate price. Additionally, the model allows for considerations of alternative family size, wage rates for family labor, subsistence requirements and various levels of risk aversion.

An overview of the decision model is given below to show how the model accounts for:

(1) the decision maker goals, and

(2) "the cost of risk", which is discounted from net revenue.

----

(1) Maximize $P_s C_s + P_c C_c \quad - \sum_{u=1}^{n} f_u Z_u$

(2) $-t_{11} C_c + C_L \quad = \quad 0$

(3) $C_c \quad = \quad C$

(4) $C_s + C_c + C_L - \sum_{j=1}^{m} (\overline{Y}_j - \lambda_h \sigma_j) X_j \quad \leq \quad 0$

(5) $\sum_{j=1}^{m} V_{uj} X_j \quad -Z_u \leq \quad 0$

(6) $C_s,\ C_c,\ C_L,\ X_j,\ Z_u,\ \geq 0 \quad -Z_u \leq \quad b_u$

where

P_s is the price per kilogram of sold corn at the farm gate

C_c is the total amount of corn allocated to sale

P_c is the value per kilogram of domestically consumed corn

C_c is the total corn production retained by the farmer

C_L is the storage losses of corn retained by the farmers

t_{11} is a constant that converts the estimate of seasonal subsistence requirement into an estimate of storage losses

f_u is the cost of the uth input

Z_u is the total quantity of the uth input in all production processes

$\overline{Y}_j$ is the average output of corn per unit of the jth production process

V_{uj} is the use of the uth input on one unit of jth production process

λ_h is the risk aversion coefficient

σ_j is the standard deviation in total yield

X_j is the number of units of the jth production process employed

C is the seasonal subsistence requirement

b_u is the maximum availability of the uth input.

Equation one maximizes the return to production less the cost of inputs; equation two estimates the storage losses of corn; equation three allocates the required corn for family consumption; equation four is an accounting equation which relates the sales of output, subsistence requirement, and storage losses to supply of output through production; equation five relates demand of inputs to supply the inputs; and equation six states bounds of the maximum input availability.

A complete description of the model is given in Table V-1. The model can be conveniently separated into 34 components.

(1) Objective function.

The objective function (row 1 of Tavle IV-1) is the maximization of net revenue above variable costs from corn production, which is discounted for the cost of risk. Specifically, the objective function is total corn allocated to sale times the farm gate price, plus the corn allocated to consumption times the retail price of corn, minus the value of family labor, minus the interest rate times the level of capital used in production.

$$P_sC_s + P_cC_c - (W_f)TFL - (r)TC$$

The objective function is maximized subject to the following constraints:

(2) Storage loss.

The percent of storage loss times the amount of corn left for home consumption minus the total loss is equal to zero.

$$-t_{11}C_c + C_L = 0$$

(3) Subsistence requirement.

The amount of corn allocated to home consumption is equal to domestic consumption for six months. (Six months is used because corn is also grown during the second season of the year.)

$$C_c = C_{cs}$$

(4) Corn production.

The total amount of corn allocated to sale and home consumption plus the amount of corn lost in storage minus the production of corn obtained from the kth system of production when using the jth weed control technology and the ith type of land by farmers with propensity to take risk equal to s, must be less than or equal to zero.

$$C_s + C_c + C_L - \sum_{i=1}^{m} \sum_{j=1}^{n} (\bar{Y}_{1ij} - \lambda_s\sigma_{1ij})X_{1ij} - (\bar{Y}_{214} - \lambda_s\sigma_{214})X_{214} - \sum_{j=1}^{n} (\bar{Y}_{32j} - \lambda_s\sigma_{32j})X_{32j} \leq 0$$

(5) Land clearing labor.

The amount of labor used in production for land clearing in the kth system of production when using the jth weed control technology on the ith type of land minus the supply of family and hired labor is less than or equal to zero.

$$\sum_{j=1}^{n} a_{12j} + \sum_{j=1}^{n} a_{32j} - LCF - FCH \leq 0$$

…ION (S_1)						SYSTEM TWO OF PRODUCTION (S_2)	SYSTEM THREE OF PRODUCTION (S_3)				FAMILY LABOR										HIRED LABOR								INPUTS				CAPITAL	LAND			
…D		NEW LAND				OLD LAND	NEW LAND																														
T_3	T_4	T_1	T_2	T_3	T_4	T_4	T_1	T_2	T_3	T_4	LCF	FRF	HAF	HAP	PF	FEMF	LEMF	SWF	HF	TFL	LCH	HAH	PH	FEMH	FLMH	SWH	HH	THH	CT	HB	HBI	FAA	TC	L_1	L_2	L_3	
																				$-W_f$TFL													rTC				
$…\lambda_h\sigma_{113})x_{113}$ ↓	$(\gamma_{114}-\lambda_h\sigma_{114})x_{114}$ ↓	$(\gamma_{121}-\lambda_h\sigma_{121})x_{121}$ ↓	$(\gamma_{122}-\lambda_h\sigma_{122})x_{122}$ ↓	$(\gamma_{123}-\lambda_h\sigma_{123})x_{123}$ ↓	$(\gamma_{124}-\lambda_h\sigma_{124})x_{124}$ ↓	$(\gamma_{214}-\lambda_h\sigma_{214})x_{214}$ ↓	$(\gamma_{321}-\lambda_h\sigma_{321})x_{321}$ ↓	$(\gamma_{322}-\lambda_h\sigma_{322})x_{322}$ ↓	$(\gamma_{323}-\lambda_h\sigma_{323})x_{323}$ ↓	$(\gamma_{324}-\lambda_h\sigma_{324})x_{324}$ ↓																											= 0 = CCa ≤ 0
$…_{113}x_{113}$ +		$a_{121}x_{121}$ +	$a_{122}x_{122}$ +	$a_{123}x_{123}$ +	$a_{124}x_{124}$ +		$a_{321}x_{321}$ +	$a_{322}x_{322}$ +	$a_{323}x_{323}$ +	$a_{324}x_{124}$	-1										-1																≤ 0
											1																										≤ LCFm
$…_{113}x_{113}$ +		$h_{121}x_{121}$ +	$h_{122}x_{122}$ +	$b_{123}x_{123}$ +			$b_{321}x_{321}$ +	$b_{322}x_{322}$ +	$b_{323}x_{323}$			+1																									≤ 0
	$c_{114}x_{114}$ +					+ $c_{214}x_{214}$							-1	-1								-1															≤ 0
													1																								≤ HHFm
$…_{113}x_{113}$ +	$d_{114}x_{114}$ +	$d_{121}x_{121}$ +	$d_{122}x_{122}$ +	$d_{123}x_{123}$ +	$d_{124}x_{124}$ +	$d_{214}x_{214}$ +	$d_{321}x_{321}$ +	$d_{322}x_{322}$ +	$d_{323}x_{323}$ +	$d_{324}x_{324}$				+1	-1								-1														≤ 0
															1																						≤ PFm
$…_{113}x_{113}$ +	$e_{114}x_{114}$ +	$g_{121}x_{121}$ +		$e_{123}x_{123}$ +	$e_{124}x_{124}$ +	$e_{214}x_{214}$ +	$e_{321}x_{321}$ +		+ $e_{323}x_{323}$ +	$e_{324}x_{324}$						-1								-1													≤ 0
																1																					≤ FEMFm
			$f_{122}x_{122}$ +					$f_{322}x_{322}$									-1								-1												≤ 0
																	1																				≤ FLMFm
$…_{113}x_{113}$ +				$g_{123}x_{123}$ +					$g_{323}x_{323}$									-1								-1											≤ 0
																		1																			≤ SWFm
$…_{113}x_{113}$ +	$p_{114}x_{114}$ +	$p_{121}x_{121}$ +	$p_{122}x_{122}$ +	$p_{123}x_{123}$ +	$p_{124}x_{124}$ +	$p_{214}x_{214}$ +	$p_{321}x_{321}$ +	$p_{322}x_{322}$ +	$p_{323}x_{323}$ +	$p_{324}x_{324}$									-1								-1										≤ 0
																			1																		≤ HFm
											-1	-1	-1		-1	-1	-1	-1	-1	+1																	= 0
																					-1	-1	-1	-1	-1	-1	-1	+1									= 0
$…_{113}x_{113}$ +	$q_{114}x_{114}$ +	$q_{121}x_{121}$ +	$q_{122}x_{122}$ +	$q_{123}x_{123}$ +	$q_{124}x_{124}$ +	$q_{214}x_{214}$ +	$q_{321}x_{321}$ +	$q_{322}x_{322}$ +	$q_{323}x_{323}$ +	$q_{324}x_{324}$																			-1								≤ 0
	$\sigma_{114}x_{114}$ +				$\sigma_{124}x_{124}$ +	$\sigma_{214}x_{214}$				$\sigma_{324}x_{324}$																				-1							≤ 0
	x_{114} +				x_{124} +	x_{214}				x_{124}																					-1						≤ 0
						x_{214}																										-1					≤ 0
																																	WhTHL+PpCT+PhHB+PhIHI+PfFAA-TC				≤ 0
																																	TC				≤ TCm
x_{113} +	x_{114} +																																	$-L_1$			≤ 0
		x_{121} +	x_{122} +	x_{123} +	x_{124} +																														$-L_2$		≤ 0
																																		$-L_1+3L_2$			= 0
						x_{214}																												$+L_1$			≤ PUL
							x_{321} +	x_{322} +	x_{323} +	x_{324}																								$L_1+L_2-L_3$			≤ 0
																																				L_3	≤ L_3m
						x_{214}																														$+4L_3$	≤ TL

Notation for Table V-1.

Activity Notation

CS, CC	Corn allocated to sale and consumption respectively
CL	Storage losses of corn
S_1, S_2, S_3	Systems one, two and three of production
T_1, T_2, T_3, T_4	Technologies one, two, three and four
LCF, LCH	Family and hired labor used for land clearing
FBF	Family labor used for field burning
HAF, HAH	Family and hired labor used for herbicide application before the planting period
HAP	Labor used for herbicide application during the planting time
PF, PH	Family and hired labor used for corn planting
FEWF, FEWH	Family and hired labor used for first early weeding
FLWF, FLWH	Family and hired labor used for first land hand weeding
SWF, SWH	Family and hired labor used for second hand weeding
HF, HH	Family and hired labor used for harvesting
TFL	Total family labor used in corn production
CF	Kilograms of corn used for planting
HB	Liters of herbicide used to control weeds
HBI	Area in which herbicide has been applied
FAA	Area in which fertilizer has bee applied
TC	Total capital used in corn production
L_1, L_2	Area planted of corn on old and new area, respectively in system one of production
L_3	Area planted of corn which has to be rotated
THL	Total hired labor used in corn production

Coefficient Notation

P_s	Price per kilogram of sold corn
P_c	Value per kilogram of domestically consumed corn
t_{12}	Coefficient which estimates storage losses as a percent of corn stored for consumption
a_{kij}	Units of labor required to clear one unit of land under the kth system of proudction on the ith type of land when using the jth weed control technology
b_{kij}	Units of labor required to burn one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
c_{kij}	Units of labor required to apply herbicide on one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
d_{kij}	Units of labor required to plant one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
e_{kij}	Units of labor required to do first early weeding on one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
f_{kij}	Units of labor required to do first late hand weeding on one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
g_{kij}	Units of labor required to do second hand weeding on one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
P_{kij}	Units of labor required to harvest one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
q_{kij}	Kilograms of corn required to plant one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
α_{kij}	Liters of herbicide required to weed one unit of land under the kth system of production on the ith type of land when using the jth weed control technology
W_f	Price per man-day of family labor

W_h	Price per man-day of hired labor
P_p	Price per kilogram of corn used for planting
P_h	Price per liter of herbicide used in controlling weeds
P_{hi}	Price per hectare of cost associated with herbicide application
P_f	Price per hectare of cost associated with fertilizer application and fertilizer use
r	interest rate on capital used
λ_h	Risk aversion coefficient
α_{kij}	Standard deviation on yield per one unit of land under the fth system of proudction on the ith type of land when using the jth weed control technology
$\overline{Y}_{kij}$	Average corn yield per unit of land under the kth system of production on the ith type of land when using the jth weed control technology
k=1	For system one of production
k=2	For system two of production
k=3	For system three of production
i=1	For previously used (old) land
i=2	For unused (new) land
j=1	For technology one of weed control
j=2	For technology two of weed control
j=3	For technology three of weed control
j=4	for technology four of weed control
h=0	For farmers with propensity to take risk equal to zero
h=0.5	For farmers with propensity to take risk equal to 0.5
h=1.0	For farmers with propensity to take risk equal to 1.0
h=1.5	For farmers with propensity to take risk equal to 1.5
h=2.0	For farmers with propensity to take risk equal to 2.0

Constraint Notation

CC_s	Semestral subsistence requirement of corn
LCF_m	Family labor available for land clearing
HAF_m	Family labor available for herbicide application before the planting period
PF_m	Family labor available for planting
$FEWF_m$	Family labor available for first early weeding
$FLWF_m$	Family labor available for first late hand weeding
SWF_m	Family labor available for second hand weeding
HF_m	Family labor available for harvesting
TC_m	Capital available for corn production
PUL	Previously used (old) land available for corn production
L_{3m}	Land available for rotation systems of production
TL	Total amount of land available for cropping

(6) Available family labor for land clearing.

The amount of family labor used by the production activities in land clearing is less than or equal to the amount available.

$$LCF \leq LCF_m$$

(7) Field burning family labor.

The amount of field burning family labor used in the production of corn in the kth system of production when using the jth weed control technology on the ith type of land minus the supply of family labor is less than or equal to zero.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} b_{1ij} X_{1ij} + \sum_{j=1}^{n} b_{32j} X_{32j} - FBF \leq 0$$

where j = 4 is equal to zero.

(8) Herbicide application labor.

The amount of labor used in herbicide application in production of corn minus the amount of family and hired labor supplied before the planting time minus the amount of labor supplied during the planting time is less than or equal to zero.

$$\sum_{i=1}^{m} C_{1i4} X_{1i4} + C_{214} X_{214} + C_{324} X_{324} - HAF - LFP - FAH \leq 0$$

(9) Available family labor for herbicide application.

