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Title: Prospects for Technical Change and Family Nutrition Effects In the Caqueza Integrated Rural Development Project of Colombia: An Economic Evaluation Under Risk

Abstract approved: ________________________________

Frank S. Conklin

This study is an attempt to determine the effects of technical change in family income and family nutritional status among small farmers within the corn growing zone of the Caqueza Project in Colombia. It is also designed to provide the Integrated Rural Development Districts with a simple tool to analyze and formulate farm production plans to accomplish the policy goal of increasing family income, fulfilling minimum living standards, and to incorporate into this analysis, technical recommendations as they become available to farmers.

Using an "average farm" to represent the entire area, a version of the MOTAD model was implemented to analyze all production activities of the farm under conditions of improved and traditional technology, different working capital constraints, prices and yield variations and family nutritional constraints. Technical coefficients were obtained from a cross-sectional sample of 163 farmers, data from experimental results, records of improved technology adopters and 28 years of monthly prices.

Due to geographical location, and variations of altitude, three different types of farms are distinguished through this study. The same model is applied to each type of farm and solutions are given by

type of technology, level of credit, and levels of risk which are parameterized from minimum to maximum within the relevant range.

Solutions of the model provide information on levels and type of production activities, factor use, profit maximization levels and efficiency frontiers depicting trade-offs between risk and expected profit. Solutions for the endogenous variables of the model are validated against the actual farmers' economic behavior.

Model conclusions, which are presented for each type of farm can be summarized as follows:

(1) Farm plans are characterized by a fairly high degree of diversification in both agricultural and animal production. There exists an inverse relationship between farm diversification and the value of risk: the higher the level of risk accepted by farmers, the less diversified the farming activities.

(2) Cropping activities for which improved technology is available are selected by the model over the same activities carried on under traditional technological patterns on all types of farms. Among the activities with recommended technology, associated crops are selected over single crops, i.e., improved corn-bean over improved corn. Solutions not considering the introduction of technological change select double and triple crop associations over single cropping activities, i.e., traditional corn-beans and corn-beans-ahuyama over traditional corn.

(3) Income generation activities such as land renting and off-farm labor play an important role in maximizing expected profit. The area of land to be rented varies inversely with the value of risk. There is no definite pattern of allocating off-farm labor since it is closely related to the total set of activities on the farm.

(4) Availability of working capital, represented by different levels of credit, is a very important factor in planning farm activities. Farmers using all credit endogenously determined by the model obtain higher levels of expected profit, allocate more land to farming activities, use more labor, and concentrate on recommended technological

patterns. Farmers using limited credit will reach the maximum risk level (after which no changes in expected profits take place) more rapidly than farmers using full credit.

(5) The value of the expected profit varies with the risk level, the type of technology and the amount of credit. For farmers using open credit, the introduction of technical change produces higher values of expected profit than for farmers with limited credit. When farming is limited in credit, the introduction of the recommended technology yields high levels of expected profit at low values of risk, but no difference in profit exists between plans with traditional or improved technology when risk levels increase to medium and large values.

(6) The validation analysis, based on comparisons of the aggregated regional supply, shows adequate model estimations for some products, and significant differences for others. The solutions of the model demonstrate that adoption of the recommended technology is a feasible option and that the level of working capital may be the crucial factor for a massive technological change. This issue is linked to the fact that the recommended technological pattern for the Caqueza Project area is capital-biased.

Prospects for Technical Change and Family Nutrition Effects in the Caqueza Integrated Rural Development Project of Colombia: An Economic Evaluation Under Risk

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Typed by Bonnie Shula for German Escobar

To:

Nelly, Vladimir, Juan Nicolas, and Camilo Esteban

Con amor, admiracion, orgullo y esperanza.

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CHAPTER I

Introduction

The rural sector in Colombia is one of an accentuated dualism between the commercial agricultural subsector, and the traditional subsector which is characterized by low levels of production, small unit farms, low income near to subsistence level, little education, mountainous terrain and deficient levels of nutrition and health. Nonetheless, over the years, national plans have concentrated efforts on the more developed commercial subsector. Only during the last fifteen years has more attention been focussed on the traditional sector.

The Colombian Agricultural Research Institute (ICA)[1] is responsible for both agricultural research and transference of technology in Colombia. During the last decade, technology transfer has been implemented through Rural Development Projects directed toward small farmers in certain rural areas. One of these projects is the Rural Development Project of Eastern Cundinamarca (the Caqueza Project), established in 1971.

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[1]The Colombian Agricultural Research Institute (ICA) is an official agency supported by the Colombian government under the Ministry of Agriculture. For more than 25 years, ICA has directed its efforts toward agricultural and livestock research, and in 1968, incorporated the responsibility of transferring research results to the agricultural sector. ICA presently operates through experiment stations, monitors commercial research in farmers' fields and conducts integrated development projects in geographical areas where small and traditional farming takes place. The rural development projects teams (staffed by professionals and technicians) are responsible for transferring the improved technology obtained from experiment stations and research fields. The process of introducing those results and technically assisting small farmers in production processes, non-formal education, and home economics programs has been called technological transference. Technology for commercial farmers is transferred by training private agricultural consultants and through the dissemination of written material.

The specific objectives of the Caqueza Project can be summarized as follows: 1) to increase family income; 2) to increase employment opportunities in the area; 3) to improve the nutritional status of the rural population; 4) to respond to the demand for food products and raw materials for industry; 5) to identify methods for institutional coordination that will lead toward clear programming, avoiding duplication, and to the better availability of massive and integrated services of the government in rural areas; and, 6) to use the project as a training laboratory for farmers and for professionals in agricultural and animal production, social and economic sciences (59).

Six instruments are employed to implement these objectives: 1) improved agricultural technology for both crop and animal production which is adjusted over time to increase its appropriateness within the region; 2) economic technology to improve the economic decision-making process; i.e., increases in production with higher elasticity of demand, marketing strategy improvements to reduce margins in favor of producers, and optimal allocation of production factors; 3) increase utilization programs to reorient income expenditure and increments in income (produced through 1) and 2)) toward operational programs to improve the level of nutrition, quality of housing, family health, and other variables affecting the level of living; 4) communication systems to diffuse information to farmers and government and private agencies; 5) institutional service improvements to increase the efficiency, effectiveness and coordination of service agencies; 6) evaluation process to appraise activities and basic strategies (15).

The development and introduction of improved technology are the principal sources of change. Increases in production, productivity and marketing-margin reductions are the income generators to accomplish the rest of the project objectives. Technical recommendations have been developed for the most common crops and crop combinations within the region: corn-beans, potato-peas, some vegetables and several management practices for livestock and poultry production.

In 1976, the creation of the National Nutritional Plan--which contains the Integrated Rural Development Program (IRD), provides a wider approach to Rural Development Projects: through integrated coordination of governmental institutions it is hoped to substantially increase physical production among small farmers by improving production techniques and farm plans, and supplying services required for a better level of living for the rural families.[2]

The Problem

The content of the IRD implies three major requirements from ICA: 1) the technology transfer service must be extended to approximately 90,000 rural families; 2) it must be directed to the total production unit in contrast to the former method of recommending technological packages for specific production activities, and, 3) activities directed toward income utilization to fulfill objectives in level of living standards must be included through either direct action and/or coordination with other agencies.

These commands of the agricultural policy suggest that the ICA must adjust its system of operation, the methods of generating, adapting and transferring technology, and the capacity to analyze and produce economic recommendations directed to increase family income within the context of the nutritional plan, and the risk factor that effects the adoption of the improved technology. For the purpose of this research effort, the component of the problem of direct concern is the economic analysis of the production unit in the corn production area of the Caqueza Project, and the relationships of a potential increase in output and income with the nutritional plan.

Specifically, the research problem is delineated to 1) analyze the production process of the total production unit under both the traditional and the recommended technological pattern and the variation in profit due to changes in yields and prices; 2) evaluate the capability of fulfilling the objectives of adequate nutritional requirements under the

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[2]The Integrated Rural Development Program (IRD) is an official effort to integrate most of the agencies in the rural sector (i.e., agricultural technical assistance, marketing, credit, education, health, etc.) The IRD's central target is to provide the poorest rural families with essential services, to increase family income, and increase total production of non-exportable agricultural products in order to subsidize the low income rural families.

present endowment of resources and social characteristics, and 3) confront the prospective of an increase in the family income in the light of the IRD plan, through adoption of the recommended technology.

Research Objectives

The overall objective is to provide the ICA a method of economically analyzing the small farm unit under conditions of profit variations and the new technological recommendations. Such farm analysis is a means of generating the income required to accomplish the objectives of the IRD plan, and the nutritional plan to which IRD is embodied. The specific objectives of this research work can be summarized as follows:

(1) Typify the "average farm" within the study area through determination of the most frequent crops, crop combinations and other farm activities, to establish its net returns with and without the technical recommendation under conditions of uncertainty.

(2) Develop a simple programming model for the total production unit to perform analysis of introducing new technological practices, sources of variability, or rearranging the available farm resources to maximize profit.

(3) Determine the effectiveness of the improved technology and/or the planning tool to fulfill minimum family nutrition standards as an objective of the national nutritional plan, within the present social customs and consumption patterns.

(4) Analyze the potential effect of increasing total farm production via technological change, after nutritional needs are met.

(5) Propose simple guidelines to make the programming model applicable to other areas with similar characteristics.

A Brief Description of the Caqueza Project

This section presents a general description of the Caqueza Project with the goal of introducing the socioeconomic environment in which production takes place. There exist hundreds of pages already written on the description and characteristics of the Project, such that what is said here is a very summarized version of some of the principle aspects of the Project. It is hoped this review will provide a quick overview of the area and some of the reasons for certain production practices. References should be kept in mind if a better understanding of the entire situation is desired.

Geographical and Physical Characteristics

The Caqueza Project is located in the eastern part of the Department of Cundinamarca.[3] It covers 227,000 hectares which are divided into nine municipios, six of which have been incorporated into the work-area. Approximately 40% of the land is in forest and about 1/2 of the rest is not exploitable due to topographic limitations (16).[4] This topographical aspect is a very important factor to consider in the region because the area is located in the eastern branch of the Andean range, which means that variations in elevation are strong, and rivers and streams tend to flow in canyons.

For the entire geographical area, altitudes go from less than 1000 m.o.s.l. to 3900 m.o.s.l., and the slopes range from 10% to more than 60%. Differences in elevation create a very wide variation in temperature and a large possibility for crop diversifications.

The region has an approximate total of 410 kilometers of passable roads, and the highway connecting the capital of the country and the capital of one of the Departments crosses the region. This results in a ratio of 175.1 squared kilometers for each road kilometer.