The amount of family labor used by the production activities in herbicide application before the planting time is less than or equal to the amount available.

$$HAF \leq HAF_m$$

(10) Planting labor.

The amount of labor used for planting plus the amount of labor used for herbicide application during the planting time minus the

the supply of family and hired labor is less than or equal to zero.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} d_{1ij}X_{1ij} + d_{214}X_{214} + \sum_{j=1}^{n} d_{32j}X_{32j} + LFP - PF - PH \leq 0$$

(11) Available family labor during planting time.

The amount of family labor used by the production activities in planting is less than or equal to the amount available.

$$PF \leq PF_m$$

(12) First early weeding labor.

The amount of labor used in first early weeding (hand weeding and herbicide) minus the supply of family and hired labor is less than or equal to zero.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} e_{1ij}X_{1ij} + C_{214}X_{214} + \sum_{j=1}^{n} e_{32j}X_{32j} - FEWF - FEWH \leq 0$$

where j=2 is equal to zero.

(13) Available family labor for first early weeding.

The amount of family labor used by the production activities in early weeding is less than or equal to the amount available.

$$FEWF \leq FEWF_m$$

(14) First late hand weeding labor.

The amount of first late hand weeding labor used in production of corn minus the supply of family and hired labor is less than or equal to zero.

$$\sum_{i=1}^{m} f_{1i2}X_{1i2} + f_{324}X_{324} - FLWF - FLWF \leq 0$$

(15) Available family labor for first land hand weeding.

The amount of family labor used by the production activities in first late hand weeding is less than or equal to the amount available.

$FLWF \leq FLWF_m$

(16) Second hand weeding labor.

The amount of second hand weeding labor used in production minus the supply of family and hired labor is less than or equal to zero.

$$\sum_{i=1}^{m} g_{1i3}X_{1i3} + g_{323}X_{323} - SWF - SWH \leq 0$$

(17) Available family labor for second hand weeding.

The amount of family labor used by the production activities in second hand weeding is less than or equal to the amount available.

$SWF \leq SWF_m$

(18) Harvesting labor.

The amount of labor used in harvesting corn minus the supply of family and hired labor is less than or equal to zero.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} P_{1ij}X_{1ij} + P_{214}X_{214} + \sum_{j=1}^{u} P_{32j}X_{32j} - HF - HH \leq 0$$

(19) Available family labor for harvesting.

The amount of family labor used by the production activities in harvesting corn is less than or equal to the amount available.

$HF \leq HF_m$

(20) Total use of family labor.

The following is an accounting equation which says that the total supply of family labor minus the used family labor to perform the different activities is equal to zero.

$$-LCF - FBF - HAF - PF - FEWF - FLWF - SWF - HF + TFL = 0$$

(21) Total use of hired labor.

The following constraint is also an accounting equation which says that the total supply of hired labor minus the used hired labor to the different cropping activities is equal to zero.

$$-LCC - HAH - PH - FEWH - FLWH - SWH - HH + THL = 0$$

(22) Corn for planting.

The total amount of corn used for planting minus the supply of corn seeds is less than or equal to zero.

$$\sum_{i=1}^{m} \sum_{j=1}^{n} q_{1ij}X_{1ij} + q_{214}X_{214} + \sum_{j=1}^{n} q_{32j}X_{32j} - CF \leq 0$$

(23) Herbicide use.

The amount of herbicide used in controlling weeds in corn production minus the supply of herbicide is less than or equal to zero.

$$\sum_{i=1}^{m} \alpha_{1i4} + \alpha_{214}X_{214} + \alpha_{324}X_{324} - HB \leq 0$$

(24) Area in which herbicide has been applied.

The following constraint is an accounting equation which sums up the total area in which herbicide has been applied. Further, in the capital constraint, this amount of land times the cost of herbicide application per unit of land will account for the total herbicide application costs. Herbicide application cost is defined as the cost of maintenance of the equipment used for herbicide application plus its depreciation.

$$\sum_{i=1}^{m} X_{1i4} + X_{214} + X_{324} - HBI \leq 0$$

(25) Area in which fertilizer has been applied.

The total amount of land in which fertilizer has been applied minus the supply of land in which fertilizer has to be used is less than or equal to zero.

$$X_{214} - FAA \leq 0$$

(26) Capital use.

The following constraint sums up the total amount of capital uses in production of corn, where the capital is used for hiring labor, purchasing corn seeds for planting, fertilizer and herbicide, and covering expenses of herbicide application. The total capital used in production less the amount of capital supplied is less than or equal to zero.

$$H_w THL + P_s C_F + P_h HB + P_{hi} HI + P_f FAA - TC \leq 0$$

(27) Available capital.

An upper limit on the amount of capital than can be used in production of corn is set. It requires that capital used in corn production be less than or equal to the maximum availability of capital for corn production.

$$TC \leq TC_m$$

(28) Previous used land to system one of production.

The amount of previously used land devoted to system one of production minus the supply of land to this system is less than or equal to zero.

$$\sum_{j=1}^{n} X_{11j} - L_1 \leq 0$$

(29) Unused land to system one of production.

The amount of unused land devoted to system one of production minus the supply of this type of land to system one is less than or equal to zero.

$$\sum_{j=1}^{n} X_{12j} - L_2 \leq 0$$

(30) System one of production

The following constraint says that if previously used land in corn production is used in corn production, one-fourth of the total cropped area must come from unused land to maintain the four years rotation cycle of production.

$$-L_1 + 3L_2 = 0$$

(31) Use of previously used land.

The amount of previously used land either under system one of production and/or system two of production must be less than or equal to the total land available.

$$L_1 + X_{214} \leq PUL$$

(32) Accounting equation for land to be used in rotation.

The amount of land planted to corn which does not receive a fertilizer application must be rotated. That is, land under system one and three of production minus the supply of land is less than or equal to zero.

$$L_1 + L_2 + \sum_{j=1}^{n} X_{31j} - L_3 \leq 0$$

(33) Maximum of land to be in rotation.

The amount of land to be in rotation is less than or equal to the land available for rotation.

$$L_3 \leq L_{3m}$$

(34) Use of land both under rotation and no-rotation systems.

The amount of cropped land under the rotation system must be equal to the total land available for corn cropping minus the amount of land devoted to the permanent system of production, and this difference divided by four.

$$L_3 \leq \frac{TL - X_{214}}{4}$$

VI. MODEL VALIDATION AND RESULTS

The empirical results of the model are presented in this chapter. In order to satisfy the reader that the model actually represents the existing production processes in the Atlantic Plain of Nicaragua, evidence of the validity of the model will be presented. Basically, this will consist of an attempt to describe how the model predicts PRICA farmer behavior. Subjective as well as empirical tests will be used to measure the difference between the actual production process and the model prediction.

Following validation, a comparison will be made in the model results of the situation where only traditional weed control technologies are allowed and where both traditional and modern (technologies proposed by IPPC) weed control technologies are allowed. Then, comparisons will be made between the two plans on farmer income and on factor intensities in the system of production with the adoption of the new technologies. The difference between constrained and unconstrained capital in technology adoption will also be considered, as well as the differences in assumed opportunity cost for family labor.

Model Validation

The ultimate test of a model's validity depends upon its purpose. If a model is to forecast then the final test is its ability to accurately predict future events. Conversely, if a model was developed to aid decision makers, its validity is ultimately measured by the degree of its use in the decision making process. Such tests, however, require large amounts of time and, hence, are not generally practical for most model validation exercises. Therefore, one must usually rely on comparison between behavior predicted by the model and what presently exists.

Before turning to the validation process, it is appropriate to review the reasons why a model may be validate. Discrepancies between solutions of linear programming (LP) models and reality arise from several causes. Among these causes for discrepancies are:

(1) Poor conceptualization of the problem.

The basic structure of the LP model may be misspecified or not relevant to the problem.

(2) Misspecification of technical coefficients and constraints.

Poor sampling may lead to misspecification of technical coefficients and constraints. That is, (a) the sample used to calculate the value of the different coefficients and constraints may not in fact represent the population, (b) the methodology used to collect the sample may be inappropriate, (c) calculation errors may exist, (d) the wrong data may be collected, and (e) the sources of data may be unreliable. The latter may be the largest problem in developing countries since the farmers do not keep records of production. Therefore, the data are almost always obtained from the farmers' memories.

(3) Error arising due to faulty coefficient placament.

Wrong placament of coefficients in the decision variables, when the computer analysis of the problem is being done, also may lead to model solutions which are discrepant from reality.

(4) Aggregation bias.

The only way in which aggregation bias can be avoided is by constructing a farm model for each individual farm (Buckwell and Hazell, 1972) but in practice it is not possible to do so. Hence, aggregation bias will occur when a "representative farm(s)"[1/] approach is used to represent the group of all farms.

(5) Solution with the wrong method.

The economic and technical relationships among factor of production and yield are assumed to be linear in LP formulations, but such relationships may be nonlinear in reality.

Many of these errors may be corrected if the user knows or can investigate what is causing the error. However, first one must judge that a model is invalid. Such a judgment requires one to identify what needs to be validated and what criteria could be used to render the model inadequate.

Two types of methods have been historically used to validate linear programming models-validation by construct (a check of internal consistency) and validation by results.

Validation by Construct

Validation by construction requires correct specification of the model as defined by an accepted theory of behavior. In this study, the economic theory of production and decision making serves as the acceptable base. The objective function, coefficients, prices, and

1/ The representative farms represent a group of homogeneous farms which tend to have the same rate of factor use, resource availability, and activities.

restrictions were developed consistent with this theory. The believability of the model can be checked by observing the economic conditions and verifying that the results are reasonable both from experience and theory. This method checks the mechanism of the model rather than the approximation of its solution to those existing in the real world.

Actual tests of the model consistency were performed by changing various model coefficients and noting the change in the performance variables. For example, when the opportunity price of family labor is reduced, more family labor is used. As the amount of family labor is increased, a marked reduction in the amount of hired labor is noted. Increasing the price of corn results in more output, as does increases in the demand for corn subsistence. Capital is not a production constraint, when family labor is abundant. It becomes a constraint, when large amounts of labor must be hired. Since these results are thoroughly explainable by economic theory, the model was assumed to pass the first test.

Validation by Results

A more formal validation process is conducted through comparison of model results with corresponding real world vectors.

Let Y_i denote the actual output of farmer i, X_j the actual amount of the jth input usage in the ith farm, C_{ij} the actual cost of the jth input used in the farm, $\overline{Y}_i$ the model solution vector for farm output, $\overline{X}_{ij}$ the model solution vector of the jth used input and $\overline{C}_{ij}$ the shadow price. Then, the deviation resulting from LP solutions will be said to be the differences between the model solutions and the correspondent real world vector. That is,

(1) $\sum_{i} |\overline{Y}_i - Y_i| = B_1$

(2) $\sum\sum_{ij} |\overline{X}_{ij} - X_{ij}| = B_2$

(3) $\sum\sum_{ij} |\overline{C}_{ij} - C_{ij}| = B_3$

where B_1, B_2, and B_3 are the deviations of the model output decision variables and input costs, from the real world solution. The greater the value of B_k, the greater the doubt of the validity of the constructed model.

To test B_k, several methods have been proposed. Two error tests will be discussed and used here, the mean absolute error (MAE) and the mean absolute relative error (MARE).

Mean Absolute Error (MAE)

The error tests[2/] have been widely used to validate risk programming models (Brink and McCarl, 1978; Escobar, 1980; Hazell *et. al.*, 1978; Nieuwouldt and Mathia, 1976) and trade forecasting models (Kost, 1980). Basically, such tests measure the "goodness of fit" or deviation of a simulated variable from its correspondent real world one. In all tests, the smaller the error, the better the fit.

Among the error tests, the mean absolute error (MAE) also known as mean absolute deviations (MAD), is probably the error test which has been most often used for validation (Brink and McCarl, 1978; Hazell *et. al.*, 1978). Hazell *et. al.*, however, recognize a problem[3/] of using

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2/ Error tests are alternative measures of simulation errors which measure the deviation path. The known error tests are (a) a sample measure in mean error, (b) the mean absolute error, (c) the root mean square error, (d) the mean absolute relative error, (e) the root mean square percentage error.

3/ This disadvantage recognized by Hazell *et. al.* when using the mean absolute error test can be generalized for the other error tests given that all of them are based on the same principle of measuring the deviation of a simulated variable for the actual path.

this test for validation. For a cross-sectional study, the MAE is specified as follows:

$$MAE = \frac{1}{N} \sum_{n=1}^{n} |\overline{Y}_n - Y_n|$$

where Y_n is the predicted value for the nth variable

Y_n is the actual level of the nth variable

N is the number of variables

The absolute value is used instead of the numeric value to avoid large positive and negative errors offsetting each other.

Mean Absolute Relative Error (MARE)

A second test is the mean absolute relative error (MARE). It provides a basis of comparison in terms of the average size of the variable validation results.

$$MARE = \frac{1}{N} \sum_{n=1}^{n} \left| \frac{\overline{Y}_n - Y_n}{Y_n} \right|$$

Validation Results

As the basic data available for this study come from a cross-sectional survey where the true estimate of the risk parameters are unknown, comparison of model solution and the real world objective function may not be an unambiguous method of model validation. Ideally, the model should validate regardless of the level of risk aversion. However, since it is impossible to do this, one is left with either assuming a value of risk aversion coefficient (for example, or risk neutral) or performing the tests varying risk aversion coefficients. The latter is done in this study.

Also, a decision must be made as to which of the various stratifications of the data will be used as the case of reference (actual case). Since there are three family sizes of labor which are in approximate equal number, a decision was arbitrarily made to accept group one (one family laborer) as the base, or actual case. Farmers in this group produce corn using production system one and production system three with the associated traditional weed control technologies. The record is not clear, however, on the number using each production system. In the author's opinion, however, production system one predominates.

The weed control techniques used by the group one farmers also vary (see Appendix Table C-1). Approximately one-third of the farmers use each of the three weed control procedures. There appears to be no marked preference for one system over the others. For purposes of validation, though, T_1 will be used as the base. Thus, the data base that constitutes the "actual situation" is derived from farms in which there is only one worker using weed control technology one.

The model predicts the exclusive use of technology one only with $\lambda \geq 0.5$. At $\lambda = 0.0$ combinations of T_2 and T_3 are selected (see Table VI-1). While this does not allow comparison with what is described as the "actual situation" (T_1 is not brought into the solution), it is consistent with group one farmers in that they use all three technologies.

Table VI-1 gives the results of the comparison of the "actual situation" with model solutions with varying risk aversion parameters. Only selected land and labor coefficients were used.

As is seen using both analytical techniques, MAD and MARE, a reduction in the absolute deviation occurs as λ is increased. The smallest absolute error is obtained with a risk aversion coefficient of two. This is consistent with previous studies. Nieuwoudt and Mathia (1976) in comparing alternative policies in peanut production, reported that a risk aversion coefficient equal to two provided the best fit between the predicted and observed peanut cropped areas in the Southeast U.S. Hazell et. al. (1978) reported that a risk aversion coefficient of 1.5 or 2.0 provided the best description of cropping patterns and process of short cycle crop in Mexico.

The purpose of this study, however, is not to determine the risk aversion coefficient of PRICA farmers. In fact, from the data available, it is impossible to do so. But the results indicate that as λ increases, the model predicts a change in the selection of the weed control technologies. As λ increases the acreage of corn also drops since the perception of gain is lowered. Again, this is consistent with the PRICA farms since they show no marked preferences for a weed control technology and have relatively low levels of corn acreage.

Based on the two tests--constructed and results--the model is believed to be sufficiently accurate for the purposes of this study.

Table VI-1. Comparison of Actual Plan with Model Solutions[a/].

	Actual	=0.5	=1.0	=1.5	=2.0
Land	1.93	3.68	3.68	3.36	1.85
Land clearing labor	13.00	28.86	28.86	25.98	13.93
Planting labor	6.00	11.77	11.77	10.75	5.95
First early weeding labor	9.00	19.87	19.87	18.14	10.04
Harvesting labor	16.00	30.92	30.92	27.88	15.43
MAD		9.83	9.83	8.04	0.53
MARE		1.05	1.05	0.86	0.06

[a/] For group one farms and T_1 is used for controlling weeds.

Results

In this section, the empirical results of the model are presented. First, for each farm case and level of farmer propensity to take risk, optimal plans of corn production are obtained with only traditional systems of weed control and then both traditional and "new technologies". Second, comparisons are made between the prediction for the two technology systems, on income and factor intensities.

Empirical Results[4/]

The empirical results for the seven different farm cases are summarized in Tables VI-2 to VI-5 and presented in detail in Tables B-1 to B-14 in the Appendix. A quick view of the tables shows that where there are two and three family workers available in the farm unit, model results indicate that capital is no longer a constraint with only traditional systems of weed management. As a consequence, cases four and five have the same optimal solutions as do cases six and seven.

Optimal solutions for each farm case are obtained under five levels of farmer propensity to take risk. These propensities are zero (risk neutral), 0.5, 1.0, 1.5, and 2.0[5/].

In this study, net revenue is a major performance variable. It is derived by subtracting total variable costs of production (including a charge for family labor) from total revenue. Total farmer revenue is defined as the quantity of corn allocated to consumption times the corn

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4/ It should be recalled that all results presented in this section are obtained from model predictions. When information about real data is presented, it is identified with the adjective "actual".

5/ The representative farms represent a group of homogeneous farms which tend to have the same rate of factor use, resource availability, and activities.

retail price plus the quantity of corn allocated to sale times the corn farm gate price. However, since the quantity of corn allocated to consumption does not have a true cash value to the farmers, net cash income is also calculated. It is the difference between the cash costs of production (no charge for family labor) and the value of corn sold.

Empirical Results for Traditional Technologies

Case One

The empirical results for case one farms using traditional systems of weed control are presented in Table VI-2, columns two, three and four; and in Table C-1 of the Appendix. Farmer net revenue, as predicted by the model, ranges from $2,806.07[6/] to -$4.25, depending on the value of λ. It is highest when λ is zero and lowest when it equals two. For the same levels of farmer propensities to take risk, the net cash incomes were calculated to be $3,778.40 and -$59.66, respectively.

At the lower levels of risk aversion, the model predicts maximum use of internal capital. Thus, capital is a production constraint for farmers who are at low levels of risk aversion. But farmers with risk aversion coefficients equal to 1.5 or higher do not use the maximum level of available internal capital and capital is no longer a constraint.

Propensity to take risk not only affects the level of capital, but it also affects the system of corn production and the amount of labor used in corn production. At the zero level of risk aversion, the farmers of case one will use a combination of production systems one and three. Farmers with higher propensity to take risk, though, tend to utilize production system one. Production system one, as previously stated, utilizes the maximum amount of previously used (old) land,

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6/ In this section $ stands for cordobas.

Table VI-2. Selected Empirical Results for the Four Cases Which Have One Family Worker, and Non-Zero Opportunity Cost is Assigned for Family Labor.

Weed Control Technologies	Traditional						Modern					
Capital	Constrained			Unconstrained			Constrained			Unconstrained		
Risk aversion coefficient	0.0	1.0	2.0	0.0	1.0	2.0	0.0	1.0	2.0	0.0	1.0	2.0
Net revenue	2806.1	989.6	-4.3	3310.7	1057.5	-4.3	3315.6	2134.9	964.2	6055.7	3657.5	1253.2
Net cash income	3778.4	1481.8	-59.7	4125.3	1553.4	-59.7	3922.7	2633.4	1462.7	6655.1	4194.0	1852.6
Total area	3.81	3.68	1.85	4.13	4.13	1.85	3.17	2.98	2.98	6.02	6.02	6.02
System One of Production												
Old Land: T_1		2.52	1.39		2.52	1.39						
T_2	0.42											
T_3	2.10						0.52					
T_4							1.10	1.17	1.17			
New Land: T_1		0.84	0.46		0.84	0.46						
T_2	0.84											
T_3												
T_4							0.54	0.39	0.39			
System Two of Production: T_4										2.52	2.52	2.52
System Three of Production												
T_1		0.32			0.77							
T_2												
T_3	0.45			4.13			1.01	1.42	1.42	3.50	3.50	3.50
Total corn production	3520.6	2124.5	662.0	4658.7	2419.6	662.0	3608.4	2824.6	2112.9	7257.2	5799.2	4337.8
Capital use	840.0	840.0	54.24	2226.5	1216.1	54.24	840.0	840.0	840.0	3812.7	3812.7	3812.7
Labor: Family	83.4	65.9	46.0	77.62	66.0	46.0	70.1	66.1	66.1	69.8	69.8	69.8
Hired	26.1	26.6	--	76.02	39.8	--	13.5	12.4	12.4	91.0	91.0	91.0
Total	109.5	92.5	46.0	153.64	105.8	46.0	83.6	78.5	78.5	160.8	160.8	160.8

bringing into production only the minimum amoung of fallowed (new) land required to maintain the rotation. This is consistent with the current systems of corn production of PRICA farmers and suggests that PRICA farmers may, on the average, have high risk aversion coefficients.

Regarding labor usage for weed control, at the lower levels of risk aversion the farmer strategy is to utilize the maximum amount of available labor in hand weeding. In fact, when the risk aversion coefficient is equal to zero, the model predicts an early hand weeding, a late hand weeding, and a second hand weeding since technology two and three to control weeds are part of the optimal solutions. When higher levels of risk aversion are introduced into the model, the amount of labor devoted to hand weeding is reduced. For instance, when the risk aversion coefficient is equal to 0.5 or higher, neither the late hand weeding, nor the second hand weeding are utilized.

The total use of family labor decreases from 84.4 (when the risk aversion coefficient is equal to zero) to 46 man-days (when the risk aversion coefficient is equal to two). Total hired labor decreases from 26.1 man-days to zero, respectively. If net revenue were used exclusively for payment to family labor, the return to family labor would be 61.2, 42.5, and 27.5 per man-day for risk aversion coefficients equal to zero, 1.0, and 2.0, respectively. All are equal to or higher than the existing wage rate. It should be remembered, though, that as λ increased, perceived yields decreased. Thus, it is natural to have a deminishing value for labor.

Case Two

The empirical results of the model for farm case two are given in columns five, six and seven of Table VI-2 and Table C-3 in the Appendix.

Case two, it will be recalled, is similar to case one except that the capital constraint is released. The optimal plans of production for farmers with risk aversion coefficients equal to 1.5 or higher, though, do not change relative to those of case one. This occurs because farmers in case one did not use the maximum amount of internal capital and were therefore already unconstrained. However, the optimal plans for farmers with low levels of risk aversion do change when the capital constraint is released. For instance, when the risk aversion coefficient is equal to zero, the net revenue increases from $2,806.07 to $3,310.70 and capital is increased from $840.00 to $2,263.48. If we assume that this increase in net revenue is exclusively caused by the increase in the use of capital, the net rate of return[7/] to borrowed capital is 36 percent. The net rate of return to borrowed capital for risk aversion coefficients of 0.5 and 1.0 were found to be 27 percent and four percent, respectively.

The optimal systems of corn production also change in case two in comparison to case one. When capital is not a constraint, the risk neutral farmers prefer to produce corn in previously unused land. Farmers with higher levels of risk aversion, however, use previously used land as in case one.

The extra borrowed capital is mainly used to hire labor. The units of hired labor increase from 26.1 man-days to 76.02 when the risk aversion coefficient is equal to zero, from 26.64 to 56.22 when the risk aversion coefficient is equal to 0.5, and from 26.64 to 39.84 when the risk aversion coefficient is equal to 1.0.

7/ Net rate of return is defined as the rate of return to borrowed capital discounted for the paid interest rate.

Case Three

The empirical results for case three are given in Table VI-3, columns two, three and four and Table C-5 in the Appendix. The assumptions made in case three are identical to those of case one, except that family labor is assumed to have a zero opportunity cost. Thus, net revenue and cash income are provided to increase in case three compared to case one. Results differ even though both cases one and three have capital as a constraint. The farmers of case three adopt different corn systems at the same levels of risk aversion than farmers of case one. Also, the farmers of case three have a tendency to crop more area. Moreover, when the risk aversion coefficient is equal to two, the farmers of case three still produce some corn for sale and hire small amounts of labor.

Cases Four and Five

The predicted empirical results for these farm cases are given in columns three, four and five of Table VI-4 and in Table C-7 of the Appendix section. The net revenues range from $3,600.74 for farmers with risk aversion coefficients equal to zero to $-6.31 for farmers with risk aversion coefficients equal to two. The total cash income ranges from $5,557.25 to $-88.57, respectively, for both farmers.

For these cases, capital is no longer a constraint. The amount of internal capital used in corn production is lower than the amount of capital available. As a consequence, case five has the same optimal solutions as case four for the various levels of risk aversion.

The optimal system of production predicted by the model for the farmers at different levels of risk aversion are similar to those of case two. That is, the farmers with low levels of risk aversion prefer

Table VI-3. Selected Empirical Results for the Farm Cases Which Have One Family Worker, and Zero Opportunity Cost is Assigned for Family Labor.

Weed Control Technology: Capital	Traditional Constrained			Modern Constrained		
Risk aversion coefficient	0.0	1.0	2.0	0.0	1.0	2.0
Net revenue	5103.1	2801.7	1654.8	5347.5	3953.3	2782.6
Net cash income	3748.3	1481.8	335.4	4028.6	2633.4	1462.7
Total area	3.88	3.68	2.89	3.69	2.97	2.97
System One of Production						
Old Land: T_1		2.52	2.17			
T_2	0.78			0.06		
T_3	1.73			1.23		
T_4				1.23	1.17	1.17
New Land: T_1		0.84	0.72			
T_2	0.84			0.84		
T_3				0.33	0.39	0.39
System Two of Production: T_4						
System Three of Production						
T_1		0.32				
T_2						
T_3	0.53					
T_4					1.42	1.42
Total corn production	3524.3	2124.5	1029.7	3672.8	2824.6	2112.9
Capital use	840.0	840.0	244.9	840.0	840.0	840.0
Labor: Family	83.7	65.9	65.7	78.2	66.1	66.1
Hired	26.0	26.0	5.8	15.6	12.4	12.4
Total	109.7	92.5	71.5	93.8	78.5	78.5

Table VI-4. Selected Empirical Results for the Farm Cases Which Have Two Family Workers, and Non-Zero Opportunity Cost is Assigned for Family Labor.

Weed Control Technologies: Capital	Traditional Unconstrained[a/]			Modern Constrained			Modern Unconstrained		
Risk aversion coefficient	0.0	1.0	2.0	0.0	1.0	2.0	0.0	1.0	2.0
Net revenue	3600.7	1294.9	- 6.31	5223.9	3343.0	1456.4	6355.5	3957.2	1533.1
Net cash income	5557.3	2618.7	-88.57	6829.8	4942.9	3056.3	8194.8	5796.4	3392.3
Total area	4.13	4.13	2.76	4.62	4.62	4.62	6.02	6.02	6.02
System One of Production									
Old Land: T_1		0.44	2.07						
T_2									
T_3									
T_4				0.38	0.38	0.38			
New Land: T_1		0.15	0.67						
T_2									
T_3									
T_4				0.13	0.13	0.13			
System Two of Production: T_4				0.65	0.65	0.65	2.52	2.52	2.52
System Three of Production									
T_1		3.54							
T_2									
T_3	4.13								
T_4				3.46	3.46	3.46	3.50	3.50	3.50
Total corn production	4658.7	2655.3	982.8	5692.7	4549.2	3402.5	7257.2	5799.2	4253.7
Capital Use	445.0	120.5	80.5	840.0	840.0	840.0	1933.3	1933.3	1933.3
Labor: Family	142.4	119.4	68.3	129.4	129.4	129.4	138.1	138.1	138.1
Hired	11.2	--	--	3.3	3.3	3.3	22.7	22.7	22.7
Total	153.6	119.4	68.3	132.7	132.7	132.7	160.8	160.8	160.8

[a/] Unconstrained solutions is identical to the constrained solution.

to crop corn in new areas each year, but as the risk aversion coefficient increases, the farmers tend to utilize previously used land.