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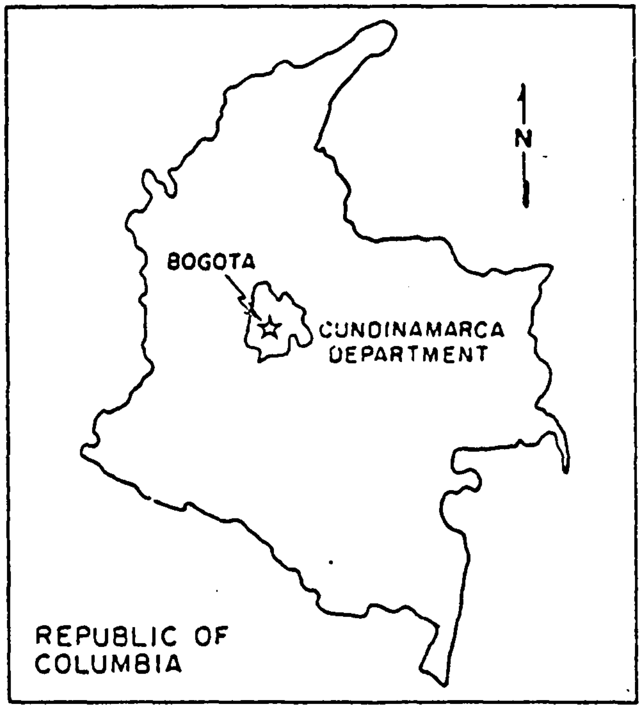
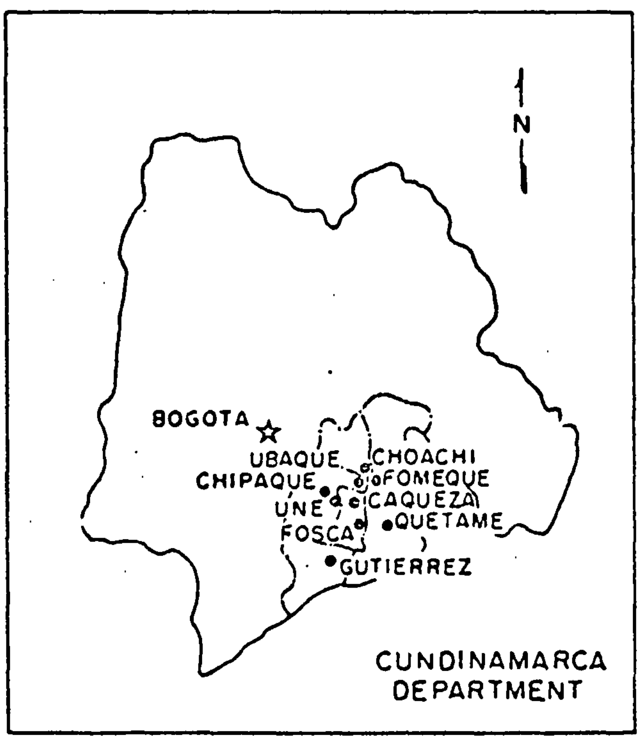
[3]The Colombian political-administrative division into departments, corresponds to the U.S. Divisions into States.

[4]Most of the information included in this section is based on the study referred to in (16).

Map 1. Caqueza Project. Localization in the Cundinamarca Department.





Source: Escobar, G., "Proyecto de Desarrollo Rural del Oriente de Cundinamarca Diagnostico Socio-Economico," ICA Documento 01-2.4-2-73., Bogota, Julio 1973, p. 13.

The climate is another factor to be considered as bearing influence on the economic activity within the area. The region has a rainy period which starts in the middle of March, and reaches its maximum by June or July. By the middle of September a new rainy period starts, but it is much shorter than the first one, its duration being a month or less. The dry season is from the middle of November to the middle of March. The rain intensity varies with the slope of the mountain range. The precipitation is 951.0 to 2235.6 mm, according to averages of the last 20 years.

The rain pattern strongly affects the timing of agricultural activities, and only the areas with irrigation are capable of producing two harvests per year of those products that require short biological growing periods.

Land Distribution and Tenure Systems

The zone of the Caqueza Project corresponds to the typical *minifundio* area. On the average, there are 1.27 has. of permanent crops and 1.11 has. of annual crops per farm, according to the 1970 census. There are, however, some large units, which in most cases are not capable of being exploited in entirety due to topographic limitations or because they are forested. Table 1 shows the information available from a 1970 agricultural census.

The most common farm size is less than 3 has., and nearly two-thirds have less than 5 has. There exists a relationship between farm size and altitude: the higher the relative altitude, the bigger the farm, and the greater the area not suitable for productive activities. The core areas which the study focusses on, are the geographical ones in which the smaller farm size is more accentuated.

More than 80% of the farm units are owned by their operators who usually live at the farm. An interesting land tenure class is the one designated "owner-leasing" which consists of farmers who own some land but at the same time lease another area for agricultural purposes. Data regarding the tenure systems is presented in Table II. The high

Table 1. Size of Farms in the Caqueza Project, 1970.

Size (has).	%Farms	Cumulative %	%Area (has).	Cumulative %
0 - .9	9.9	9.9		
1 - 2.9	34.6	44.5		
3 - 4.9	20.2	64.7	28.5	28.5
5 - 6.9	11.8	76.5		
7 - 8.9	6.2	82.7		
9 - 10.9	4.2	89.9	11.1	39.6
11 - 12.9	3.2	90.1		
13 - 14.9	1.2	91.3	8.3	47.9
15 - 29.9	4.8	96.1	9.8	57.7
30 + more	3.9	100.0	42.3	100.0

Source: Escobar, G. "Proyecto de Desarrollo Rural del Oriente de Cundinamarca; Diagnostico Socioeconomico." P.D.R.O.C. ICA Regional No.1 Documento 01-2.4-2-73., 1973, pp. 159.

proportion of land ownership is conducive to some families to remain in the area, although the migration to the city of young people is significant.

Table 2. Land Tenure System in the Caqueza Project, 1972.

Tenure System Owners	% of Farms
Owners	69.4
Leasing	18.4
Owner-Leasing	11.8
Other Systems	.5

Source: Escobar, G. "Proyecto de Desarrollo Rural del Oriente de Cundinamarca: Diagnostico Socioeconomico," ICA Regional No. 1. Documento 01-2.4-2-73, 1973, pp. 162.

Residents would oppose any programs to consolidate ownership or otherwise change land tenure, with the exception of increasing individual farm size.

Land Uses and Production Systems

From national statistics, it is known that about 35% of the land is devoted to pastures, and about 21% of the land is relief land (this includes land prepared to be used and land not used at the time of the census). This classification does not identify areas not suitable for economic exploration, and the class "others" represents nearly 30% of the area. From these numbers, it follows that the area cropped is roughly 14% of the total extension. This explains the small farm size exploitation of permanent and annual crops. In absolute numbers, it makes 15,900 hectares and 13,835 farm units. The 78.5% of the cropped areas is dedicated to annual crops, which are the main source of agricultural production in the area.

The livestock industry has a significant role in the economy of the area. In 1970, the total amount of cattle was 46,577 heads, 11,326 of hogs, and 182,608 barnyard fowls were reported in the census. However, these numbers are not indicators of numerous large or medium formal exploitations. It is really difficult to find a farm without one or two cows or without a few dozen chickens and two or three hogs.

A general characteristic of the production system, which applies to any minifundio area in Colombia, is the presence of multiple cropping. Although single crop cultivation exists at all altitudes of the region, it has been estimated that at least 80% of the current cultivated area is planted in crop-combination. This cropping pattern involves the use of two more more crops at a time on the same plot of land.

Another important characteristic is the absence of machinery use in agricultural activities. Large curved hoes, rudimentary plows and animal power are the principle tools used. The level of technology is not uniform within the area and technological patterns vary with crops. Differences between farmers in low altitudes and those in the higher areas are significant. In general, farmers of high lands (potato zone) are more sophisticated in the type of inputs used than farmers of low lands (corn zone). Still, the vegetable grower (intermediate altitude) is a bit more sophisticated than the potato grower in choosing and planting seeds as well as in taking care of the crop during the biological cycle. The highest technical level is found among commercial poultry growers (500 animals or more) who work at levels close to those recommended by experiment stations. Cattle farmers are characterized by poor management practices, especially in animal nutrition levels.

Productivity and Income

Agricultural and cattle enterprises are the main source of income in the region, given the limitations in cropland area and the traditional level of technology. Yields are low compared to national figures. A fairly complete and detailed study on land productivity by crops can be found in the literature produced for the Caqueza Project (for figures on productivity with both traditional and improved technology for the corn area, see references (16), (17), (51), (59)). Field research has demonstrated that room for increases in productivity is enormous; it is possible to obtain 25 tons/ha. of potatoes, while at present farmers obtain roughly 10 tons/ha. It is also possible to have a yield of 3.5 tons/ha., in corn where less than 1 ton/ha. is presently harvested. Nevertheless, the process of improving productivity is not troublefree. Estimates in which inputs are used at the recommended level, using the farmers' production functions, are not that promising, although they are significantly higher than yields under traditional technology (17).

No statistics are available for family income in the region of the Caqueza Project. Some estimations have been attempted over time, to account for income generated outside the agricultural subsector, and have been calculated as less than 20% fo the total income, including off-farm labor. Two of those estimates are presented in Table III. These are not comparable item by item, due to the form of the calculation system, but comparison of per capita income will provide an idea of the income level and its dynamics through time. Since the estimation for 1975, incorporates changes in labor use due to partial adoption of the recommended technology, the overall conclusion derived from Table III is that family income is low and well below the national average income.

Some Social Characteristics

As mentioned before, there are several studies concerning sociological and anthropological characteristics of the Caqueza Project region. Differences regarding the topic may be found in (59).

Table 3. Estimated Income Level of Families in the Caqueza Project, 1972 and 1975.

1972		1975	
Source	$(pesos)	Source	Total $ (pesos)
Total agricultural and cattle income	44509580	Labor in crop production	90667027
Per capita income originated in the agricultural sector	1562	Labor in animal production	27620744
Per capita income originated out of the agricultural sector	337	Return to capital in crop production	14386906
Total per capita income	1879 (U.S.$ 86)*	Return to capital in animal production	18083518
Total family income	14243 (U.S.$ 645)	Return to land	11810646
		Off-farm labor	9792000
Rural wage/day	12-25 (U.S.$ .60 - 1.10)	Per capita income	3403 (U.S.$ 142)**
		Family income	25523 (U.S.$ 1065
		Rural wage/day	25-40

* 1 dollar = 22.10 pesos
** 1 dollar = 24.0 pesos

Sources: Escobar, G. "Proyecto de Desarrollo Rural del Oriente de Cundinamarca Diagnostico Socioeconomico". P.D.R.O.C. documento 01-204-2-73. ICA, Bogota, Colombia, pp. 189.

Escobar, G. and K. Swanberg. "Uso de la Mano de Obra en dos zonas Rurales. Pleno Empleo Estacional." ICA, Division de Estudios Socioeconomicos, Bogota, Colombia, 1976, pp. 23.

Population Characteristics

Total population estimated for 1975 is 94,414 inhabitants. Approximately 85% live in the countryside and the remaining live in villages. It is a young population: for 1972, 45% were less than 15 years of age and 84% were younger than 40 years of age. A sample taken in 1972 from 642 farmers indicates that the average family size is 7.51 persons, which is greater than the national average.

Population density for 1975 was estimated to be 41.40 inhabitants/km^2, and projections for 1980 show 43.98 persons/km^2. Given the strong limitations for cropping land, that relationship has a more serious meaning. The active economic population has decreased since 1938 in an inverse proportion to the population growth, due to the increasing birth rate and to the period which it takes for the new generation to reach their productive ages. Unfortunately, there is no new information available at the region level to analyze the reduction in population growth rate found for Colombia in 1978.

It has been estimated in 1972, that every occupied person has to support not only himself, but 3.36 other persons in the region. The population growth rate as of 1972 is about 2% per year which is significantly smaller than the national rate. It may be that this rate reflects a fairly large rural-urban migration from the region.

Educational Characteristics

Education as referred to here focusses on formal instruction in spite of the fact that large scale efforts have been devoted to a more vocational type of education, i.e., an extension-type of instruction in agriculture, home economics, use of economic information and social organization.

The total population of school age children represented was 24% of the overall population, with only 72% of them registered as formal students. The educational level of the entire population is low. The 1972 survey showed that 62% of the total population has some primary school education and 1.2% have college level or equivalent. Illiteracy is near 27%, but according to the district school statistics, it has been reduced over time at a progress rate of 1.2% per year.

It has been found that capacity to assimilate information is rather reduced in the family atmosphere. Communicators have concluded that technical printed matter would not be an effective means of providing information to the typical adult.