The rate of return to family labor is $52.79, $38.35, and $27.50 for risk aversion coefficients equal to 0.0, 1.0, and 2.0, respectively. The rate of return to family labor is lower for cases four and five than for cases one and two since the rate of family labor used per unit of land is greater than in case one and two. In case two the intensity of family labor use was 28.79, 15.99 and 24.85 units of family labor per hectare for risk aversion coefficient equal to 0.0, 1.0, and 2.0, respectively. For case four the use of family labor per hectare of cropped area is 34.48, 28.91, and 24.73, respectively for the same levels of risk aversion.

Survey data indicate that low levels of capital use and high levels of family labor used in corn production are common strategies of the PRICA farmers who belong to this group. The above results confirm such strategies.

Predictions from the model indicate that farmers of case four behave as farmers of cases one and two with respect to weed management strategies. At low levels of risk aversion, such farmers tend to utilize the maximum amount of labor in hand weeding, but when the risk aversion coefficient increases, the farmers tend to use the traditional technology that minimizes the use of labor, i.e., technology one.

Cases Six and Seven

Columns two, three and four of Table VI-5 and Table C-10 in the Appendix show the empirical results for a farm unit in which there are three family workers available.

For farm cases that have three family workers, the net revenue is $3,518.71 and $-4.23 for farmers with propensity to take risk equal to zero and two, respectively. For the same farmers the corresponding levels of cash income are \$6,430.30 and \$-59.38.

Similar to the farmer cases which have two family workers, capital is not a constraint under the traditional systems of production for farmers with three family workers. They do not utilize the internal capital available to them.

The rates of return to family labor for these cases are \$50.40, \$37.20, and \$27.50 per man-day for level of risk aversion equal to 0.0, 1.0, and 2.0, respectively. Farmers of cases six and seven use slightly higher amounts of family labor in corn production relative to farmers of cases four and five. Similar to cases four and five, farmers of cases six and seven do not use hired labor for corn production. Again, this is consistent with what present PRICA farmers of this group are doing.

With respect to systems of production, farmers with low propensity to take risk produce corn using the system of production that produces the highest yields, that is, cropping in a new area every year (system three). Moreover, these farmers will use the weed control technology that also produces the highest yield (technology three). But farmers with higher levels of risk aversion tend to produce corn using system of production one which maximizes the use of previously used land, and using weed control technology one, which minimizes the use of labor in weed control.

Empirical Results for New Weed Control Technologies

The predicted impact of introducing the new weed control technologies into the current systems of corn production of PRICA farmers under the three sizes of available family labor are examined in the following material. Each case is compared to its corresponding case where only traditional technologies were allowed.

Case One

The empirical results of case one are presented in Table VI-2, columns eight, nine and ten and in more detail in Table C-2 in the Appendix.

The introduction of new weed control technologies as predicted by the model increases the net revenue by $509.57, $1,145.31, and $968.44 to the farmers who have risk aversion coefficients equal to 0.0, 1.0, and 2.0, respectively. The variation in farmer net revenue occurs because of changes in intensity of cropping done by farmers at different levels of propensity to take risk. In fact, when the risk aversion coefficient is equal to zero, farmers utilizing traditional weed control technologies employ the maximum internal capital in the production of corn, but farmers with higher levels of risk aversion tend to use only part of their resources (farmers with risk aversion equal to 1.5 or higher were not utilizing the maximum amount of internal capital). When the new technology of weed control is introduced, farmers with low levels of risk aversion increase net revenue by substituting the new technologies for hired labor. Farmers with higher levels of risk aversion, however, employ all of the internal capital, crop more areas, and actuall increase the amount of hired labor.

The system of production does not change when the risk aversion parameter is varied between 0.5 and 2.0. Farmers use a combination of systems one and three of production, cropping 1.56 hectares under system one of production (1.17 hectares in previously used land and 0.39 hectares in unused land) and 1.42 hectares under system three.

Table VI-5. Selected Empirical Results for the Farm Cases Which Have Three Family Workers, and Non-Zero Opportunity Cost is Assigned for Family Labor.

Weed Control Technology:	Traditional			Modern					
Capital	Unconstrained[a]			Constrained			Unconstrained		
Risk aversion coefficient	0.0	1.0	2.0	0.0	1.0	2.0	0.0	1.0	2.0
Net revenue	3518.7	1185.3	-4.23	5438.4	3416.8	1388.8	6305.0	3906.6	1502.5
Net cash income	6430.3	3233.7	-59.38	8057.9	6036.3	4008.4	9413.7	7015.32	4611.2
Total area	4.13	4.13	1.85	4.94	4.94	4.94	6.02	6.02	6.02
System One of Production									
Old Land: T_1			0.39						
T_2									
T_3									
T_4									
New Land: T_1			0.46						
T_2									
T_3									
T_4									
System Two of Production: T_4				1.08	1.08	1.08	2.52	2.52	2.52
System Three of Production									
T_1		4.13							
T_2									
T_3	4.13								
T_4				3.86	3.86	3.87	3.50	3.50	3.50
Total corn production	4658.6	2705.2	658.8	6119.2	4890.0	3657.2	7257.2	5799.2	4337.8
Capital use	135.9	120.46	54.0	840.0	840.0	840.0	1309.7	1309.7	1309.7
Labor: Family	153.6	122.25	45.8	143.0	143.0	143.0	160.8	160.8	160.8
Hired	--	--	--	--	--	--	--	--	--
Total	153.6	122.25	45.8	143.0	143.0	143.0	160.8	160.8	160.8

[a] Unconstrained solution is identical to the constrained solution.

If net revenue is considered as the return to family labor, the return per man-day of labor is \$74.82, \$59.89, and \$42.08 for farmers with propensity to take risk equaling 0.0, 1.0, and 2.0, respectively.

Case Two

Case two results as predicted by the model are presented in Table VI-2, columns 11, 12, and 13 and in more detail in Table C-4 in the Appendix. If the capital constraint is released, the farmers use production system two (production on previously used land), and production system three. Comparing the optimal solutions of thise case with case one when modern weed control technologies are available, net revenue increases by \$2,740.054, \$1,522.57, and \$289.05 for farmers with risk aversion coefficients equal to 0.0, 1.0, and 2.0, respectively. Such increases in net revenue represent a net return to borrowed capital equaling 92, 51, and 10 percent, respectively.

Case Three

A summary of the predicted empirical results for case three are given in columns five, six and seven in Table VI-3. Complex results are shown in Table B-6 in the Appendix. When only the traditional weed control technologies are available for corn production, cases one and three have different optimal plans of production for farmers with the same level of risk aversion. In contrast, when the new technology is introduced, farmers of cases one and three with equal propensity to take risk and propensity equal to or greater than 0.5 have the same optimal plans of production. Only farmers with risk aversion coefficients equal to zero use different systems of production. In this situation, the farmers prefer to use more labor for weed control and purchase hired labor rather than herbicide.

Case Four

Table VI-4, columns five, six, and seven provides a summary of predicted results for case four. They are presented in more detail in Table C-8 in the Appendix.

When the new weed control technologies are introduced into the production system of case four, the farmer net revenue increases by $1,623.11, $2,048.09, and $1,462.74 for farmers with risk aversion coefficients equal to 0.0, 1.0, and 2.0, respectively. The increase in net cash income for the same farmers is $1,266.50, $2,324.17, and $3,144.89, respectively.

All the farmers in case four, even with different propensities to take risk, use the maximum amount of internal capital, which is in marked contrast to the situation when only traditional technologies are available. Previously farmers did not use the maximum amount of internal capital.

The farmers use all three systems of production for corn and the amount of land cropped by the farmers remains constant regardless of the level of risk aversion, i.e., 0.5 hectares in production system one (0.38 hectares in previously used land and 0.13 hectares in new land), 0.65 hectares in system two, and 3.46 hectares in system three. In all cases, the farmers use weed control technology four (the new weed control technology) for controlling weeds.

With respect to labor use intensities, the farmers with risk aversion coefficients equal to zero hire 70 percent less labor, while farmers with risk aversion coefficients equal to 0.5 will hire 70 percent more labor when compared to the situation when only traditional technologies are available. Farmers with risk aversion coefficients equal to 1.0 or greater will hire 3.34 man-days compared to zero labor when only the traditional weed control technologies are available.

If net revenue is assumed to be the return to family labor, each man-day of family labor will be valued at $67.85, $53.33, and $38.75 for farmers with risk aversion coefficients equal to zero, 1.0, and 2.0, respectively.

Case Five

Table VI-4, columns eight, nine and 10 and Table C-9 in the Appendix give the empirical results for case five.

If the capital constraint is released, the increase in net revenue for farmers with propensity to take risk equal to 0.0, 1.0, and 2.0 will be $1,131.68, $614.19, and $96.95, respectively. If this increase in net return is returned to the use of external capital, the net rate of return to borrowed capital will be 104, 56, and nine percent for the same level above risk aversion coefficients.

When the capital constraint is released, the farmers crop the previously used land under production system two (the 2.52 hectares) and the rest of the land (3.50 hectares) under production system three. Additionally, the availability of external capital will generally increase the use of family labor from 129.43 to 138.13 man-days and the use of hired labor from 3.34 to 22.67 man-days.

Case Six

Table VI-5, columns five, six and seven and Table C-11 in the Appendix show the empirical results for this case.

The new technology will benefit the farmers of case six. They generally utilize higher proportions of family labor and their entire unused internal capital when the new weed control technology is introduced. Famaily labor changes by -7, 19, and 165 percent, respectively, for propensity to take risk coefficients of 0.0, 1.0, and 2.0. Increases in these of internal capital and family labor which accompanied an increased in cropped area, result in an increase of net revenue for these farmers of -1,919.70, $2,231.48, and $1,309.07, respectively, when compared to the corresponding net revenues when only the traditional weed control technologies were available.

If the increased net revenue is entirely credited to family labor, the net return to a family worked day will be $65.53, $51.39, and $37.21 for farmers with risk aversion coefficients equal to 0.0, 1.0, and 2.0, respectively. Comparison of the returns to family labor with the corresponding return under the traditional systems reveals the increase in return to a family worked day of $15.33, $14.19, and $9.71, respectively.

Production systems two and three and the new weed control technology are used exclusively by farmers, regardless of the level of risk aversion when the new technologies are made available. That is, 1.08 hectares under system two of production and 3.86 hectares under system three of production.

Case Seven

Table VI-5, columns eight, nine and ten in this chapter and Table C-12 in the Appendix show the empirical results for case seven.

When the capital constraint is released for case six, the farmers will increase the amount of land used in production to 6.02 hectares. However, the systems of production and the weed control technologies remain the same. Although comparatively more of the total production area is in system two in the unconstrained case, this results in more total labor use.

The relaxation of the capital constraint will increase the use of capital by $469.70, the use of labor by 17.78 man-days, and the use of land by 1.08 hectares. Such increases in factors of production will increase net revenue of case seven by $866.54, $489.81, and $113.67. If we assume that the increase in net revenue occurs because of borrowed capital, the net rate of return to borrowed capital will be 184, 104, and 24 percent. Even though the extra use of capital will increase the net return of the farmers, the rate of return per family worked day will not increase. In fact, such returns are $66.71, $51.79, and $35.84 (which are similar to the constrained case).

VII. SUMMARY AND CONCLUSIONS

Summary

The objectives of this study were:

(1) To determine the existing weed control techniques for corn in the Atlantic Plain of Nicaragua.

(2) To evaluate the likelihood of adoption of weed control technology for corn by small farmers on the Atlantic Plain of Nicaragua.

(3) To determine the effect of risk aversion upon the likelihood of acceptance of the proposed weed control technology.

A version of a production function-convex approximation model (McCarl, 1978) modified to account for stochastic yield response coefficients from the several technological processes, was used in the analysis. To measure the economic difference between the use of the two systems of weed control (traditional and new methods), alternative assumptions were specified, in which family labor and capital availabilities were varied under one of the two systems of weed control is made available to the farmers. A comparison was made between model results utilizing traditional and modern weed control coefficients.

Cross-sectional sample data of 42 farmers in the study area, experimental results in weed control technology obtained by IPPC researchers in the North Atlantic Zone of Costa Rica and primary and secondary input and output information from Nicaraguan institutions were used to estimate the model coefficients of all included activities. As prices are fixed by the Nicaraguan government, the gross income variations come from changes in yield response from different technological processes. Consequently, risk measures were estimated as the yield deviations from the average yield of the different technological processes. To do so, the standard deviation in yield of each technological process is multiplied by a risk aversion parameter and discounted from the average yield. Hence, the availability of corn for consumption and sale was reduced as long as the risk aversion coefficient increases.

As corn is grown both for consumption and sale, two different prices are used to value the crop production. The amount of corn retained by the farmers for home consumption was valued at the retail price and surplus over consumption available for sale, was valued at the farm rate price.

Based on family labor availabilities, three types of farms were specified, farms with the availability of one, two, or three family workers in the farm unit. Solutions of the model for each type of farm are constrained by the availability of weed control technologies (traditional and new), farmer propensities to take risk, and level of capital available for production. The solutions of the model include net revenue, net cash income, system of land use, amount of corn allocated to consumption and sale, storage losses of corn in the storage place, capital use, amount of corn seeds used for planting, herbicide use cost, fertilizer use cost, total family labor use, total hired labor use and amount of family and hired labor used to perform land clearing, field burning, herbicide application, planting, first early weeding, first late and second hand weeding and harvesting. Each solution satisfied the subsistence requirement constraint. A set of solutions for each type of farm is given in Chapter VI.

Presently there are three weed control systems used for the production of corn in the PRICA zone. They are T_1, an early hoeing; T_2, a late hoeing, and T_3, an early and late hoeing. As the sample data indicates, they are approximately equally likely to be used by PRICA farmers regardless of the availability of family labor. While T_3 provides the largest net return to the farmer as well as the largest cash income, it also requires the greatest amount of labor. Weed control technology T_2 yields the smallest net return and cash income but also requires the smallest amount of labor, and the weed control labor occurs late in the season.

There are also two different traditional systems of production. Production system one employs both previously tilled and previously fallowed land, while production system three utilized only previously fallowed land for production. Yields are also higher. The PRICA sample data are unclear as to the percentage of farmers using each of the two systems.

When only the traditional weed control systems are allowed and where no consideration is made for risk, the model predicts the use of production system one, when only one farm laborer is available, and a shift to production system two as more family labor is available. However, when capital is not a constraint even the farms with limited labor shift to production system three, hiring the labor they need. As would be expected, T_3, since it has the highest net return (see Table VII-3), is the preferred weed control system when capital and/or labor are not constraints. If capital and labor are limited, a combination of T_2 and T_3 are predicted.

When new technologies are tested in the model in a riskless environment, the model predicts an immediate shift to weed control technology T_4 (the IPPC recommendation). Most acreage is farmed utilizing production system three when capital or labor are not constraints. Production system two is the next largest (production system two, it will be recalled, uses fertilizer on previously farmed land). The traditional technologies are only used where capital and labor are limiting and then only in relatively small acreages. (See Table VII-2).

Farm net revenue and net cash income rise significantly as a shift from traditional to modern weed control techniques occur. This results from the higher yields obtained from T_4 with similar costs (compare Tables IV-7 and IV-9) as well as an increase in the area farmed. It should also be noted that when the new technologies are employed, the use of hired labor increases when capital is unconstrained. Thus, unemployment may not be increased by the new technology if capital can be made available to farmers to expand the area farmed.

McCarty, in his analysis, indicated that only 30 percent of the 20 NAZ sampled farms would benefit from the technology. However, he assumed no yield increase associated with the new technologies. This was consistent with the data available to him at the time. However, recent results in Costa Rica indicate that yield increase is likely. This assumption is basic to this study. Had he assumed a 13 percent increase in yield as assumed in this study, the number of adopters would have greatly increased.

Another reason for the difference in results between the two studies is the large amount of underutilized land in the PRICA area which allows farmers an option of employing production system three. Only production system one and two are used in NAZ. From McCarty's data, however, it is impossible to determine the number of farmers employing each system. Nevertheless, since production system three

Table VII-1. Farm Plan for Varying Size Family Labor Force and Capital Constraint Utilizing Traditional Weed Control Technologies.

Farm Labor Force:	One	One	One	Two	Three
Capital	C[a]	U[b]	C,U	C,U	C,U
Opportunity cost of labor	W[c]	W	Z[d]	W	W
Net revenue	2806.1	3310.7	5103.1	3600.7	3518.7
Net cash income	3778.4	4125.3	3748.3	5557.3	6430.3
Total area	3.81	4.13	3.88	4.13	4.13
System One of Production					
Old Land: T_1					
T_2	0.42		0.78		
T_3			1.73		
T_4					
New Land: T_1					
T_2	0.84		0.84		
T_3					
T_4					
System Two of Production: T_4					
System Three of Prodcution					
T_1					
T_2					
T_3	0.45	4.13	0.53	4.13	4.13
T_4					
Total corn production	3520.6	4658.7	3524.3	4658.7	4658.7
Capital use	840.0	2226.5	840.0	445.0	135.9
Labor: Family	83.4	77.62	83.7	142.4	153.6
Hired	26.1	76.02	26.0	11.2	--
Total	109.5	153.64	109.7	153.6	153.6

[a] Constrained capital.

[b] Unconstrained capital.

[c] Prevailing wage rate.

[d] Zero.

Table VII-2. Farm Plan for Varying Size Family Labor Force and Capital Constraints Utilizing Traditional and Modern Control Technologies.

Farm Work Force:	One	One	One	Two	Two	Three	Three
Capital	C[a]	U[b]	C	C	U	C	U
Opportunity cost of family	W[c]	W	Z[d]	W	W	W	W
Net Revenue	3315.6	6055.7	5347.5	5223.9	6355.9	5438.4	6305.0
Net cash income	3922.7	6655.1	4028.6	6829.6	8194.8	8057.9	9413.7
Total area	3.17	6.02	3.69	4.62	6.02	4.94	6.02
System One of Production							
Old Land: T_1							
T_2			0.06				
T_3	0.52		1.23				
T_4	1.10		1.23	0.38			
New Land: T_1							
T_2		0.84					
T_3							
T_4	0.54			0.13			
System Two of Production: T_4		2.52		0.65	2.52	1.08	2.52
System Three of Production							
T_1							
T_2							
T_3							
T_4	1.01	3.50	0.33	3.46	3.50	3.86	3.50
Total corn production	3608.4	7257.2	3672.8	5692.7	7257.2	6119.2	7257.2
Capital use	840.0	3812.7	840.0	840.0	1933.3	840.0	1309.7
Labor: Family	70.1	69.8	78.2	129.4	138.1	143.0	160.8
Hired:	13.5	91.0	15.6	3.3	22.7	--	--
Total:	83.6	160.8	93.8	132.7	160.8	143.0	160.8

[a] Constrained capital.

[b] Unconstrained capital.

[c] Prevailing wage rate.

[d] Zero.

Table VII-3. Net Return and Cash Income by Weed Control Technology.

Technology	T_1	T_2	T_3
Yield[a/]	783	753	981
Price (c/kg)	1.64	1.64	1.64
Gross value	1284	1235	1609
Family labor	554	445	712
Hired labor	170	247	199
Non-cash cost	29	31	33
Total cost	753	723	944
Net return[b/]	531	512	665
Cash income	1114	998	1410

[a/] Production system one, production system three yield 10 percent more.

[b/] Return to land and invested capital.

provides the highest yield, and the best environment for the new technologies, the new technologies appear to be less favorable in NAZ than in PRICA.

It will be recalled that risk is indirectly handled in the objective function by discounting "the cost of risk" (the standard deviation of yield times a risk aversion coefficient) from total output. It previously has been admitted that no empirical estimates of risk aversion from PRICA farmers are available to the author and thus the use of risk in the analysis is questionable. However, by varying the coefficient estimates of behavior are predicted which, hopefully are useful in showing the adoption potential of risk averse producers.

Farms with One Family Worker Available

Under traditional systems of weed control with only one family worker, the model predicts that capital will become a production constraint for the low to medium level of risk aversion (0.0 to 1.0) (see Table VII-4). However, capital was not a constraint for high level of risk aversion (1.5 to 2.0) and farmers tend to produce only the amount of corn required for home consumption.

When the new technology of weed control is available and adopted by farmers of this group, several important changes in production occur. The most important are the following:

(1) The net revenue increased by an average of $979 and $2,342 when capital is constrained and unconstrained, respectively. If such increases in net revenue are returned to family labor, the return to a family worked day will increase by $16.00 and $34.00, respectively. These increases in return to a family worked days represent gain of 40 and 75 percent over the present rates of return.

(2) To afford the cost of the new weed control technology when capital is constrained, the amount of family labor is slightly increased and the amount of hired labor is reduced. There is a substitution of capital input use for hired labor. However, when the capital constraint is released, the use of family labor is significantly increased and the amount of hired labor as well. The use of family labor is reduced only for cases in which the risk aversion coefficient is equal to zero.

(3) When capital is a constraint, the total use of capital is increased by an average of $526.00 at high levels of risk aversion (1.5 and 2,0). At low-medium levels of risk aversion the maximum amount of capital available

Table VII -4. Changes in Farm Returns and Factors of Production Caused by the Adoption of the New Technology on Farms Which Have One Family Worker (Percentage).

Capital	Constrained					Unconstrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0	0.0	0.5	1.0	1.5	2.0
Net revenue	18	65	116	343	960.0 a/	83	160	246	631	1257.0 a/
Increase in net cash income	4	51	78	370	1403	61	131	170	264	1852.6 a/
Return per family worked day	22.0	31.0	41.0	55.0	53.0	63.0	74.0	84.0	91.0	65.0
Total family labor use	-16	b/	b/	b/	44	-10	6	6	6	52
Total hired labor use	-48	-54	-54	29	12.4 a/	20	62	1.29	423	91.0 a/
Total capital use	b/	b/	b/	47	1449	71	129	214	565	6929
Cropped area	-17	-19	-19	-11	61	46	46	46	79	225

a/ Absolute value, since it is impossible to calculate the percentage

b/ There is no change.

for production is used in both traditional and modern production. When the capital constraint is released, the total use of capital increases by an average of $2,662. Such an increase represents an increase of capital use of $345 per hectare.

(4) The cropped area is generally reduced by an average of 0.61 hectares except for the case in which the risk aversion coefficient is equal to 2.0, where the cropped area is increased by 1.13 hectares, when capital remains as a constraint. However, when the capital constraint is released, the cropped area increased by an average of 2.5 hectares.

Farms with Two Family Workers Available

Under traditional systems of weed control, farms which have two family workers, capital was not a production constraint. As in the previous case, farmers (at high levels of risk aversion) tend to produce only the amount of corn required for home consumption (Table VII-5). Labor is hired only at low levels of risk aversion 0.0 and 0.5). When the new technology was adopted, the most important production changes that occur are the following:

(1) The net revenue increased by an average of $1,835 and $2,450 when capital is constrained and unconstrained, respectively. If such increases in net revenue are returned to family labor, the return to a family worked day will increase by $14.1 and $17.0, respectively. These increases in the rates of return represent

Table VII -5. Changes in Farm Return and Factors of Production Caused by the Adoption of the New Technology on Farms Which Have Two Family Workers (Percentage).

Capital	Constrained					Unconstrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0	0.0	0.5	1.0	1.5	2.0
Increase in net return	45	102	158	361	1462.0[a]	77	143	206	429	1559.0[a]
Increase in return per family worked	29.0	34.0	39.0	42.0	41.0	39.0	44.0	46.0	48.0	41.0
Increase in cash income	23	70	89	172	3145[a]	47	102	121	212	348[a]
Increase in total family labor use	-9	8	8	22	90	-3	15	16	31	102
Increase in total hired labor use	-70	55	3.34[a]	3.34[a]	3.34[a]	101	949	22.7[a]	22.7[a]	22.7[a]
Increase in total capital use	89	367	595	595	943	334	975	1505	1505	2300
Increase in cropped area	12	12	12	12	67	46	46	46	46	118

[a] Absolute value, since it is impossible to calculate the percentage.

Table VII -6. Changes in Farm Return and Factors of Production Caused by the Adoption of the New Technology on Farms Which Have Three Family Workers (Percentage).

Capital	Constrained					Unconstrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0	0.0	0.5	1.0	1.5	2.0
Increase in net revenue	55	119	188	489	1396[a]	79	153	230	563	1510[a]
Increase in cash income	25	73	87	152	4068[a]	46	102	117	190	4670[a]
Increase in return of family worked day	30.0	33.0	38.0	42.0	35.0	32.0	35.0	39.0	42.0	34.0
Increase in total family labor use	-7	17	17	35	213	5	32	32	52	251
Increase in total hired labor use	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]
Increase in total capital use	518	597	597	597	1456	864	987	987	987	2326
Increase in cropped area	20	20	20	20	167	46	46	46	46	222

[a] Absolute value, since it is impossible to calculate the percentage.

[b] There is no change.

increases in the order of 37 and 44 percent over actual rates of returns.

(2) When capital is a constraint, the use of family labor per hectare is reduced at low-medium levels of risk aversion and increased at high levels of risk aversion. But generally, as the cropped area is increased, the total use of family labor is increased. An exception is with the case in which the risk aversion coefficient is equal to zero. When the capital constraint is released, the use of family labor per hectare is generally reduced over all risk aversion levels but as the cropped area is increased, total use of family labor is also increased.

(3) Hired labor use is slightly increased when capital is a constraint over all levels of risk aversion, except for the case in which the risk aversion coefficient is equal to zero, where hired labor use is reduced. When the capital constraint is released, the use of hired labor is significantly increased across all levels of risk aversion.

(4) Capital use increases by $651 when capital is constrained and by $1,744 when capital is unconstrained. Such increases in capital use represents increases of $134 and $273 per hectare, respectively.

(5) The cropped area is increased by an average of 0.76 hectares under the capital constraint conditions and 2.16 hectares under the unlimited capital conditions.

Farms with Three Family Workers Available

As in the previous case, farms which have three family workers in the farm units do not have capital as a production constraint under the present systems of production (Table VII-6). Additionally, consistent with the two previous cases, these farmers also tend to produce only the required amount of corn for family consumption at high levels of risk aversion. In this case, labor is not hired at any level of risk aversion. The adoption of the new weed control technology will produce the following changes for these farmers:

(1) The net revenue increased by an average of $1,991.00 and $2,481.00 when capital is constrained and unconstrained, respectively. If such increases in net revenue are returned to family labor, the return to a family worked day will increase by $13.3 and $13.7, respectively. These increases in rate of return to a family worked day represent increases of 35 and 36 percent over the actual rates of return.

(2) The use of family labor per hectare is reduced at low-medium levels of risk aversion and it is increased at high levels of risk aversion relative to the traditional systems of production, under both capital conditions--constrained and unconstrained. However, the total use of hired labor is increased at all levels of risk aversion in both cases of capital availabilities, except the case in which farmers have a propensity to take risk equal to zero and capital is constrained. In such a case, the use of family labor is reduced.

(3) Labor is not hired for production when the new technology was adopted.

(4) The total use of capital is increased by an average of $730 and $12,00 for the constrained and unconstrained capital situations, respectively. Such increases in total capital use represent increases in capital use per hectare equal to $140 and $188, respectively.

(5) The cropped area was increased by 1.29 and 2.33 hectares under constrained and unconstrained capital situations, respectively .