CHAPTER II

The Conceptual Framework

There are at least two aspects which need to be discussed and defined in order to place the objectives of this study within an analysis framework. Those aspects are: the interrelation between economic activities and human nutrition, and the technical characteristics of programming models, which are some of the instruments through which both economic and nutritional variables can be analyzed together.

There exists different conceptions among economists and nutritionists about the direction of the relation between the economic activity, i.e., income, and the nutritional status. It has been claimed that the nutritional status produces a side effect on productivity through the quality of labor, decreases the incidence of diseases and infections among the labor force, and hence decreases absenteeism from employment, and produces the appropriate level of stamina to work efficiently (4, 39). On the other hand, data have been presented to support the idea that the quality of the diet, and consequently, the nutritional status, depend on the level of income (1, 50, 55).

From a more pragmatic angle, some authors have explained the evidence of the disastrous effects of undernutrition in human brains during the first two years of life (39). As a strategy of action to attack the problem, Mellor has written:

> ...I would thus give little emphasis to measuring the effects of improved nutrition on economic output...a key means of improving nutrition for the poor is their increased participation in economic growth...We need to change our approach to growth so as to provide full employment to the poor if we are to sufficiently deal with their nutritional problems (36, p. 70).

This approach seems to be one alternative of establishing a starting point for this double-direction relationship, since as Berg points out (4), there is no pragmatic method of isolating the effects of nutrition on economic production because several other variables are combined, and probably it is a combination of all factors that produce such effects.

A good synthesis of the effects of nutrition to human capital and food production to nutritional status is provided by Schmitt (49). These relations are shown in Figure 1, and are called the cyclonutritional phenomenon. The figure is self-evident, illustrating the two-way relationship between food production and an adequate balanced nutritional intake, and the role of income and human capital within the cycle.

The relationship established in Figure 1 can be used to link the specific objectives of the Caqueza Project, the instruments to implement these objectives, the IRD program, and the objectives of the present research work. The inclusion of the family nutritional status into the production analysis and the introduction of technological change responds not only to national development policy goals, but to the complexity of the farm unit production process as embodied in its own socioeconomic environment which is signalling the characteristics and change possibilities of such a process.

It could be argued that nutritional conditions are not the only component interrelating and affecting the production process. As this point is unquestionable, it should be made clear that there exists no intention of analyzing the socio-economic system where production takes place through the study of family nutritional needs. A cursory view of some limitations of this study is presented later in this chapter.

Based on former concepts, the research objectives related to the analysis of the farm production and the family nutritional condition can be studied together within the same framework, using the same analytical tool. This possibility brings into discussion the conceptualization of the optimization models, and the inclusion of risk and uncertainty in a farm programming method to jointly analyze farm production and family nutrition.

Planification of farms both at the individual and at the regional level has been frequently undertaken through programming models, especially in a case where the number of possible activities is considerable. These have been widely used as planning tools for situations in which risk and uncertainty enter into consideration (2).

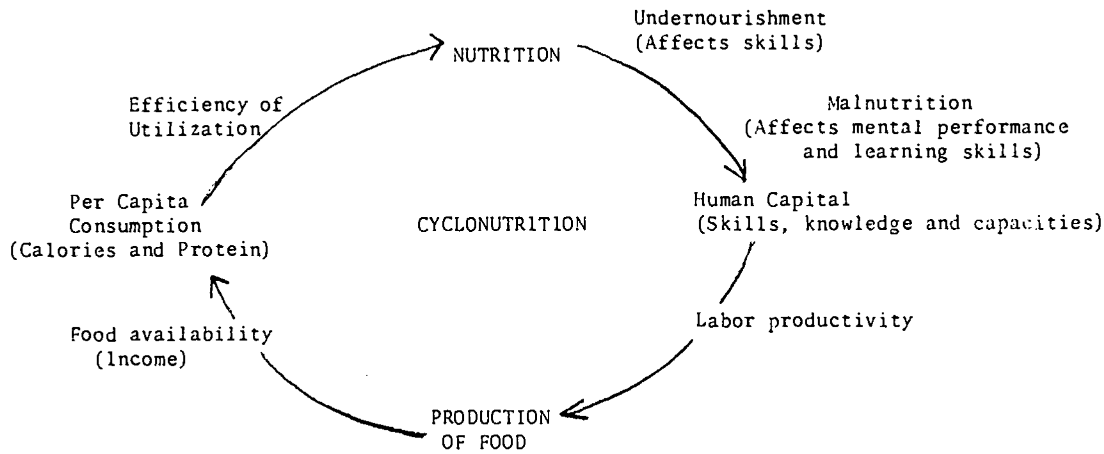


Figure 1. The Cyclonutritional Phenomenon

Source: "Protein, Calories and Development: Nutritional Variables in the Economics of Developing Countries," by B.A. Schmitt, Westview Press, Inc. 1979, p. 166.

Among the programming models, quadratic programming (QP) and linear programming (LP) are the most frequently used to determine maximizing combinations of inputs in the production process, accounting for uncertainty in any or all of the functional coefficients, the objective function, and the constraints. The several approaches that have been employed to implement the optimization of the production process have been classified as follows (7, 30):

(1) The "portfolio selection" in which risk is introduced through the objective function. This is an expected margin/dispersion analysis which assumes a continuous farmer's utility function. This approach originates the efficient frontier of expected gross margin (E)-expected value of income variance (V) pairs which the external stipulation of utility function to yield the optimal combination of resource use along a minimum variance for a given total gross outcome, E-V frontier.

(2) The "game theory" approach in which risk is introduced as a "states of nature" which are opponent factors to producers. Those states are introduced into LP through different conceptual postulates to account for uncertainty. As in (1) above, choice selection is based on an

external utility function.

(3) The safety-first or chance constraint program approach that accounts for uncertainty within the constraints of the programming model. This approach assumes a probability value for the least desired outcome, and it serves either as a constraint or as an objective function, depending on the specific assumptions and model to be analyzed.

The list of reports in the literature of the use of all three general approaches is large since Markowitz's portfolio selection, especially during the late 60's and 70's (2, 7, 24, 25, 28, 33, 42). Such affluence of research and empirical applications have resulted in a great diversification, and improvements of the pioneer models, as well as interesting controversies about the properties and theoretical foundations of some of the proposed methods (12, 13, 24, 37). Major emphasis has focussed on simplifying the use of programming techniques, since the QP algorithm required for the portfolio selection approach was found inconvenient due to inefficiencies in computations, availability of the tool, specification of the utility function, and cost of operation (2, 25, 43, 56). In this respect, one of the better known innovative proposals is Hazell's Motad Model (25) which requires conventional LP procedures to generate an E-M efficiency frontier which yields very similar results to the orthodox E-V analysis. This approach will be discussed more precisely elsewhere in this text. In the same direction, other attempts have been introduced by using separable programming (56), decomposition algorithms (58), linear approximation based on the Taylor series expansion, and direct approximation (43).

Functional Definitions

In order to determine the specific model to be applied to the optimization problem, it is necessary to analyze the linkage between the research objectives, the available data, and the known systems of application summarized within the previous pages. Those relationships require some common factors: the explanation of the producer behavior to diversification in farming, his objective function, and basic definitions and assumptions that enable the selection of the optimization tool.

Assumptions and Definitions

From both theoretical and empirical views, it is assumed an objective function according to which the typical small farmer looks at the satisfaction of basic family needs and at the maximum profit that is obtainable within his specific socioeconomic environment (i.e., resource availability, technological status, the risk and uncertainty attached to farming, managerial capability, market structure, institutional arrangements, family structure, wealth endowment, sociological conditions, and risk and change attitudes).

This multidimensional utility function is narrowed down by the research objectives to a bidimensional function which is aimed at the satisfaction of the minimum family nutritional needs, and the maximum profit attainable from the farm operator. It is further assumed that this utility function has lexicographic characteristics according to which the typical farmer does not allow tradeoffs between the two basic objectives (3). This latter assumption is complemented by assigning equal priority to each objective, such that both must be satisfied simultaneously. Based on experience and former research, this assumption could be extended by postulating a specific utility function as it has often been done among agricultural economists (2, 8, 20, 23). However, in absence of the pertinent data, it is preferred to restrict the assumptions to the former statement, hoping not to lose generality for the maximization analysis.[5]

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[5]One of the limitations that can be easily pointed out is the apparent exclusion of the expected utility and the Bayesian models which allow the incorporation of subjective probabilities, since the Bernoullian principle requires risk to be measured in conjuction with the utility function. However, the objective function as described is compatible with the expected utility theorem if $U=f(\pi)$. In a risk situation: $U=E(u) = E(\pi \max)$ if the expectations are originated by a subjective evaluation of the profit distribution, for discrete cases it follows that $U=\Sigma_i U(\pi/\theta i)(P(\theta i))$ where θi denotes the ith possible event and $P(\theta i)$ is the prior probability or the producer's judgment of the occurrence of θi.

The introduction of risk and/or uncertainty also requires an operative definition. This is an issue in which no consensus exists among economists (45) and it is often found that both concepts are given the same meaning, or that no definition is used at all. According to Knight (31), uncertainty refers to unknown future situations which are not susceptible to being measured; risk corresponds to the concept of probabilities that an event occurs. This distinction implies that both risk and uncertainty stand for any decision. Although measures of risk usually involve arguments of dispersion of probabilistic distributions, the idea of identifying risk with a measure of variability generating different outcomes is adopted in establishing the programming model.

The former distinction does not, however, solve the problems involved in measuring risk. In addition to the existing approaches to incorporating risk into the decision making process, it is necessary to define what the risk elements are that the farmer faces, and what data are available for the corresponding analysis. One point that has been maintained by the majority of economists is that the variation, of say net returns over time, is what concerns most farmers. This is an appealing framework that is implicitly accepted by researchers since almost in every case the analysis of risk is undertaken with time-series data, even if for short time periods, usually recognizing that the risk measurement is a subjective matter (2, 20). In contrast, there are cases in which the use of cross-sectional data has been clearly stated as valid. This is the case of estimating an expected loss function to account for variations in resource endowments, weather effects, and managerial services and attitudes based on the probabilistic nature of production coefficients estimated from a cross-sectional sample (13). A further step has been given by Murphy who generalized risk evaluation with planning data arranged in statistical forms of mean expected values, standard deviations of a simple observation, and correlation coefficients (zero-order correlation between pairs), which can be obtained using cross-sectional data if homogeneous samples are available up to the point where the efficiency of the subsequent data is no longer improved (38).

In any event, if variation over time is an adequate interpretation of the farmers' interests, the best data for analysis will consist of records of inputs and outputs, and prices through time. In absence of complete records over time, it is possible to pool time series and cross-sectional data. This could be the case when historical data is incorporated into the decision-making process (2). Another alternative could be to use extraneous information (i.e., former research findings).

As explained elsewhere, the data which are available consist of a cross-sectional observation, historical data, agronomic research records, and results of previous economic research. With such data it is possible to include a measurement of risk into the estimates to allow for a non-deterministic analysis through LP algorithms.

Sources of Uncertainty

The uncertain events affecting farming have a direct impact on the farmer's decisions on products, systems of farming and quantities to be produced. For farmers in the Caqueza Project area these events can be categorized in three general sources: 1) uncertainty due to market conditions; 2) uncertainty due to non-controllable factors affecting the production process (i.e., weather, some plagues and diseases, credit policy, etc.); 3) uncertainty due to the new technical recommendation.[6] These three sources of uncertainty are closely related to each other, such that their division into groups responds to facility of explanation.