The study results indicate that a strong potential for adoption of new weed control techniques exists in PRICA. However, the author is uncomfortable in recommending an extension program to encourage adoption without further research. Several major assumptions must be verified before a program should be started. These limitations are discussed in the next chapter.

VIII. LIMITATIONS OF THIS STUDY AND SUGGESTIONS FOR FURTHER ANALYSIS

There are a number of limitations to this study which should be kept in mind. The scope of the study is very limited. It is restricted to a single crop in a single production season. The data are in part questionable and several major assumptions were made with only limited empirical support.

While, it is believed, that they do not invalidate the results, the results should not be used for policy formulation without additional research. The major limitations perceived by the author are:

(1) The PRICA sample may not be representative. Forty-two small farmers were interviewed in an area where there are actually more than 3,000 small farmers. Farm information obtained was based on the farmers' recall, not on actual farm records.

(2) The Costa Rican coefficients may not adequately serve as measures of response of the new weed control technology under PRICA conditions. While care was taken to find a zone similar to the NAZ, an exact duplicate was not possible. Agronomic responses have been repeatedly shown to be site specific. Also, question exists as to the appropriateness of the 13 percent yield increase over traditional weed control technologies.

(3) The measure of standard deviation of yield is not an ideal measure since it was estimated from cross-sectional observations within one year. The perception about yield distribution under different states of nature is acquired

by farmers over time and not from the distribution of yields obtained within a particular year.

(4) Only one season of corn production is analyzed in the study. Farmers, however, make decisions for multiple periods of production and certainly for the entire year. For instance, hand weeding before planting (Guazapea), a practice commonly done in the NAZ, is not done by PRICA farmers because, according to the farmers, the mulch reduces the germination of the "frijol tapado" (covered beans), a crop which is commonly raised the second season on an area where corn was previously grown.

(5) The analysis was restricted to corn production when in fact farmers raise other crops such as upland rice, plantain and coffee. Thus, the whole farm should be studied for a complete evaluation.

(6) If the technology increases corn yields, the price may fall. According to a previous study, the elasticity of demand for corn in Nicaragua is inelastic (-0.032) (Fajardo, 1977). Hence, increases in the supply of corn could decrease the price of corn. While this may be beneficial to the consumers, farmers are likely to suffer. Since the government of Nicaragua presently guarantees the price of corn, increased subsidy may be required to maintain the price at present levels.

Suggestions for Further Analysis

In this section, some suggestions for further analysis are presented.

Suggestions to Improve the Present Study

The limitations of this study can be reduced by future research and training. It is recommended that:

(1) Field experiments be established in the PRICA area to test the recommended weed control technology. Two important results will be achieved: (a) better estimates for the production coefficients of the new technology for the PRICA area, and (b) better estimates of the yield variability associated with the new technology under different states of nature.

(2) A system to obtain better farm records must be developed. Periodic visits by researchers to the farms for the purpose of keeping a record should be considered.

(3) The model should be expanded to include the whole farm, i.e., multiple enterprise activities, off-farm activities, complete production year, and household consumption.

(4) Herbicides are potentially hazardous to small farmers. Paraquat is particularly hazardous to humans. Farmers, unfortunately, are often unaware of such hazards, or even if they do, they may not know how to handle herbicides safely. Therefore, training will be required to handle and apply herbicides safely and efficiently.

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APPENDIX A

Table A-1. Summarized Information Obtained From PRICA Farmers Who Are Presently Using "Technology One" in Controlling Weeds (General Information).

	Farm[a/] size	Unused[a/] land	Farmer age	Family size	Family labor	Years of living in the PRICA
Farmer 1	31.5	12.6	45	9	2.5	6
Farmer 2	29.4	22.05	29	3	1	5
Farmer 3	35	19.35	30	8	1	7
Farmer 4	29.4	11.9	43	10	2	8
Farmer 5	33.6	9.8	35	6	3	5
Farmer 6	29.05	8.22	48	8	1	9
Farmer 7	29.4	12.6	38	6	2	11
Farmer 8	35	18.55	24	9	1	5
Farmer 9	38.5	14.7	38	8	2	9
Farmer 10	35	25.46	42	8	2	11
Farmer 11	28	12.95	46	3	3	6
Farmer 12	29.05	12.60	55	12	4	8
Farmer 13	35	27.65	37	7	3	1
Farmer 14	56	18.20	38	10	2	12
Farmer 15	39.2	9.8	49	4	4	7

[a/] Hectares of land.

Table A-2. Summarized Information Obtained from PRICA Farmers Who Are Presently Using "Technology One" in Controlling Weeds (Information Related to Corn Production).

	Corn Area[a/]	Land clearing labor		Family field burning labor[b/]	Planting labor		Corn seeds for planting[c/]	FEHWL[d/]		Harvesting labor		Calculated[e/] yield
		Family[b/]	Hired[b/]		Family[b/]	Hired[b/]		Family[b/]	Hired[b/]	Family[b/]	Hired[b/]	
Farmer 1	2.8	16	16	1.0	2	6	28.6	3	3	20	0	1596
Farmer 2	1.75	0	10.9	0.13	2	2	28.6	5	0	8	0	638
Farmer 3	2.8	0	18.2	0.25	8	0	28.6	13	0	24	0	2690
Farmer 4	2.8	46.4	0	0.50	8	0	28.6	24	0	29	0	2918
Farmer 5	2.1	19.2	0	0.25	6	0	28.6	14	0	20	0	2189
Farmer 6	1.4	12	0	0.25	4	0	28.6	6	0	12	0	1459
Farmer 7	1.4	0	12.36	0.50	5.7	0	28.6	3.4	0	7	0	737
Farmer 8	1.75	0	10.91	0.25	4	4	28.6	12	0	15	5	1368
Farmer 9	1.75	14	0	1.0	7	0	37.5	10	0	20	0	1596
Farmer 10	2.10	0	27.27	0.50	9.9	0	28.6	12	0	12	0	1459
Farmer 11	1.05	6	0	0.50	3	0	28.6	3	0	4	0	547
Farmer 12	2.8	32	0	0.25	8	0	28.6	12	0	22	0	2098
Farmer 13	2.8	24	0	1.0	8	0	28.6	24	0	24	0	2554
Farmer 14	6.3	10	26.18	1.0	6	12	28.6	21	42	24	63	5335
Farmer 15	2.1	0	21.82	2.18	6	0	28.6	9	3.3	12	4	1642

a/ Hectares of land.

b/ Man-days of eight hours.

c/ Kgs per hectare.

d/ First early hand weeding labor.

e/ Kgs per total cropped area.

Table A-3. Summarized Information Obtained From PRICA Farmers Who Are Presently Using "Technology Two" In Controlling Weeds (General Information).

	Farm[a/] Size	Unused[a/] land	Farmer age	Family size	Family labor	Years of living in the PRICA
Farmer 1	35	30.45	35	5	1.4	6
Farmer 2	32.2	9.8	44	6	1	3
Farmer 3	50	5.25	40	8	2	15
Farmer 4	--	--	42	5	1	2
Farmer 5	35	8.4	45	13	4	8
Farmer 6	35	11.2	24	7	1	6
Farmer 7	35	22.4	52	11	6	6
Farmer 8	36.4	7	45	5	3	10
Farmer 9	35	26.25	46	12	2	3
Farmer 10	35	24.15	48	5	1	1
Farmer 11	35	5.07	44	7	2	4
Farmer 12	35	30.28	42	5	3	10
Farmer 13	29.4	16.63	53	10	2	9

[a/] Hectares of land.

Table A-4. Summarized Information Obtained From PRICA Farmers Who Are Presently Using "Technology Two" in Controlling Weeds (Information Related to Corn Production).

	Corn area[a/]	Land clearing labor		Family field burning labor[b/]	Planting labor		Corn seeds for planting[c/]	FLHWL[d/]		Harvesting labor		Calculated yield[e/]
		Family[b/]	Hired[b/]		Family[b/]	Hired[b/]		Family[b/]	Hired[b/]	Family[b/]	Hired[b/]	
Farmer 1	2.8	3	20	2	0	8	28.6	0	24	0	20	1277
Farmer 2	2.8	0	21.8	1	0	8	28.6	0	10.9	14	0	547
Farmer 3	3.5	16	18.2	1	7	2	31.4	10	0	19	-	4546
Farmer 4	6.3	0	45.8	2	0	18	35.7	0	32.7	0	60	6566
Farmer 5	2.8	0	43.6	1	4	4	28.6	0	14.6	30	0	2918
Farmer 6	1.4	8	7.27	0.5	2	2	28.6	6	0	10	0	912
Farmer 7	1.4	0	14.55	3	4	0	28.6	6	0	6	0	684
Farmer 8	2.1	24	0	0.13	6	0	28.6	12	0	20	0	1915
Farmer 9	3.5	30	0	0.5	13.3	0	35.7	25	0	28	0	3648
Farmer 10	3.15	18	0	0.25	8	0	28.6	8	0	15	0	912
Farmer 11	2.45	33.6	0	0.25	10.5	0	42.9	5	0	22	0	547
Farmer 12	1.75	20	0	0.50	4	0	34.3	4	0	8	0	912
Farmer 13	1.92	0	13	0.13	6	0	28.6	6	0	26	0	3135

[a/] Hectares of land.

[b/] Man-days of eight hours.

[c/] Kgs per hectare.

[d/] First late hand weeding labor.

[e/] Kgs per total cropped area.

Table A-5. Summarized Information Obtained From PRICA Farmers Who Are Presently Using "Technology Three" In Controlling Weeds (General Information).

	Farm[a/] size	Unused[a/] land	Farmer age	Family size	Family labor	Years of living in the PRICA
Farmer 1	35	29.4	64	4	3	8
Farmer 2	35	10.15	45	3	1	9
Farmer 3	42	27.82	60	5	1	14
Farmer 4	50	7.61	55	12	4	16
Farmer 5	35	22.4	45	4	1	13
Farmer 6	35	13.3	43	8	1	4
Farmer 7	35	18.2	57	11	2	10
Farmer 8	39.2	26.25	45	9	3	4
Farmer 9	29.4	24.32	37	9	1	2
Farmer 10	35	18.37	54	8	3	7
Farmer 11	35	25.11	52	11	2	11
Farmer 12	35	23.42	39	6	3	9
Farmer 13	31.5	--	70	8	3	8

[a/] Hectares of land.

Table A-6. Summarized Information Obtained From PRICA Farmers Who Are Presently Using "Technology Three" In Controlling Weeds (Information Related to Corn Production).

	Corn area[a]	Land clearing labor		Family field burning labor[b]	Planting labor		Corn seeds for planting[c]	FEHWL[d]		SHWL[e]				Calculated yield[f]
		Family[b]	Hired[b]		Family[b]	Hired[b]		Family[b]	Hired[b]	Family[b]	Hired[b]	Family[b]	Hired[b]	
Farmer 1	3.5	25	0	0.75	10	0	28.6	25.0	0	25.0	0	40	0	3648
Farmer 2	2.8	0	23.3	0.50	0	8	28.6	17.0	0	9.0	0	12	17.5	2554
Farmer 3	2.1	12.8	7.3	0	12.5	0	28.6	6	3	6	3	23	0	2734
Farmer 4	4.2	0	40	0.25	15.6	0	28.6	10	9.1	10	9.1	48	0	6270
Farmer 5	2.8	64	0	1.5	16	0	57.1	9	0	7	0	36	0	5471
Farmer 6	2.1	8	14.6	0.5	3	3	35.7	6	6	6	6	0	15.3	1231
Farmer 7	2.1	25.2	0	1	7.8	0	35.7	18	0	18	0	21	0	821
Farmer 8	1.4	16	0	0.25	6	0	28.6	10	0	6	0	11	0	1641
Farmer 9	1.92	2	12.9	0.50	7	1	28.6	3.9	2	1	2	5	2	638
Farmer 10	2.1	24	0	0.25	6	0	35.7	12	0	12	0	18	0	1368
Farmer 11	2.8	16	0	0.25	8	0	28.6	12	0	12	0	32	0	2918
Farmer 12	1.75	10	0	0.50	7	0	35.7	6	0	6	0	15	0	1003
Farmer 13	2.8	0	29.1	0.25	0	8	28.6	0	16	0	16	7	0	3648

a/ Hectares of land.

b/ Man-days of eight hours.

c/ Kgs per hectare.

d/ First early hand weeding labor.

e/ Second hand weeding labor.

f/ Kgs per total cropped area.

APPENDIX B

Table B-1. "PRICA Average Farms" Stratified by Availability of Family Labor and Post-Plant Weed Control Technology (General Information).

Average/Farm	Number of farmers	Farm size	Corn area	Weedy land	Horses & mules	Age of farmer	Family size	Family labor	Years of living in the PRICA
One Farmer									
T_1	4	32.1	1.93	17.0	1.3	32.8	7.0	1	6.5
T_2	4	25.6	3.41	15.1	0.3	39.5	5.3	1	3
T_3	5	35.3	2.3	19.6	1.2	46	5.4	1	8.4
	13								
Two Farmers									
T_1	5	37.7	2.9	16.6	1.2	45.8	8.4	2	10.2
T_2	4	37.4	2.8	13.3	1.8	39.8	9.3	2	7.8
T_3	2	35	1.9	20.8	0.5	48	10.5	2	9.5
	11								
Three Farmers									
T_1	3	32.2	2.0	16.8	2	39.3	5.7	3	4
T_2	2	35.7	1.9	19.8	1.5	43.5	7.5	3	10
T_3	5	35.1	2.5	18.6	1.5	57	5.8	3	7.6
	10								

Table B-2. "PRICA Average Farms" Stratified by Availability of Family Labor and Post-Plant Weed Control Technology (General Information).

	Land clearing labor	Field burning labor	Planting labor	Seed/ hole	Planting distance	Seeds/ hectare	FEHW[a/]	FLHW[b/]	SHW [c/]	Harvesting	Total yield
One Farmer											
T_1	13	0.2	6	4.3	1.0	28.6	9	--	--	16	1539
T_2	25.2	0.9	9.5	4.5	1.1	30.4	--	14.4	--	24.8	2234
T_3	29	0.6	10.1	3.3	0.8	35.7	10.6	--	8	25.7	2526
Two Farmers											
T_1	27.3	0.7	9.7	3.7	0.9	30.4	22.5	--	--	31	2408
T_2	27.7	0.5	9.7	3.8	1.0	34.7	--	11.5	--	23.8	2973
T_3	17.3	0.8	7.4	5.3	0.9	35.7	12	--	3	18	1824
Three Farmers											
T_1	16.4	0.6	5.7	4.5	1	28.6	13.7	--	--	16	997
T_2	22	0.3	5	4	0.9	31.5	--	8.0	--	14	1413
T_3	22	0.4	7.6	4.1	0.9	30	15	--	14.2	21.6	2645

[a/] First early hand weeding.

[b/] First late hand weeding.

[c/] Second hand weeding.

APPENDIX C

Table C-1. Empirical Results for Farm Case One Under Three Traditional Weed Control Technologies.

Tenant: Owner; Number of family workers: one	Cost of family labor: non-zero; Capital: constrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	2806.07	1645.64	989.58	349.98	-4.25
	3778.40	2137.87	1481.80	839.58	-59.66
Total area (hectares)	3.81	3.68	3.68	3.36	1.85
System 1--Old Land: Area under Tech. 1		2.52	2.52	2.52	1.39
Area under Tech. 2	0.42				
Area under Tech. 3	2.10				
Area under Tech. 4					
--New Land: Area under Tech. 1		0.84	0.84	0.84	0.46
Area under Tech. 2	0.84				
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c/]					
System 3: Area under Tech. 1		0.32	0.32		
Area under Tech. 2					
Area under Tech. 3	0.45				
Area under Tech. 4					
Total corn production	3520.64	2523.36	2124.53	1555.69	662.04
Corn allocated to consumption	601.85	601.85	601.85	601.85	601.85
Storage losses	60.19	60.19	60.19	60.19	60.19
Corn allocated to sale	2858.60	1861.32	1462.49	893.65	--
Capital use	840.00	840.00	840.00	573.16	54.24
Corn for planting	56.32	48.94	48.94	44.69	24.73
Herbicide use					
Herbicide implement costs					
Fertilizer use					
Total family labor	83.4	65.89	65.89	65.80	45.98
Total hired labor	26.1	26.64	26.64	17.28	--
Total labor	109.5	92.53	92.53	83.08	45.98
Land clearing labor: Family	21.36	21.36	21.36	21.36	13.99
Land clearing labor: Hired	10.59	7.50	7.50	3.92	--
Field burning labor: Family	1.01	1.10	1.10	1.00	0.56
Field burning labor: Hired					
Herbicide appl. labor: Family					
Herbicide appl. labor: Hired					
Planting labor: Family	7.43	7.43	7.43	7.43	5.95
Planting labor: Hired	4.78	4.34	4.34	3.32	
First early weed. labor: Family	12.00	12.00	12.00	12.00	10.04
First early weed. labor: Hired	1.53	7.87	7.87	6.14	
First late H.W. labor: Family	5.54				
First late H.W. labor: Hired					
Second H.W. labor: Family	12.00				
Second H.W. labor: Hired					
Harvesting labor: Family	24.00	24.00	24.00	24.00	15.43
Harvesting labor: Hired	9.15	6.92	6.92	3.88	--

Table C-2. Empirical Results for Farm Case One Under Three Traditional and One Improved Weed Control Technologies.

Tenant: Owner Number of family workers: one	Cost of family labor: non-zero Capital: constrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	3315.64	2722.69	2134.89	1552.00	964.19
	3922.68	3221.20	2633.41	2050.51	1462.70
Total area (hectares)	3.17	2.98	2.98	2.98	2.98
System 1--Old Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3	0.52				
Area under Tech. 4	1.10	1.17	1.17	1.17	1.17
--New Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	0.54	0.39	0.39	0.39	0.39
System 2: Area under Tech. 4[c/]					
System 3: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	1.01	1.42	1.42	1.42	1.42
Total corn production	3608.41	3181.92	2824.60	2470.25	2112.92
Corn allocated to consumption	601.90	601.85	601.85	601.85	601.85
Storage losses	60.20	60.19	60.19	60.19	60.19
Corn allocated to sale	2946.31	2519.88	2162.56	1808.21	1450.88
Capital use	840.00	840.00	840.00	840.00	840.00
Corn for planting	45.00	42.25	42.25	42.25	42.25
Herbicide use	6.71	7.38	7.38	7.38	7.38
Herbicide implement costs	27.76	31.29	31.29	31.29	31.29
Fertilizer use	--				
Total family labor	70.07	66.12	66.12	66.12	66.12
Total hired labor	13.48	12.35	12.35	12.35	12.35
Total labor	83.55	78.47	78.47	78.47	78.47
Land clearing labor: Family	21.36	21.36	21.36	21.36	21.36
Land clearing labor: Hired					
Field burning labor: Family	0.10				
Field burning labor: Hired	2.74	2.92	2.92	2.92	2.92
Herbicide appl. labor: Family					
Herbicide appl. labor: Hired					
Planting labor: Family	7.43	7.43	7.43	7.43	7.43
Planting labor: Hired	4.86	4.47	4.47	4.47	4.47
First early weed. labor: Family	12.00	10.41	10.41	10.41	10.41
First early weed. labor: Hired					
First late H.W. labor: Family					
First late H.W. labor: Hired					
Second H.W. labor: Family	2.43				
Second H.W. labor: Hired					
Harvesting labor: Family	24.00	24.00	24.00	24.00	24.00
Harvesting labor: Hired	8.62	7.88	7.88	7.88	7.88

Table C-3. Empirical Results for Farm Case Two Under Three Traditional Weed Control Technologies.

Tenant: owner Number of family workers: one	Cost of family labor: non-zero	Capital: unconstrained			
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	3310.70	1867.45	1057.49	349.98	-4.25
	4125.30	2363.38	1553.44	839.58	-59.66
Total area (hectares)	4.13	4.13	4.13	3.36	1.85
System 1--Old Land: Area under Tech. 1			2.52	2.52	1.39
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
--New Land: Area under Tech. 1			0.84	0.84	0.84
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c]					
System 3: Area under Tech. 1		4.13	0.77		
Area under Tech. 2					
Area under Tech. 3	4.13				
Area under Tech. 4					
Total corn production	4658.65	3213.04	2419.56	1555.68	662.04
Corn allocated to consumption	601.85	601.85	601.85	601.85	601.85
Storage losses	60.19	60.19	60.19	60.19	60.19
Corn allocated to sale	3996.61	2551.10	1757.52	893.64	--
Capital use	2226.48	1666.53	1216.07	573.16	51.24
Corn for planting	61.95	54.93	54.93	44.69	21.73
Herbicide use					
Herbicide implement costs					
Fertilizer use					
Total family labor	77.62	66.01	66.03	65.80	45.98
Total hired labor	76.02	56.22	39.84	17.28	--
Total labor	153.64	122.23	105.87	83.08	45.98
Land clearing labor: Family	21.36	21.36	21.36	21.36	13.99
Land clearing labor: Hired	33.98	24.90	12.55	3.92	
Field burning labor: Family	0.83	1.24	1.24	1.00	0.56
Field burning labor: Hired					
Herbicide appl. labor: Family					
Herbicide appl. labor: Hired					
Planting labor: Family	7.43	7.43	7.43	7.43	5.95
Planting labor: Hired	6.20	5.79	5.79	3.32	
First early weed. labor: Family	12.00	12.00	12.00	12.00	10.04
First early weed. labor: Hired	9.89	10.30	10.30	6.14	
First late H.W. labor: Family					
First late H.W. labor: Hired					
Second H.W. labor: Family	12.00				
Second H.W. labor: Hired	7.41				
Harvesting labor: Family	24.00	24.00	24.00	24.00	15.43
Harvesting labor: Hired	18.54	15.23	11.20	3.89	--

Table C-4. Empirical Results for Farm Case Two Under Three Traditional and One Improved Weed Control Technologies.

Tenant: owner / Number of family workers: one	Cost of family labor: non-zero / Capital: unconstrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	6055.69	4864.35	3657.46	2460.25	1253.24
	6655.07	5463.72	4193.95	3059.63	1852.63
Total area (hectares)	6.02	6.02	6.02	6.02	6.02
System 1--Old Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
--New Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c/]	2.52	2.52	2.52	2.52	2.52
System 3: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	3.50	3.50	3.50	3.50	3.50
Total corn production	7257.19	6532.96	5799.23	5071.51	4337.77
Corn allocated to consumption	601.85	601.85	601.85	601.85	601.85
Storage losses	60.19	60.19	60.19	60.19	60.19
Corn allocated to sale	6596.15	5870.92	5137.19	4409.47	3657.73
Capital use	3812.68	3812.68	3812.68	3812.68	3812.68
Corn for planting	85.48	85.48	85.48	85.48	85.48
Herbicide use	15.33	15.33	15.33	15.33	15.33
Herbicide implement costs	63.21	63.21	63.21	63.21	63.21
Fertilizer use	272.20	277.20	277.20	277.20	277.20
Total family labor	69.79	69.79	69.79	69.79	69.79
Total hired labor	91.01	91.01	91.01	91.01	91.01
Total labor	160.80	160.80	160.80	160.80	160.80
Land clearing labor: Family	21.36	21.36	21.36	21.36	21.36
Land clearing labor: Hired	22.04	22.04	22.04	22.04	22.04
Field burning labor: Family					
Field burning labor: Hired					
Herbicide appl. labor: Family	5	5	5	5	5
Herbicide appl. labor: Hired	1.30	1.30	1.30	1.30	1.30
Planting labor: Family	7.43	7.43	7.43	7.43	7.43
Planting labor: Hired	17.15	17.15	17.15	17.15	17.15
First early weed. labor: Family	12.00	12.00	12.00	12.00	12.00
First early weed. labor: Hired	9.07	9.07	9.07	9.07	9.07
First late H.W. labor: Family					
First late H.W. labor: Hired					
Second H.W. labor: Family					
Second H.W. labor: Hired					
Harvesting labor: Family	24.00	24.00	24.00	24.00	24.00
Harvesting labor: Hired	41.45	41.45	41.45	41.45	41.45

Table C-5. Empirical Results for Farm Case Three Under Three Traditional Weed Control Technologies.

Tenant: Owner; Number of family workers: one; Cost of family labor: zero; Capital: constrained					
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	5103.11	3656.08	2801.65	2163.79	1654.83
	3784.25	2336.21	1481.80	843.94	335.40
Total area (hectares)	3.88	3.61	3.68	2.89	2.89
System 1--Old Land: Area under Tech. 1			2.52	2.17	2.17
Area under Tech. 2	0.78				
Area under Tech. 3	1.73	2.52			
Area under Tech. 4					
--New Land: Area under Tech. 1		0.81	0.84	0.72	0.72
Area under Tech. 2	0.84	0.03			
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c/]					
System 3: Area under Tech. 1		0.25	0.32		
Area under Tech. 2					
Area under Tech. 3	0.53				
Area under Tech. 4					
Total corn production	3524.26	2643.93	2124.53	1338.80	1029.66
Corn allocated to consumption	601.90	601.85	601.85	601.85	601.85
Storage losses	60.20	60.19	60.19	60.19	60.19
Corn allocated to sale	2862.16	1981.89	1462.49	676.76	367.62
Capital use	840.00	840.00	840.00	244.85	244.85
Corn for planting	57.23	52.32	48.94	38.46	38.46
Herbicide use					
Herbicide implement costs					
Fertilizer use					
Total family labor	83.69	77.62	65.89	65.66	65.66
Total hired labor	25.98	26.37	26.64	5.83	5.83
Total labor	109.67	103.99	92.53	71.49	71.49
Land clearing labor: Family	21.36	21.36	21.36	21.36	21.36
Land clearing labor: Hired	11.63	6.74	7.50	0.40	0.40
Field burning labor: Family	1.10	0.82	1.10	0.87	0.87
Field burning labor: Hired					
Herbicide appl. labor: Family					
Herbicide appl. labor: Hired					
Planting labor: Family	7.43	7.43	7.43	7.43	7.43
Planting labor: Hired	4.92	4.37	4.34	1.82	1.82
First early weed. labor: Family	12.00	12.00	12.00	12.00	12.00
First early weed. labor: Hired		7.23	7.87	3.61	3.61
First late H.W. labor: Family	7.15				
First late H.W. labor: Hired					
Second H.W. labor: Family	10.64	12.00			
Second H.W. labor: Hired					
Harvesting labor: Family	24.00	24.00	24.00	24.00	24.00
Harvesting labor: Hired	9.43	9.03	6.92	--	

Table C-6. Empirical Results for Farm Case Three Under Three Traditional and One Improved Weed Control Technologies.