The uncertainty due to the market conditions is mainly reflected in price variability in both inputs and outputs. For the Caqueza Project

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[6]Schluter and Mellor have argued that the introduction of new technological patterns, the lack of knowledge of cultivation methods and the crop's response to different weather conditions are a high source of uncertainty, but that it decreases over time (48). It could be argued that the physical characteristics of the new technology remain as a source of uncertainty, due to variations in biological plant behavior and its relation to environmental factors.

area output prices vary more frequently than input prices. Inputs are supplied by few retail stores that charge similar prices, but output buyers are several with the characteristics of atomistic competition and a poor adjustment process with the wholesale price (16). For the purpose of this work, the uncertainty due to output price is the only one taken into account, based on the assumption that input prices can be known in advance in the short run, and that all inputs are available to farmers.

The uncertainty due to non-controllable factors are specific to the region, but no less important to the decision maker. Factors like credit, opportunity of technical assistance, and transportation are essential for production within the region. Changes in national policies of which small farmers have little influence, are important in increasing or reducing the risk involved in farming. Nevertheless, operative changes introduced with the creation of the Caqueza Project, and former policy developments introduced along the IRD plan, allow us to disregard credit and technical assistance as significant sources of uncertainty. As far as the present analysis is concerned, those factors are considered to be certain, although specific considerations are often allowed for in the case of credit.

The uncertainty due to technological change is basically reflected in variations of physical output, since costs have been already accepted as certain. It has been demonstrated that the proposed combination of inputs and some changes in managerial decisions (i.e., quality of land preparation, timing of certain practices) yield a higher output per unit of land than the output obtained using the traditional technological pattern under controlled experimental conditions (15, 59). However, it is recognized that there exists a gap between experimental plots and actual "commercial" cropping and research agronomists who often view yield variability as a secondary factor in generating "good" research results as their livelihood is independent of the outcomes unlike the farmers. Variability in yields will be taken into account as a risk factor for the purpose of this research work.

The Model

As briefly mentioned before, one of the several systems to account for risk and uncertainty within a framework of a simple optimization model, is the Minimization of Total Absolute Deviations, MOTAD. This model has been applied to entire farm analysis since it allows an incorporation of risk through the mean of absolute deviations M, which can be minimized for a given level of expected profit $E(\pi)$, using the conventional LP algorithm.

The MOTAD model was presented by Hazzell in 1971 (25) and several alternative formulations have been developed from that pioneer effort (3, 9, 30, 34, 47). Hazzell claims that an unbiased estimator of the population mean absolute income deviation is (25).

$$M = s^{-1} \sum_{h=1}^{s} \left| \sum_{j=1}^{n} (c_{hj} - g_i) x_j \right|$$

where:

M = mean absolute income variation
$h=1$ to s denotes s observations in a random sample of gross margins.
c_{hj} = total gross margin for the jth activity ($j=1$ to n)
g_j = mean of gross margins of the jth activity
x_j = level of the jth activity.

M is used as a measure of risk which is to be minimized by producers for a given $E(\pi)$. In order for the problem to be solved by using the LP algorithm, Hazzell defines new variables as:

$$y_n = \sum_{j=1}^{n} c_{hj} x_j - \sum_{j=1}^{n} g_i x_j \quad , \text{ for all } h,\ h = 1, \ldots, s.$$

such that

$$y_h = y_n^+ - y_h^-$$

and

$$y_h^+,\ y_h^- \geq 0$$

For a given farm plan,

$$y_n^+ = \left| \sum_{j=1}^{n} (c_{hj} - g_i)\ x_j \right|$$

when $\sum_{j=1}^{n} (c_{hj} - g_i)\ x_j$ is positive and zero otherwise, it is $\sum_{h=1}^{s} y_h^+$, is the sum of the absolute values of the positive total gross margin deviations from the expected return.

In a similar fashion,

$$y_h^- = \sum_{j=1}^{n} \left| (x_{hj} - g_i)\ x_i \right|$$

when the summation is negative and zero otherwise. Thus $\sum_{h=1}^{s} y_h^-$ is the sum of the absolute values of the negative total gross margin deviations from the expected return.

Hazzell illustrates that $\sum_{h=1}^{s} y_h^+ = \sum_{h=1}^{s} y_h^-$ when g_j $(j=1,\ldots,n)$ are mean gross margins. This allows him to formulate the MOTAD model as follows:

$$\text{minimize} \quad \sum_{h=1}^{s} y_h^- \qquad [1]$$

such that

$$\sum_{j=1}^{n} (c_{hj} - g_i)\ x_j + y_h^- \geq 0 \qquad \text{for all } h(h=1,\ldots s) \qquad [2]$$

and

$$\sum_{j=1}^{n} a_{ij}x_j \leq b_i \quad \text{for all } i, (i=1,...,m) \qquad [3]$$

$$\sum_{j=1}^{n} f_jx_j = \lambda, \quad \lambda = 0 \text{ to unbounded} \qquad [4]$$

$$x_j, y_n^- \geq 0 \text{ , for all } h, j \qquad [5]$$

where a_{ij} = technical coefficients of the jth activity for the ith resource

b_i = ith constraint

f_j = expected (forecasted) gross margin of the jth activity

λ = a scalar

Consider $\quad \text{prob.} (P_j = P_{tj}) = r_t' > 0 \qquad [6]$

and $\quad \text{prob.} (Y_j = Y_{tj}) = r_t'' > 0$

where

$$\sum_{t=1}^{t} r' = 1 \text{ and } \sum_{t=1}^{t} r_t'' = 1 \quad \text{, and}$$

That statement of this model is wide enough to incorporate the conceptual framework, the assumptions, and definitions already explained. The selected sources of risk are to provide the basis for the estimator of the population absolute deviation, and an alternative formulation of the model takes care of the objective function that has been assumed for the purpose of this study.

Specifically, the sources of risk are random variables which take a finite number of values, P_{tj} and Y_{tj} for prices and yields, respectively, with their corresponding probabilities r_t.

P_j = price of the jth output

Y_j = yield of the yth activity

P_{tj}, Y_{tj} = number of "possible" values of P_j and Y_j, $t=1,\ldots,T$

According to the objective function, the expression to be maximized is

$$\pi = C_j X_j$$

where

C_j = net revenue of the jth activity [7]

but, $C_j = (P_{tj})(Y_{ij}) - V_j$ where V_j represents the production costs.

If $P_{tj} \sim N(\mu_p, \sigma_p^2)$

and $Y_{tj} \sim N(\mu_y, \sigma^2 y)$

then $C_j \sim N(Y_e, \sigma_e^2)$, since V_j are deterministic values. [8]

Farm production in the Caqueza Project area can be considered to take place under conditions close to perfect competition. With this structure of the supply side, producers' response to the dynamics of the market will show a strong relation between total product and prices. However, when the analysis focusses in on per unit yields, it could be expected that for empirical purposes, prices and yields are not strongly correlated, especially in the situation of subsistence agriculture. If this is the case,

$$\text{Prob} \quad (P_j, Y_j) = (P_{tj}, Y_{tj}) = r_t > 0 \qquad [9]$$

and, $\sum_{t=1}^{T} r_t = 1$ [6a]

Following expressions [8] and [9], the mathematical expectation for net revenue is:

$$E(C_j) = \bar{C}_j = \sum_{t=1}^{T} r_t C_j \qquad [10]$$

From [10], the value of π in [7] becomes a random variable with expectation

$$E(\pi) = \sum_{t=1}^{T} \bar{C}_j X_j \qquad [11]$$

[6a] The assumption of independency between the two sources of risk should be clearly distinguished from the interrelationships between activities gross or net margins. Hazzell has shown that the MOTAD model recognizes the sample vectors of activities as being mutually exclusive together with the corresponding relative frequencies (25). It implies that interrelations between net or gross revenues of the activities are allowed by taking the full joint distribution of net revenues, to which covariance terms belong.

Expression [11] can be used to reformulate the MOTAD model in such a way that the expected farm profit can be maximized subject to a constraint on the sum of the absolute deviations from the mean (3).

Expanding [11] to account for the components of net revenue, the model can be expressed as follows:

maximize

$$E(\pi) = \sum_{t=1}^{T} (P_{tj} Y_{tj}) X_j - V_j \qquad [12]$$

subject to

$$\sum_{j=1}^{n} a_{ij} x_j \{\geq \; = \; \leq\} b_i \quad , \; i=1,\ldots,m \qquad [3a]$$

$$\sum_{j=1}^{n} (c_{hj} - g_j) X_j + Y_h \geq 0 \quad , \; h=1,\ldots,s \qquad [2a]$$

$$\sum_{h=1}^{s} Y_h \leq \lambda \quad , \quad \lambda = 0 \rightarrow \lambda_{max} \qquad [13]$$

In addition to former constraints, the objectives of this study call for others related to the satisfaction of minimum family nutritional needs. It is required to reach a minimum level of production and/or disposable income such that consumption of the family is attained according to their consumer pattern, and the physiological requirements.

As suggested by Low (33), the minimum margin can be obtained whenever

$$\bar{C}_j X_j \geq S' \qquad [14]$$

where:

S' = minimum nutritional requirements in money equivalent.

In that sense, [14] can be equally attained by

$$d_{ij} X_j \geq S \qquad [15]$$

where: d_{ij} = nutritional components of products obtained from activity X_j; S = nutritional requirements in physical nutrient units.

Actually, the minimal nutritional needs may be satisfied by any combination of [14] and [15]. To account for these possibilities, it is necessary to allow all or any proportion of $\bar{C}_j X_j$ to "buy" S - if it is desired to accomplish the analysis of physical units. This means that $S' \sim S$, since the difference is given by the measurement units.

Continuing [14] and [15], S will be satisfied by

$$(\bar{C}_j + d_{ij})\ X_j \geq S \qquad [16]$$

The proportion by which [14] and/or [15] will contribute to fulfill [16] is determined by prices of production and consumption goods for the family diet. The actual proportions are to be set by the optimal solutions.

Food production prices have been accounted for in [12]. In order to introduce the prices of food items to be bought by the family - if the proportion of [14] is greater than zero -, the objective function of the model becomes

$$\text{maximize } E(\pi) \qquad \sum_{t=1}^{T} [Y_{tj} X_j) - (Q_j X_j] P_{tj} - V_j - F_j P_{Fj} \qquad [12a]$$

With this expression, the version of the MOTAD model to be used has been completed: maximize [12a], subject to [3a], [2a], [13], [16] and [5a]. This model preserves the properties of the one represented by expressions [1] to [5]. The addition of inequality [16] to satisfy objectives of this study does not alter the properties of MOTAD, since the market price of food consumption items does not introduce another source of risk.

It should be reaffirmed that expression [13] is equivalent to expression [4] in providing the E-M efficiency boundary as explained by Anderson, Dillon and Hardaker (3). The parametric solution for different values of λ allows the development of a linear relationship between $E(\pi)$ and the sum of the absolute deviations around the mean of net returns of each of the j activities to be considered in the problem. This relation (Figure 2) illustrates for farmers, the tradeoff between expected profit and the occurrence of events that have been assumed to be risky for them. Farmers may apply their own utility function to this relationship in order to decide the optimum allocation of their resources and still fulfill their family nutritional needs.[7]

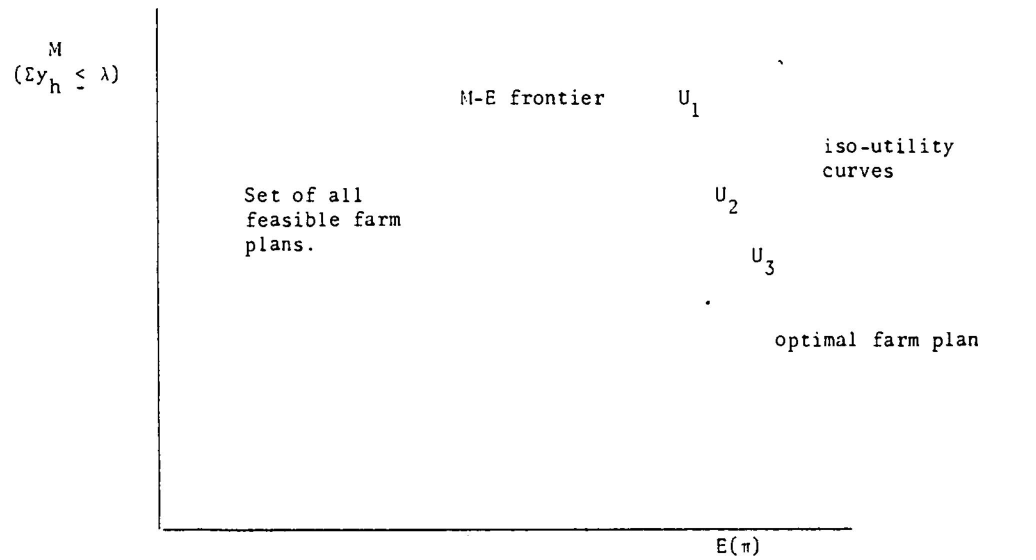

Figure 2. An illustration of the M-E analysis for farm planning.