Tenant: owner Number of family workers: one	Cost of family labor: zero Capital: constrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	5347.49	4541.05	3953.25	3370.24	2782.55
	4028.63	3221.20	2633.41	2050.51	1462.70
Total area (hectares)	3.69	2.98	2.97	2.98	2.97
System 1--Old Land: Area under Tech. 1					
Area under Tech. 2	0.06				
Area under Tech. 3	1.23				
Area under Tech. 4	1.23	1.17	1.17	1.17	1.17
--New Land: Area under Tech. 1					
Area under Tech. 2	0.84				
Area under Tech. 3					
Area under Tech. 4		0.39	0.39	0.39	0.39
System 2: Area under Tech. 4[c/]					
System 3: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	0.33	1.42	1.42	1.42	1.42
Total corn production	3672.82	3181.92	2824.60	2470.25	2112.92
Corn allocated to consumption	601.90	601.85	601.85	601.85	601.85
Storage losses	60.20	60.19	60.19	60.19	60.19
Corn allocated to sale	3010.72	2519.88	2162.56	1808.21	1450.88
Capital use	840.00	840.00	840.00	840.00	840.00
Corn for planting	53.50	42.25	42.25	42.25	42.25
Herbicide use	1.56	7.38	7.38	7.38	7.38
Herbicide implement costs	16.42	31.29	31.29	31.29	31.29
Fertilizer use					
Total family labor	78.20	66.12	66.12	66.12	66.12
Total hired labor	15.61	12.35	12.35	12.35	12.35
Total labor	93.81	78.47	78.47	78.47	78.47
Land clearing labor: Family	21.36	21.36	21.36	21.36	21.36
Land clearing labor: Hired					
Field burning labor: Family	0.60				
Field burning labor: Hired	3.08	2.92	2.92	2.92	2.92
Herbicide appl. labor: Family					
Herbicide appl. labor: Hired	7.43	7.43	7.43	7.43	7.43
Planting labor: Family	5.58	4.47	4.47	4.47	4.47
Planting labor: Hired	12.00	10.41	10.41	10.41	10.41
First early weed. labor: Family					
First early weed. labor: Hired					
First late H.W. labor: Family	3.94				
First late H.W. labor: Hired					
Second H.W. labor: Family	5.79				
Second H.W. labor: Hired					
Harvesting labor: Family	24.00	24.00	24.00	24.00	24.00
Harvesting labor: Hired	10.03	7.88	7.88	7.38	7.88

Table C-7. Empirical Results for Farm Cases Four and Five Under Three Traditional Weed Control Technologies.

Tenant: owner   Cost of family labor: non-zero
Number of family workers: two   Capital: constrained

Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	3600.74	2128.00	1294.90	521.58	-6.31
	5557.25	3471.18	2618.72	1473.62	-88.57
Total area (hectares)	4.13	4.13	4.13	4.13	4.13
System 1--Old Land: Area under Tech. 1			0.44	2.52	2.07
Area under Tech. 2					
Area under Tech. 3			3.54		
Area under Tech. 4					
--New Land: Area under Tech. 1			0.15	0.84	0.69
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c/]					
System 3: Area under Tech. 1		4.13		0.77	
Area under Tech. 2					
Area under Tech. 3	4.13				
Area under Tech. 4					
Total corn production	4658.65	3213.14	2655.28	1959.17	982.80
Corn allocated to consumption	893.45	893.45	893.45	893.45	893.45
Storage losses	89.35	89.35	89.35	89.35	89.35
Corn allocated to sale	3675.85	2230.34	1672.48	976.37	--
Capital use	445.02	179.75	120.46	120.46	80.52
Corn for planting	61.95	54.93	54.93	54.93	36.71
Herbicide use					
Herbicide implement costs					
Fertilizer use					
Total family labor	142.39	120.09	119.38	105.87	68.26
Total hired labor	11.24	2.16	--	--	--
Total labor	155.63	122.25	119.38	105.87	68.26
Land clearing labor: Family	44.10	44.10	44.10	39.91	20.77
Land clearing labor: Hired	11.24	2.16			
Field burning labor: Family	0.826	1.24	1.24	1.24	0.83
Field burning labor: Hired					
Herbicide appl. labor: Family					
Herbicide appl. labor: Hired					
Planting labor: Family	13.63	13.22	13.22	13.22	8.83
Planting labor: Hired					
First early weed. labor: Family	21.89	22.30	22.30	22.30	14.90
First early weed. labor: Hired					
First late H.W. labor: Family					
First late H.W. labor: Hired					
Second H.W. labor: Family	19.41				
Second H.W. labor: Hired					
Harvesting labor: Family	42.54	39.24	38.53	35.20	22.91
Harvesting labor: Hired					

Table C-8. Empirical Results for Farm Case Four Under Three Traditional and One Improved Weed Control Technologies.

Tenant: owner Number of family workers: two	Cost of family labor: non-zero Capital: constrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	5223.85	4290.06	3342.99	2403.51	1456.43
	6823.75	5889.95	4942.89	4003.42	3056.32
Total area (hectares)	4.62	4.62	4.62	4.62	4.62
System 1--Old Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	0.38	0.38	0.38	0.38	0.38
--New Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	0.13	0.13	0.13	0.13	0.13
System 2: Area under Tech. 4[c/]	0.65	0.65	0.65	0.65	0.65
System 3: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	3.46	3.46	3.46	3.46	3.46
Total corn production	5692.68	5125.02	4549.20	3978.19	3402.45
Corn allocated to consumption	893.45	893.45	893.45	893.45	893.45
Storage losses	89.35	89.35	89.35	89.35	89.35
Corn allocated to sale	4709.88	4142.22	3566.50	2995.39	2419.65
Capital use	840.00	840.00	840.00	840.00	840.00
Corn for planting	65.54	65.54	65.54	65.54	65.54
Herbicide use	9.50	9.50	9.50	9.50	9.50
Herbicide implement costs	48.46	48.46	48.46	48.46	48.46
Fertilizer use	71.50	71.50	71.50	71.50	71.50
Total family labor	129.43	129.43	129.43	129.43	129.43
Total hired labor	3.34	3.34	3.34	3.34	3.34
Total labor	132.77	132.77	132.77	132.77	132.77
Land clearing labor: Family	44.10	44.10	44.10	44.70	44.70
Hired					
Field burning labor: Family					
Hired					
Herbicide appl. labor: Family	2.57	2.57	2.57	2.57	2.57
Hired					
Planting labor: Family	18.59	18.59	18.59	18.59	18.59
Hired					
First early weed. labor: Family	16.16	16.16	16.16	16.16	16.16
Hired					
First late H.W. labor: Family					
Hired					
Second H.W. labor: Family					
Hired					
Harvesting labor: Family	48.00	48.00	48.00	48.00	48.00
Hired	3.34	3.34	3.34	3.34	3.34

Table C-9. Empirical Results for Farm Case Five under Three Traditional and One Improved Weed Control Technologies.

Tenant: owner; Number of family workers: two	Cost of family labor: non-zero; Capital: unconstrained				
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	6355.53	5164.19	3957.18	2760.01	1553.08
	8194.79	7003.44	5796.44	4599.34	3392.34
Total area (hectares)	6.02	6.02	6.02	6.02	6.02
System 1--Old Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
--New Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c]	2.52	2.52	2.52	2.52	2.52
System 3: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	3.50	3.50	3.50	3.50	3.50
Total corn production	7257.19	6533.50	5799.23	5071.50	4253.67
Corn allocated to consumption	893.45	893.45	893.45	893.45	809.35
Storage losses	89.35	89.35	89.35	89.35	89.35
Corn allocated to sale	6274.39	5550.17	4816.43	4088.71	3354.97
Capital use	1933.26	1933.26	1933.26	1933.26	1933.26
Corn for planting	85.48	85.48	85.48	85.48	85.48
Herbicide use	15.33	15.33	15.33	15.33	15.33
Herbicide implement costs	63.21	63.21	63.21	63.21	63.21
Fertilizer use	277.20	277.20	277.20	277.20	277.20
Total family labor	138.13	138.13	138.13	138.13	138.13
Total hired labor	22.67	22.67	22.67	22.67	22.67
Total labor	160.80	160.80	160.80	160.80	160.80
Land clearing labor: Family	43.40	43.40	43.40	43.40	43.40
Land clearing labor: Hired					
Field burning labor: Family					
Field burning labor: Hired					
Herbicide appl. labor: Family	6.30	6.30	6.30	6.30	6.30
Herbicide appl. labor: Hired					
Planting labor: Family	19.36	19.36	19.36	19.36	19.36
Planting labor: Hired	5.22	5.22	5.22	5.22	5.22
First early weed. labor: Family	21.07	21.07	21.07	21.07	21.07
First early weed. labor: Hired					
First late H.W. labor: Family					
First late H.W. labor: Hired					
Second H.W. labor: Family					
Second H.W. labor: Hired					
Harvesting labor: Family	48.00	48.00	48.00	48.00	48.00
Harvesting labor: Hired	17.45	17.45	17.45	17.45	17.45

Table C-10. Empirical Results for Farm Cases Six and Seven Under Three Traditional Weed Control Technologies.

Tenant: owner — Cost of family labor: non-zero
Number of family workers: three — Capital: constrained

Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	3518.71	2020.97	1185.32	408.62	-4.23
	6430.30	4069.38	3233.77	2006.57	-59.38
Total area (hectares)	4.13	4.13	4.13	4.13	4.13
System 1--Old Land: Area under Tech. 1				2.52	1.39
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
--New Land: Area under Tech. 1				0.84	0.46
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c/]					
System 3: Area under Tech. 1		4.13	4.13	0.77	
Area under Tech. 2					
Area under Tech. 3	4.13				
Area under Tech. 4					
Total corn production	4658.64	3213.14	2705.15	1958.65	658.80
Corn allocated to consumption	598.91	598.91	598.91	598.91	598.91
Storage losses	59.89	59.89	59.89	59.89	59.89
Corn allocated to sale	3999.84	2554.34	2046.35	1300.35	--
Capital use	135.85	120.46	120.46	120.46	53.98
Corn for planting	61.95	54.93	54.93	54.93	24.61
Herbicide use					
Herbicide implement costs					
Fertilizer use					
Total family labor	153.63	122.25	122.25	105.87	45.76
Total hired labor	--				
Total labor	152.63	122.25	122.25	105.87	45.76
Land clearing labor: Family	55.34	46.36	46.26	33.90	13.93
Land clearing labor: Hired					
Field burning labor: Family	0.87	1.24	1.24	1.24	0.56
Field burning labor: Hired					
Herbicide appl. labor: Family					
Herbicide appl. labor: Hired					
Planting labor: Family	13.63	13.22	13.22	13.22	5.92
Planting labor: Hired					
First early weed. labor: Family	21.89	22.30	22.30	22.30	10.00
First early weed. labor: Hired					
First late H.W. labor: Family					
First late H.W. labor: Hired					
Second H.W. labor: Family	19.41				
Second H.W. labor: Hired					
Harvesting labor: Family	42.54	39.24	39.42	35.20	15.36
Harvesting labor: Hired					

Table C-11. Empirical Results for Farm Case Six Under Three Traditional and One Improved Weed Control Technologies.

Tenant: owner | Cost of family labor: non-zero
Number of family workers: three | Capital: constrained

Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	5438.41	4434.84	3416.80	2406.87	1388.84
	8057.93	7054.37	6036.32	5056.39	4008.35
Total area (hectares)	4.94	4.94	4.94	4.94	4.94
System 1--Old Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
--New Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c/]	1.08	1.08	1.08	1.08	1.08
System 3: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	3.86	3.86	3.86	3.86	3.87
Total corn production	6119.20	5508.87	4890.00	4276.06	3657.19
Corn allocated to consumption	598.91	598.91	598.91	598.91	598.91
Storage losses	59.89	59.89	59.89	59.89	59.89
Corn allocated to sale	5460.14	4850.07	4231.20	3617.26	2998.39
Capital use	840.00	840.00	840.00	840.00	840.00
Corn for planting	70.14	70.14	70.14	70.14	70.14
Herbicide use	10.10	10.10	10.10	10.10	10.10
Herbicide implement costs	51.87	51.87	51.87	51.87	51.87
Fertilizer use	118.80	118.80	118.80	118.80	118.80
Total family labor	143.02	143.02	143.02	143.02	143.02
Total hired labor					
Total labor	143.02	143.02	143.02	143.02	143.02
Land clearing labor: Family	47.86	47.86	47.86	47.86	47.86
Land clearing labor: Hired					
Field burning labor: Family					
Field burning labor: Hired					
Herbicide appl. labor: Family					
Herbicide appl. labor: Hired					
Planting labor: Family	2.70	2.70	2.70	2.70	2.70
Planting labor: Hired					
First early weed. labor: Family	19.98	19.98	19.98	19.98	19.98
First early weed. labor: Hired					
First late H.W. labor: Family	17.29	17.29	17.29	17.29	17.29
First late H.W. labor: Hired					
Second H.W. labor: Family					
Second H.W. labor: Hired					
Harvesting labor: Family	55.19	55.19	55.19	55.19	55.19
Harvesting labor: Hired					

Table C-12. Empirical Results for Farm Case Seven Under Three Traditional and One Improved Weed Control Technology.

Tenant: owner; Number of family workers: three; Cost of family labor: non-zero; Capital: unconstrained					
Risk aversion coefficient	0.0	0.5	1.0	1.5	2.0
Net revenue	6304.95	5113.61	3906.61	2709.51	1502.51
	9413.64	9222.32	7015.32	5818.22	4611.22
Total area (hectares)	6.02	6.02	6.02	6.02	6.02
System 1--Old Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
--New Land: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4					
System 2: Area under Tech. 4[c]	2.52	2.52	2.52	2.52	2.52
System 3: Area under Tech. 1					
Area under Tech. 2					
Area under Tech. 3					
Area under Tech. 4	3.50	3.50	3.50	3.50	3.50
Total corn production	7257.18	6532.96	5799.22	5071.50	4337.76
Corn allocated to consumption	598.91	598.91	598.91	598.91	598.91
Storage losses	59.89	59.89	59.89	59.89	59.89
Corn allocated to sale	6598.38	5874.16	5140.42	4412.70	3678.96
Capital use	1309.70	1309.70	1309.70	1309.70	1309.70
Corn for planting	85.48	85.48	85.48	85.48	85.48
Herbicide use	15.33	15.33	15.33	15.33	15.33
Herbicide implement costs	63.21	63.21	63.21	63.21	63.21
Fertilizer use	277.20	277.20	277.20	277.20	277.20
Total family labor	160.80	160.80	160.80	160.80	160.80
Total hired labor	43.40	43.40	43.40	43.40	43.40
Total labor					
Land clearing labor: Family					
Hired					
Field burning labor: Family					
Hired					
Herbicide appl. labor: Family	6.30	6.30	6.30	6.30	6.30
Hired					
Planting labor: Family	24.58	24.58	24.58	24.58	24.58
Hired					
First early weed. labor: Family	21.07	21.07	21.07	21.07	21.07
Hired					
First late H.W. labor: Family					
Hired					
Second H.W. labor: Family					
Hired					
Harvesting labor: Family	65.45	65.45	65.45	65.45	65.45
Hired					