The Data

The data available for this research work consists of several different types and sources, which are described as follows:

[1] A cross-sectional survey of 168 observations among small farmers in the corn production area of the Caqueza Project. It was directed to the

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[7]The scope of this tradeoff is limited by the assumption that farmers make decisions on the basis of minimizing risk. In addition, it is assumed that farmers are either risk neutrals or risk averters (as shown by the convex set of isoutility curves). These assumptions restrict farmers to choices in which the associated variation in income are minimum for a given level of expected income.

total production unit and was stratified by farmers who have and have not adopted the corn-beans recommended technology. Each observation contains information about the input-output relationship of each of the activities on the farm, economic resource availability, off-farm income, and the family food consumption over the last 24 hours as to the date of the interview. Prices were recorded as paid or received by farmers in 1976.

[2] A second observation of 70 families on family food consumption one week after the first observation.

[3] Time-series of prices of the most common products of the area. Prices from 1949 to 1977 on monthly basis have been deflated by the index to agricultural products for Colombia (27).

[4] From former research there are available full descriptions of corn-bean yield distributions (i.e., means and variances) for traditional technology in corn-beans, as reported by farmers, in 1975-76 (16, 17, 51, 54, 59, 60).

In addition, yield distributions for corn and beans from experimental trials for 1973, and 1974 are available as well as descriptions of distributions for the most common crops for 1973 (16, 59, 60).

[5] The nutritional content of all food products most frequently consumed in Colombia, and the minimal nutritional human requirements by sex and age, as established by the Colombian Institute of Family Welfare (26).

Limitations

This research work as presented from the problem, the functional definitions, and the model for analysis can be cited as containing several shortcomings. This is, however, a statement that applies to most research work, at least in economics, which is directed to abstract reality via a theoretical model, within the framework of the neoclassical economic theory applied to static comparative analysis. That is, the analysis is restricted by the set of assumptions about the position of the individual within the economic state which attributes to him a specific utility function, perfect factor divisibility, linear-homogeneous and continuously differential production which is common to all producers, wholly impersonal market relations, perfect price responsiveness, and compares situations ignoring all adjustment processes or disregarding trends and movements involved in the "quality adjuster" role that the perfectly competitive farm is to play.

There are other types of limitations to this work that may be worthwhile to mention. Those have to do with the evaluation and the consequences of the Colombian rural development and national policy, in which the Caqueza Project and the IRD plan are operating. In the same sense, this work does not directly undertake the Caqueza Project analysis within the framework of development issues such as the duality of the rural sector, the impact--or the lack of it--upon income distribution, priority of actions, present institutional arrangements, land reform, and analysis of social welfare as a result of devoting resources to those types of projects and the potential benefits of having them implemented, if any.

It is evident that no single research piece can effectively account for those topics within reasonable time, human elements, and budget constraints. Nevertheless, this overall limitation does not preclude the analysis of some of those factors. It is the nature of the problem and the objectives of this research that become a restriction of the topics to be covered, as well as the technical capacity of the researcher.

CHAPTER III

Methodological Procedures

The content of this part will explain the process of determining the technical coefficients to be used in the maximization model, and the risk measurements accounted for in the analysis of the problem.

The Average Farm

Due to topographic variations in the area under study, and the high degree of adaptability of corn to different climatic regions, the corn production area covers a range of altitude which goes from less than 1000 m.o.s.l. to approximately 1900 m.o.s.l. (16). This range allows farmers to grow different crops that in contrast to corn, cannot be grown at every altitude. As a result, some crops which are planted in the same farm which grows corn are not found across the corn production area, but in specific altitude levels. In view of these facts, and the economic relevance of some crops other than corn (54), it is not appropriate to generalize an average farm which would consist of crops that could not be together in most cases. In order to account for these factors, three different types of farms are established as follows:

(a) The corn-tomato farm. This farm is situated at the lowest altitude of the corn producing region along both sides of the Rio Negro (The Black River), from which farmers take the water for irrigation of tomatoes. The elevation of the area in which this farm is situated varies, approximately from 900 to 1300 m.o.s.l. This area is on the average warmer than the rest of the region. The average rainfall is roughly 2000 mm (16). Because of this, crops like onion and potato are very uncommon, according to the frequencies of crops found in the sample.

(b) The corn-potato farm. This type of farm is the most often found within the corn production region of the Caqueza Project. This farm has no irrigation facilities and the elevation varies between 1300 and 1700 m.o.s.l. It follows the same rain regime of the entire area, although the average rainfall is slightly less than 2000 m.o.s.l. per year. Tomato and onion are not usually grown on this type of farm. Potato was found to be a frequent crop despite the low elevation and is recommended for this climate zone.[8]

(c) The corn-onion farm. This type of farm is situated at higher elevations of the crop production region. Its elevation is from 1700 to approximately, 1900 m.o.s.l., with an early average rainfall between 1300 and 2000 mm. This type of farm has an overall smaller average area within the region. In addition to corn and potato, onion is a frequent crop grown with and without irrigation facilities. No tomato is found in this specific area.

For each of the former types of farms which are identified by geographical situation of *veredas*;[9] frequencies of crops and livestock activities were established from the sample. To select the production activities for each type of farm, the most frequent crops, crop combinations and livestock enterprises were selected out of the 39 different production enterprises found within the region. The activities selected for each farm type are summarized in Table 4.

Activities of the Model

The general expression of the model presented in Chapter II can be explained in terms of activities that the typical farmer accomplishes in order to satisfy his objective function. Those activities stem from both the objective and the restriction equations. A brief

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[8] Actually, the total Caqueza Project region has been divided into two zones: the corn zone, and the potato zone. This is due to the difference in elevation, and the suitability of high lands for potato growing. In fact, agronomists of the project do not favor planting potatoes below 1800 m.o.s.l.

[9] A *vereda* is a subdivision of a *municipio*, which is equivalent to a county.

Table 4. Most frequent production activities selected by type of farm in the corn production region of the Caqueza Project.

Type of farm	No. of sample cases	Most typical production activities Traditional technology	Recommended technology
corn-tomato	35	corn-beans, corn-tomato (two crop seasons) corn-bean-ahuyama*, pasture, cows, hogs, chickens, milk and milk by-products.	corn-beans corn
corn-potato	91	corn-beans, corn, potato green peas, pasture, corn-bean-ahuyama, cows, hogs, chickens, milk and milk by-products.	corn-beans corn
corn-onion	42	corn-beans, corn, potato onion, green peas, pasture corn-bean-ahuyama, cows, chickens, hogs, milk and milk by-products.	corn-beans corn

* Ahuyama is a kind of squash. No English translation is available.

explanation of the nature of those activities is given in the following sections.

The Production Activities

The term $(P_{tj}Y_{tj})X_j$ in expression [12a] represents the gross product/ha that could be obtained from each of the j activities, j=1,... n. Those activities represented by X_j are the production activities that each of the farm types could perform if they contribute to the maximization of the objective function.

The specific production activities that each type of farm could actually undertake are explained in Table 4. Which of them should be performed, and in what proportion should each activity be completed are questions to be answered in the solution of the optimization model.

"Input Purchasing" Activities

The term V_j of equation [12a] leads to a set of activities resulting from the production cost of the jth production activity. This cost factor can be disaggregated as follows:

$$V_j = \sum_{j=1}^{T} (I_{ij} PI_{ij}) + FC_j \qquad [17]$$

where,

I_{ij} = variable input i used in the jth production activity, i=1, ...n

PI_{ij} = price of variable input i

FC_j = fixed cost of the jth production activity

Expression [17] determines the "input purchasing" activities which have to be completed if a production activity is to take place. Among the input purchasing activities, labor plays a special role due to the timing of some activities and the fact that it is a resource owned by the family and it could be bought and/or sold.

"Product Consumption" Activities

Another set of activities are delineated by the term $Q_j X_j$ of equation [12a]. This term is designed to satisfy expression [16] through the component depicted in inequality [15]. The activities for the typical farmer consist of devoting all or a fraction of the total product obtained from the jth production activity, to family consumption in order to meet the minimum family nutritional status. These are transfer activities from production to consumption. For this reason, the kind of products to be consumed are given by those X_j activities that have been selected by the optimal solution from all possible activities for each type of farm as shown in Table 4. From here it follows that one restriction imposed to this "product consumption" activities is

$$\sum_{t=1}^{t} Q_j X_j \leq Y_{tj} X_j \qquad [18]$$

which implies that total quantity devoted to family consumption is equal to or less than total quantity produced on the farm.

"Product Selling" Activities

The inequality case of expression [18] makes room for the "product selling" activities as shown in equation [12a] by the term $(P_{tj} Y_{tj}) X_j$. These are the activities that allow farmers to enter the product market with a supply schedule depicted by [18]. These activities are the main source of cash income generation which allows the system within the model to work: "buying activities", including working capital borrowing, are financed by these "selling activities." In the same line of reasoning, any profit to be obtained will be mainly generated through these "product selling" activities.

The specific products to be sold will depend on the initial selection of the production activities X_j, and the absolute value of inequality [18]. The determination of values for these activities are set by the optimal solution of the model.

"Labor Selling" Activities

Another source of cash income generation and profit determination is given by the possibility for farmers to sell labor that may be in surplus due to the seasonality and the timing of the production activities. "Labor selling" is a very frequent activity in the region of the Caqueza Project. It may take the form of simply neighborhood off-farm working, to seasonal inter-region emigration during the dry season in which the bulk of the production activities in the corn are in recess. Figure 2 shows the general labor utilization pattern in the area, as well as the surplus periods in which off-farm work takes place.

In relation to the model, this activity results from restrictions shown by the expression [3a]. The value of this activity is a function of the X_j selected to be performed on each type of farm, the b value for available family labor, and the a_{ij} coefficient for labor use corresponding to each X_j activity. As in former cases, the determination of these activities is set by the optimal solution of the model.

The "Land Renting" Activity

Due to the relative importance of leasing and owner-leasing land tenure categories in the area (Table 2), and former findings according to which some land is left uncultivated (59), a "land renting" activity is defined in the model to offer the option to farmers of leasing out their land, or exploiting it on a sharing basis, which is a practice also found in the area (48).

Because it is difficult to differentiate the specific use of the non-cultivated land, the model will consider the choice between utilizing the land for farm production activities, or leasing it for the entire planning period, in which case, land becomes another source of income to farmers. The levels of this activity are also endogenous to the model.

"Food Purchasing" Activities

This set of activities is marked to fulfill the restriction [16] through the component of that expression, represented by inequality [14]. These are income-expending activities used to complete the family nutritional intake, in conjunction with the "product consumption" activities which are restricted by [18].

These activities are open to farmers to either obtain those food consumption items that are part of their usual diet but are not home-produced, or to replace consumption products that were sold due to a favorable market.

The determination of the value of these activities is internally set by the model. It depends on the selection of the X_j activities, the value of the "product consumption" activities, the actual yields and market prices of the products, the customs and diet habits, and the restriction S imposed by expression [16].

The Financial Activity

Although the optimization model has been constructed for a "typical year" in which capital formation over time is not of direct concern, the experience in the study area, and former research demonstrates that farming in the Caqueza Project region cannot be separated from the credit market (16, 17, 57, 59). Nevertheless, there are several indicators regarding actual misuses of the credit which is intended exclusively for production activities (16, 57, 59), and a negative reaction from farmers to get into debt beyond certain limits (59). Despite these issues, there exists an institutional policy on credit, according to which there is no virtual limit to credit, whenever a farm's investment plan is approved and supervised by a professional member of the Project team. Due to these reasons, the financial activity represents for farmers, the possibility of using credit in the amount determined by [17] according to the X_j of each type of farm. In order to represent the reluctancy of farmers to use an indeterminate amount of credit, both an open and a limited options credit are introduced into the model solutions.

The Technical Coefficients and Constraints

Both technical coefficients and constraints are established according to the different activities introduced into the model. As a common denominator, all input and output coefficients are estimated on per-hectare basis for each type of farm. The basic source of information for those coefficients is the sample recorded from the farmers, although historical data, and farmer research findings are used in some cases, specifically in the setting of constraints.

A brief explanation about coefficients and constraints is presented in the following parts of this section and some data (where needed) is shown in the appendices.

Land Constraint

The land constraint is set for each type of farm according to the average farm size recorded in the sample. This constraint defines the maximum land available for production purposes. It can be expressed as follows:

$$\sum_{j=1}^{J} l_{jp} \leq L_p \qquad [19]$$

where:

l_j = vector of crop activities in per hectare units

L = land available

p = refers to different periods during the cropping year, when applicable.

The availability of land is slightly different for each type of farm: 2.34 has, 1.98 has, and 2.18 has for corn-tomato, corn-potato, and corn-onion farm types respectively, although no statistical difference exists among the three sizes of farms.[10]

Labor Coefficients and Constraints

As mentioned before, labor is considered as a production input and as a cash generator activity. As an input, it could be extracted from the family members, or it could be hired within the area. As cash generator, any family labor surplus could be allocated to off-farm work.

In addition to this distinction, the factor demand of each production activity varies during the season due to double cropping, rain periods, biological cycles, and double use of land in some cases.

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[10]The following test was performed to all technical coefficients and constraints for the three types of farms: Ho: $A_{ij1} = A_{ij2} = A_{ij3}$

Ha: $A_{ij3} \neq A_{ij2} \neq A_{ij3}$

Ho was not rejected in any case at $\alpha = .05$. Due to this result, no major consideration is devoted to pointing out differences among types of farms in relation to technical coefficients.

Table 5. General Schematic Presentation of the Optimization Model

	Production Activities	25 Labor Activities	23 Input-Buying Activities	20 Output-Selling Activities	17 Farm-Product Consumption Activities	24 Food-Buying Activities	Left-Hand Side	One Financial Activity	Right-Hand Side
1 land constraint	1,...,1								$\leq$ L
8 labor requirements	$n_{1.1}\dots n_{1.16}$ ⋮ $n_{8.1}\dots n_{8.16}$	-1,...,-1 ⋮ -1,...,-1							= 0
9 labor restrictions		1 ⋱ 1							$\leq N_1$ ⋮ $\leq N_9$
36 input requirements	$I_1 \ddots I_{16}$	-1 ⋱ -1							= 0
20 output equations	$-O_1 \ddots -O_{16}$			1 ⋱ 1	1 ⋱ 1				= 0
1 capital flow equation		1	-1,...,-1	1,...,1			1	-1	$\leq$ 0
1 credit constraint								1	$\leq$ Cr
1 cash flow equation		1		-1,...,-1		1,...,1	-1		$\leq$ 0
1 calorie intake restriction					$C_1,\dots,C_{17}$	$C_1,\dots,C_{24}$			$\leq$ Ca
1 protein intake restriction					$P_1,\dots,P_{17}$	$P_1,\dots,P_{24}$			$\leq$ P
14 deviations from the mean of net revenues	$D_{1.1}\dots D_{1.16}$ ⋮ $D_{14.1}\dots D_{14.16}$								minimum and maximum limits
upper bounds	3				17	24			$\leq$ max
lower bounds					17	24			$\leq$ min

The number of these activities could be slightly different for each type of farm, since not all products are present on every type of farm.

Former research findings are taken into consideration in order to establish the pattern of labor use for activities selected for each type of farm (refer to Table 4) (18, 59). A general view of the seasonal variation of the labor demand is presented in Figure 3. Extensive detailed information may be obtained from the sample farm and the cited sources.

Based on the farmer information, the cropping year is divided into 9 different time periods for the purpose of labor utilization: 8 periods (March to October) in which agricultural and animal production activities take place, and 1 period (December, January, February) in which animal production activities are the only farm enterprises. For each of these periods, technical coefficients represented by the term

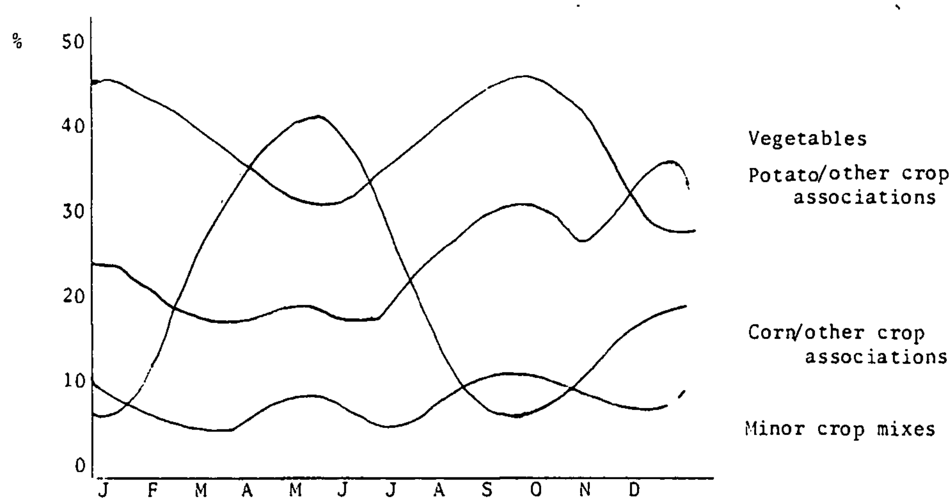

Figure 3. Monthly pattern of use of labor for the Caqueza Project.

Source: Escobar, G. and K. Swanberg. "Uso de la Mano de Obra en Dos Zonas Rurales: Pleno Empleo Estacional?" I.C.A. Bogota, Colombia, 1976

a_{ij} in [3a] are set in man-days of 8 hours/day for each activity in each type of farm. The coefficients are the average values estimated from the sample for total labor. The quantities of labor to be hired were left open such that the optimal solution of the model will generate them. For each of the nine periods, an off-farm work activity was allowed. Coefficients for these "labor selling" activities are to be determined by the solution as well. Labor constraints are of the form:

$$\sum_{j=1}^{J} FL_{jp} - OFL_p < N_p$$

and [20]

$$\sum_{j=1}^{J} HL_{jp} < K$$

where: Fl_j = family labor required in the jth production activity

OFL = Off-farm labor

N = available family labor

HL_j = hired labor used in the jth production activity

K = working capital available

p = refers to periods of labor utilization

The constraint N_p in [20] was defined on the basis of 20.5 days-month which is found to be the monthly working time of the household (18). From the sample, the average family size was estimated at 7.2 persons. Average number of productive members of the family (from ages 14 to 64), was 2.38 persons. In order to account for domestic occupations that are usually performed by women, female labor days were weighted by .50. Children of school age were accounted for with 8 days of work/ month with a weight of .25.

Price coefficients for labor allocation are estimated from the sample at the average value paid by farmers during the labor hiring periods. No imported charge was made for family labor used on the farm. Hired labor, if any, must be paid the current wage, which is the amount that farmers could make by working off-farm.

It should be noted that for the long period of labor utilization

(December to February), no hiring labor activity was allowed, because this activity was not reported in the sample. On the contrary, this is the period in which a large number of farmers temporarily emigrate to other areas (16). The average wage received by off-farm workers was employed as the price of labor during this period.

Input Coefficients

As in the case of labor, all coefficients for inputs are determined from the sample for each activity selected. Average figures of physical units of input per hectare are used as coefficients, with the exception of a few cases in which monetary values/ha were required due to the data collection process (i.e., pest and disease control inputs are usually mixed in such a way that farmers find it easier to estimate the cost of a full back pack sprayer than the physical units of the products. The same is true for other costs like property taxes, input transportation, and paid utilities).

In general, input coefficients follow the form of expression [3a]. For the purpose of solving the model, these technical coefficients are set in rows equated to zero, but linked to prices, capital and financial constraints, as shown in Table 5. Prices of those inputs are derived from the sample at the average value paid by farmers. Those prices are estimated per unit of physical input. Both input, and labor prices conform to the layouts of a working capital flow expression which is a constrained equation. The function of this equation is to set limits for each expenditure according to capital availability. Following the terms of equations [17] and [20], the general form of the working capital constraint is:

$$\sum_{j=1}^{J} (I_{ij} P_{ij}) + FC_j \leq K = Cr + OFL_p + AS_p + LR \qquad [21]$$

where:

Cr = available credit

OFL_p = off-farm labor income by period

AS_p = animal selling by period

LR = land renting income

As explained before, OFL_p, AS_p, and LR are endogenously determined by the solution of the model and therefore, no technical coefficient exists for those terms.

Working Capital Constraints

It was previously noted that the amount of credit available to farmers is, at least in theory, open, but other circumstances affect the use of that credit in the production process. To represent those circumstances, the amount of available credit is set at two levels: the "open credit" level which is endogenously determined by the model, and the "limited credit" level which is exogenously set. These levels add the possibility of comparing solutions under different working capital restrictions. The interest rate that is assigned to borrowed money is the government bank charge (18% per year) which is a lower rate compared to the rate of interest of private banks. Since this difference is significant (6 to 8%), it is assumed that farmers will prefer to borrow money from the government bank which, in addition, offers more flexible payback terms and operates in accordance with the national agricultural policy.

It should be briefly mentioned that a 1974 study attempted to measure the real cost of credit by accounting for all bureaucratic and time consuming paper work. It was found that in spite of the official interest rate, farmers may be paying as much as 42% interest rate, if full values of time and traveling are accounted for (57). Since no information on these costs was provided by the farmers, this problem is ignored in estimating the technical coefficient for credit.

Nutritional Coefficients and Constraints

The nutritional components of a human diet are complex to manage when the level of analysis requires a high degree of information, or takes into account primary and secondary biological relationships (53).

Working at a simpler level, the Colombian Nutrition Institute has determined 15 nutritional components for each 100 grs. of food products consumed in the country (26). Those components have several measured units that make it difficult to aggregate them. With the idea of keeping the model as simple as possible, only two nutritional components were analyzed, yet they have been widely used for similar purposes by other researchers and international institutions (1, 49, 50, 53). Those nutritional components are proteins and calories.

Technical coefficients are already established in the Colombian table of nourishment. They were all converted to kilogram units, accounting for inedible proportions for each food item.

The actual food products that compose the family diet in the study area were selected from the sample. A total of 57 different food items were reported in both the initial sample and the 70 families which were reinterviewed for food consumption purposes. Because the frequency of consumption of some of the products is very low, food items reported by less than 5% of the farmers were not incorporated in the family diet. A total of 24 food consumption items were selected to represent a set of the most common products consumed in the region. Technical coefficients and limits of the nutritional constraints can be expressed as follows, using expressions [16] and [12a]:

$$\sum_{1}^{24} Ca_j \, (Q_j + F_j) \quad \{ > < \} \text{ min and max}$$

and

$$\sum_{1}^{24} P_{rj} \, (Q_j + F_j) \quad \{ > < \} \text{ min and max} \qquad [22]$$

where:

C_{aj} = calories contained in food item j/kilogram of edible product.

P_{rj} = grams of protein in food item j/kilogram of edible product.

The minimum and maximum limits are coefficients already developed by nutritionists (26). These criteria were extended to the average family found in the region, which was weighted by age, sex and a percentage of pregnant and nursing women. Those limits were set for a period of a year. The same criterion applies to consumption items selected to integrate the regional diet.

Actual quantities and products consumed by the family are to be provided by the solution of the model. Nevertheless, upper and lower bounds on consumption of some products were imposed on the model in order to preserve the food consumption habits that are known for the area (16, 22, 55). The nature of these boundaries is explained in the next section.

Bounds

Upper and lower delimeters for food consumption are set on the basis of the annual estimates of consumption of certain products. Those estimates are minimum and maximum values reported in the sample, but extended to a year. These bounds are imposed on both farm produced and bought food items. Market prices for bought products are used, and no monetary value was assigned to farm product items, which is equivalent to setting the production cost, forced by [21].

In addition, upper bounds are established on animal production activities. The reason behind this limitation is technical in nature (16, 59). Members of the professional team of the project have determined that if the number of animals (chickens, hogs or cows) were to be significantly increased, major technical and managerial changes should take place in order to have an acceptable probability of success. In the absence of upper limits forcing these enterprises to maintain their typical size, a farmer will switch to a different production function for which no technical coefficients are known.

For these specific cases, the size of animal production enterprises which can be found in almost every farm within the corn area of the Caqueza Project, was used as bounds: one milk cow, up to three hogs, and a number of chickens up to twenty-five.

Determination of Risk Coefficients

As explained in Chapter II, the sources of risk for this study have been defined to be output price and yield variations. For the model itself the mean of absolute deviation λ is the measure of risk as represented by expression [2a].

It was also mentioned that the available data to determine the risk factors consist of a cross-sectional observation, historical data, and agronomic research records. Specifically, yields of all production activities under conditions of traditional technological patterns were acquired through the sample. Farmers were asked to provide an estimation of their yields for a period of ten years in which the average, minimum and maximum yields were obtained, in such a way that a triangular distribution of yields could be constructed for each production activity. For crops for which improved technology has been developed, field experiment and records of the participants of the corn-plan are available, such that the same type of yield distribution can be estimated. This information provides data from 1971 to 1977.

Prices for the year of the survey were recorded from the farmers. It includes both input and output prices. Moreover, there are available time series of prices for 12 of the most frequent products of the region. These records date from 1949 to 1977 on a monthly basis. For 5 other activities, prices from former studies were extracted. The resulting observations of the past 3 or 4 years: three activities, livestock, chickens and hogs, do not include price variations over time due to the difficulty of comparing size, age and quality of animals. For these three activities, the average price received by the farmers as to the year of the survey is used, and no measure of risk is estimated for them in equation [2a].

In order to generate values for M, the expression [10] is the value from which deviations are going to be estimated. However, with equation [9] all possible combinations of the probabilistic distributions of prices and yields should be considered. This set of combinations would include 20 different products, since some of the production activities are associated crops. The size of all possible combinations will depend on the number of intervals in which prices and yields distributions are divided. However, the number of combinations could reach a fairly large matrix.[11]

To overcome the practical impossibility of evaluating the model at each possible combination, probabilistic distributions were simulated by using a Monte Carlo distribution generator for both prices and yields. Descriptions of both distributions are the subject of the following two sections.

The Price Probability Distributions

The historical data on prices was assumed to be normally distributed, once prices were deflated. This conclusion was based on graphical representations of data, some of which are shown in Appendix A.

Through the representation generator a random sample of 100 cases was drawn, each set of prices using as parameters of the distribution, the mean and the variance estimated from the historical data. The underlying assumption is that 100 cases are being randomly selected to typify a set of estimators of all possible prices that may appear in the market in which farmers sell their products. That random sample is the counterpart of the finite number of values P_{tj} that prices can take, according to expression [6].

The Yield Probability Distribution

Data recorded in the sample allow the establishment of a triangular probabilistic distribution for traditional crops, and similar types of distributions are estimated for production activities under conditions of the improved technology, some of which are presented in Appendix A. Since the distributions generator does not have the option of triangular distribution, the following qualifications are made. The cumulative distribution function for the triangular distribution of a random

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[11]For example, if prices and yield probabilistic distributions were divided into 10 intervals each, the number of combinations for each product will be $(10)^2$. Accounting for all 20 products, the total number of combinations would be 2,000, if all pairs of observations are not susceptible to combinations.

variable X, has the form (41):

$$F_X(x) = \begin{cases} (x-a)^2/(b-a)(c-a) & , \quad a \le x \ge b \\ b-a/c-a + (c-b)^2 - (c-x)^2/(c-b)(c-a) & , \quad b \le x \ge c \end{cases}$$

where:

b = the mode value

a = the minimum value

c = the maximum value

By equating the random variate RN to $F_X(X)$, the above equations can be solved for X. Thus a sample value of X is derived. This results in the equations

$$X = \begin{cases} a + \sqrt{(b-a) \cdot (c-a) \cdot RN} & , \quad 0 \le RN \le b-a/c-a \\ c - \sqrt{(c-b) \cdot (c-a) \cdot (1-RN)} & , \quad b-a/c-a \le RN \le 1 \end{cases} \qquad [23]$$

The variate was obtained through the distribution generator by using a uniform distribution to a random sample of 100 cases for numbers within the interval of 0 to 1. The straight application of [23] for each of the values of RN results in 100 different values Y_{tj}, that yields can take, according to expression [6]. Again, the implicit assumption is that the 100 cases estimated on the basis of a random sample of variates are good estimates of all possible yields that farmers can obtain from the production process.

Deviations for the Mean Revenue

To obtain a gross revenue for each production activity, prices and yields are combined. The 100 random prices and yields obtained by the explained procedure are multiplied with each other on a one to one basis. As in the former cases, this operation implies the assumption that taking both prices and yields at random, their direct multiplication will result in a good estimate of all combinations of the two variables, for each of the production activities.

The former step results in 100 gross revenue cases for each activity. For each of those cases, the production costs V_j are substracted to follow the definition of expression [12]. This results in 100 cases of net revenues for each production activity. The mean value of the net revenue is obtained from the generated sample.

In order to determine the deviations from that mean value in such a way that the distribution of the revenue would be represented by the deviation values, the total sample of 100 cases was divided into 15 intervals from which 14 observations could be derived. One observation was randomly selected from each observation set which is intended to represent the net revenue of the farmer. Those are the values used to satisfy inequality [2a].

For generating the E-M frontier, the sum of the 14M value obtained through the explained process should be given different values as shown in [13]. Those values can be selected from the post optimal analysis of the solution of the model.

CHAPTER IV

The Optimal Farm Plans

The intent of this chapter is to aummarize some of the results of the empirical evaluation of the model, as described in previous chapters. For explanatory purposes, the discussion is separated into 4 sections: the production activities resulting from the model solutions, the factor use according to the level of technology, the impact of risk on family income and some comments on the fulfillment of the nutritional objectives.

It should be noted that data presented in this chapter could be expanded to a fairly detailed level, since the structure of the basic matrix of the model provides room for a good amount of information (Table 5). However, it is the goal of this chapter to refer to the aspects that are more relevant to the research objectives. Some data have been reserved in the appendices.

Production Activities Under Traditional and Recommended Technology

The solution of the model for each type of farm explains which production activities the model selects as more appropriate for farm adoption and what type of technology should be employed in carrying out each activity. Due to the nature of the model, a set of several different solutions is obtained as the parameter λ varies from minimum to maximum. Changes in λ imply linear changes in the level of activities, up to a point where λ=max in which the solution is identical to the one obtained through the linear programming problem (where certainty is assumed for all parameters). With these ideas in mind, summary tables are presented for every type farm, according to levels of technology and credit limits considered in the model.

Production Activities on the Corn-Tomato Farm

Production activities and levels of those activities in terms of land use are presented in Tables 6 and 7, by technological patterns, the two credit limits set for the model, and the range of variation of the risk value.

With both open and limited credit the selection of activities and their levels follow a pattern according to variations in the level of risk that farmers may undertake, as represented by the value of λ: the higher the risk level accepted by farmers, the more specialized they become. That is, an inverse relation exists between the level of risk and the degree of diversification of production activities on the farm. In the case of open credit, the number of production activities decreases from 13 to 10 as the risk value goes from minimum to maximum for farmers using the recommended technology. For farmers using the traditional technological pattern, the number of production activities decreases from 11 to 9. These differences are more obvious for cropping activities. With recommended technology, activities decline from 7 to 4 as the risk level increases, and from 5 to 3 with the use of traditional technology.

The same type of relation exists with the model evaluated under conditions of limited credit, except the negative decline in number of cropping activities is more pronounced, dropping from 7 to 2 as λ increases when improved technology is used, and from 4 to 2 for cropping under conditions of traditional technology.

The level at which selected production activities are set by the solution of the model varies according to the value of the risk measure as well. The higher the risk level, the higher the level for some of the selected activities. This is not, however, the case with animal production activities. These are fairly steady for farmers with and without improved technology, and with open and limited credit except in the case of home made cheese. These results are influenced by the upper limits set on those activities in the model to represent existing technological conditions (Chapter III).

The level of some agricultural activities is very accentuated for higher levels of risk. For farmers using open credit and adopting the technological change, the level of recommended corn-beans represents 77% of the area in agricultural activities on the farm. In the same fashion, the concentration of corn-beans-ahuyama for traditional farmers

Table 6. Production activities for the optimal corn-tomato type of farm with traditional and improved technology, by different levels of risk with open credit.

Activities	Improved Technology — Level of Activities (Has.)					Traditional Technology — Level of Activities (Has.)			
	λ=2000	λ=5000	λ=10000	λ=20000	λ=max	λ=2000	λ=5000	λ=10000	λ=max
corn-beans traditional	.03	.11	.11	--	--	.07	.13	.01	--
corn-beans recommended	.07	.15	.58	1.05	1.33	--	--	--	--
green peas	.06	.02	.11	--	--	.02	.05	.02	--
corn traditional	--	--	--	--	--	.01	--	.09	--
corn recommended	.05	.12	.14	.09	--	--	--	--	--
corn-beans-ahuyama, traditional	.22	.44	.74	.54	.35	.17	.41	1.06	1.67
tomato (1st semester)	.00009	.002	.02	.02	.04	--	.002	.02	.02
tomato (2nd semester)	.00009	.002	.02	.02	.04	--	.002	.02	.02
pasture	.59	.67	.67	.67	.67	.57	.67	.67	.67
milk cows* (animals)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
hogs* (animals)	1.0	3.0	3.0	3.0	3.0	1.0	3.0	3.0	3.0
poultry* (animals	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
milk by-products (cheese)	150.0	150.0	43.0	29.0	27.0	144.0	144.0	120.0	26.0
off-farm work* (days)	171.0	150.0	142.0	140.0	139.0	178.0	104.0	142.0	143.0
renting land	1.32	.84	--	--	--	1.44	1.08	.47	--

* The level of these activities has been approximated to the nearest unit number, since no integer programming option was used.

Table 7. Production activities for the optimal corn-tomato type of farm with traditional and improved technology by different levels of risk with limited credit to Colombians, $5000.00

Activities	Improved Technology				Traditional Technology			
	---Level of Activities (Has.)---				---Level of Activities (Has.)---			
	λ=2000	λ=5000	λ=10000	λ=max	λ=2000	λ=5000	λ=10000	λ=max
corn-beans, traditional	.03	.07	.19	.23	.07	.12	.19	.23
corn-beans, recommended	.07	.004	--	--	--	--	--	--
green peas	.06	--	--	--	.02	.02	--	--
corn traditional	--	--	--	--	.01	--	--	--
corn recommended	.05	.04	--	--	--	--	--	--
corn-beans, ahuyama, traditional	.22	.52	.45	.41	.17	.47	.45	.41
tomato (1st semester)	.00009	.002	--	--	--	--	--	--
tomato (2nd semester)	.00009	.002	--	--	--	--	--	--
pasture	.59	.67	.67	.67	.57	.64	.67	.67
milk cows* (animals)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
hogs* (animals)	1.0	3.0	3.0	3.0	1.0	2.0	3.0	3.0
poultry* (animals)	25.0	9.0	24.0	25.0	25.0	24.0	24.0	25.0
milk by-products (cheese)*	150.0	122.0	87.0	82.0	144.0	159.0	87.0	82.0
off-farm work * (days)	171.0	174.0	176.0	177.0	178.0	161.0	161.0	177.0
renting land	1.32	1.04	1.04	1.03	1.44	1.09	1.04	1.03

* The level of these activities has been approximated to the nearest unit number, since no integer programming option was used.

goes up to 98% of the land in agricultural production on the farm. In the case of limited credit, the same type of activity level concentration exists although it is not as accentuated as in the former case. Here, 64% of the land in crops is devoted to corn-beans-ahuyama for farmers with and without improved technology.

There is one more general characteristic that should be pointed out from the results presented in Tables 6 and 7, and that is the direct relation between the use of available land and the level of risk. The higher the risk level, the higher the proportion of land devoted to farm activities. This is the case for both technological patterns with or without credit limitations. When credit is a constraint, the relation is not as clear as in the case of open credit, due to the fact that not even the linear programming solutions devote all available land to farm production, but increments of 22% and 28% of land use are found for farms with and without improved technology respectively.

There are, on the other hand, several differences in the solutions of the model according to the different circumstances in which it has been evaluated. Some of the differences are apparent from the Tables and are not repeated here. Others are worth mentioning, particularly those concerning the changes in the risk level.

Solutions for technical change adopters concentrate on agricultural activities for which recommended technology exists. This is the case of improved corn-beans. For higher levels of risk, the traditional corn-beans disappear from the solution. Non-adopters concentrate on a triple crop, although they maintain small plots of corn-beans with the old technology. This situation is quite different when credit is restricted for both adopters and non-adopters. Crops with technical recommendations are not selected in solutions with high risk levels or for the linear programming solutions. This is an indication of capital biased technology or at least of relatively heavier demand for capital with recommended technologies than with traditional technologies. This issue may be better understood with the help of data presented in the following segments.

Comparison of Tables 6 and 7 shows a definite superiority of associated crops over single crops to maximize expected profit. This is true even for cases in which the possibility of a single crop with improved technology is available. In order to gain more information on single and associated crops, Table 8 illustrates coefficients of variation for corn (in all instances the crop is taken as a production activity). It is clear that the lowest two coefficients of variation correspond to the association of corn and beans, regardless of the level of technology.

In addition to the information in Table 8, statistical tests were performed regarding differences of standard deviations as estimated from the sample.[12] The differences of standard deviations between corn when associated with beans and corn as a single crop were found to be significant when grown with traditional technology. This is an indication of less variability due to the crop association, Ceteris paribus. All other differences were found to be non-significant.

One finding related to Tables 6 and 7 is the unimportant role of tomatoes in the configuration of the activities set by the optimal solutions. Although there are differences created by the capital availability, the level of the activity in both semesters of the year is limited to a garden size, instead of a commercial activity. These results constitute a relevant contrast with prior economic analysis accomplished for the same area. It was reported, for instance, that returns to total cost in tomatoes per hectare were 143% at 1973 prices. The same estimation for traditional and recommended corn-beans was 30% and 91% respectively (59). According to the data analyzed in this study, tomatoes have a coefficient of variation of .614 and .603 for the first and second

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[12]The hypothesis tested is of the following form:

Ho: $S^2_{ci} = S^2_{cj}$ Ha: $S^2_{ci} \neq S^2_{cj}$

where ci and cj refer to differences in corn cropping. These differences apply to other crops grown with corn. Both i and j take no value when the test applies to corn as a single crop. The statistics $F_{.05}(v_1, v_2) = S^2_{ci}/S^2_{cj}$ were used as a criterion for rejection of the null hypothesis.

Table 8. Coefficients of variation for corn associated and as a single product.

Activities	$\bar{x}$ yield Corn	s^2 corn	coefficient variation
corn/beans traditional	1030.16	277.85	.269
corn traditional	1107.72	468.53	.423
corn/beans recommended	2268.53	478.29	.211
corn recommended	2668.78	825.72	.309
corn/beans ahuyama	1276.78	400.32	.314

semesters, which is much higher than coefficients for other crops like corn, as shown in Table 8 (in absolute terms, first semester tomatoes have an average production of 8559.39 Kg/ha, and the standard deviation is 5256.30). This wide variation is minimized by the MOTAD model, provided that risk is measured by variations about the mean, and the model is aimed to minimize it. Nevertheless, the sample indicates that 34% of farmers of the area in which the corn-tomato type of farm would take place, do grow tomatoes with an average area of .24 has. and .26 has. for the first and second semester respectively. This level of the activity is higher than the level recommended by the model when open credit is used.

Another production activity with a pattern of variation is cheese production. This activity is dependent on dairy cow production which is a bounded activity, but it appears at the upper limit in all solutions regardless of the technological level and the credit availability. In all cases, cheese production varies inversely with the value of risk and has lower levels when farmers make use of all credit required by each solution. Cheese production is an alternative use of milk and can be either a family item or produced for commercial purposes. Measured in number of cheeses of 1 kilogram, this activity seems to follow a trade off mold with agricultural activities: the higher the level of some agricultural activities (and the risk value), the lower the level of cheese production. This relationship is a reflection of competition for labor of both activities, as well as the higher content of nutrients that cheese has over milk. A case could be made for higher cheese consumption in family situations of low physical agricultural products. The same reasoning may apply to explain a lower rate of the activity level when farming takes place under conditions of limited capital.

Another activity exhibiting differences in levels according to credit availability is off-farm work. Although this activity appears in all solutions, there are some distinctions depending on the amount of credit used in the production process: more days worked off-farm are required when a farmer faces a credit constraint than when the amount of credit is open. The level of this activity is particularly important since it has a built in evaluation factor for family labor utilization in the farm production process during the year. It has been assumed for individual farms, that demand for off-farm labor exists year around at the hiring labor wage, which varies with the cropping season, such that farmers can allocate labor in and/or off farm according to the value of marginal products. From this aspect, marginal products of labor used for agricultural production seem to increase with the concentration of some activities when farmers use all required credit and accept higher levels of risk. On the other hand, when credit is limited, there are no significant changes in labor allocation at different levels of risk.

Distinctions between technological patterns of production do not make labor allocations change much. At this point, it is difficult to say that improved technology has no effect on labor use, because traditional activities are present in the solution, and the level of activities varies according to the type of technology being used. These relations will be addressed in more detail elsewhere.

Production Activities on the Corn-Potato Farm

Model solutions for the corn-potato farm are of special interest due to the fact that this farm type portrays the bulk of the small corn growers of the Caqueza Project region. This type of farm roughly applies to 54% of the population sample, and it could be used as a generalized form for the entire corn production zone, since it differs from the others in only one or two specific crops. Selected activities for this farm according to the type of technology used, the availability of credit, and different levels of risk are shown in Tables 9 and 10. The information presented in these tables follows the general characteristics already mentioned on the corn-tomato farm. That is, higher levels of risk result in concentration of fewer agricultural activities with increasing allocation of land. Associated crops are selected over simple crops with and without credit restrictions, crops for which improved technology is available are chosen over the same crops produced with traditional technology; off-farm labor allocation decreases as the risk level increases when open credit is used, and more land is devoted to production as farmers undertake higher levels of risk for the cases analyzed at full credit. Thus, corn and its associated crops, are by in large, the agricultural activities from which farmers generate income and family subsistence.

There are, however, some results that merit a comment, since they seem to play an important role in the planning of the farm. That is the case of the relationship between credit and risk levels. While variations in the level of λ make room for different solutions of the model, limitations in the use of credit result in very few options before the maximum is obtained with both recommended and traditional technology. While Table 9 has for example, the five solutions for similar values of

Table 9. Production activities for the optimal corn-potato type of farm with traditional and improved technology, by different levels of risk with open credit.

Activities	Improved Technology						Traditional Technology			
	---Level of Activities (Has.)---						---Level of Activities (Has.)---			
	λ=2000	λ=5000	λ=10000	λ=15000	λ=20000	λ=max	λ=2000	λ=5000	λ=10000	λ=max
corn-beans traditional	.05	.09	--	--	--	--	.07	.12	.07	.06
corn-beans recommended	.11	.29	.60	.77	.97	1.31	--	--	--	--
green peas	.02	.05	--	--	--	--	.11	--	--	--
potato	.03	.06	.04	.02	--	--	.02	.02	.04	.04
corn traditional	--	--	--	--	--	--	--	--	.008	--
corn recommended	.09	.13	.21	.05	--	--	--	--	--	--
corn-beans, <u>ahuyama</u>, traditional	.26	.51	.46	.47	.34	--	.23	.47	.99	1.22
pasture	.59	.67	.67	.67	.67	.67	.57	.60	.67	.67
milk cows* (animals)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
hogs* (animals)	1.0	3.0	3.0	3.0	3.0	3.0	1.0	3.0	3.0	3.0
poultry* (animals)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
milk by-products* (cheese)	145.0	129.0	102.0	99.0	100.0	94.0	132.0	139.0	138.0	97.0
off-farm work* (days)	166.0	142.0	140.0	140.0	139.0	139.0	177.0	164.0	142.0	143.0
renting land	.84	.18	--	--	--	--	.97	.70	.20	--

* The level of these activities has been approximated to the nearest unit number, since no integer programming option was used.

Table 10. Production activities for the optimal corn-potato type of farm with traditional and improved technology by different levels of risk with limited credit to Colombians $5000.00

Activities	Improved Technology ---Level of Activities (Has.)---			Traditional Technology ---Level of Activities (Has.)---		
	λ=2000	λ=5000	λ=max	λ=2000	λ=5000	λ=max
corn-beans traditional	.04	.08	.06	.07	.12	.06
corn-beans recommended	.11	.02	--	--	--	--
green peas	.006	--	--	.11	--	--
potato	.03	--	--	.02	.02	--
corn traditional	--	--	--	--	--	--
corn recommended	.07	.05	--	--	--	--
corn-beans, ahuyama, traditional	.24	.50	.56	.23	.47	.56
pasture	.59	.65	.67	.57	.66	.67
milk cows* (animals)	1.0	1.0	1.0	1.0	1.0	1.0
hogs* (animals)	1.0	3.0	3.0	1.0	3.0	3.0
poultry* (animals)	23.0	9.0	19.0	25.0	2.0	19.0
milk by-products* (cheese)	146.0	122.0	109.0	132.0	156.0	109.0
off-farm work* (days)	169.0	174.0	174.0	177.0	172.0	174.0
renting land	.89	.67	.69	.97	.71	.69

* The level of these activities has been approximated to the nearest unit number, since no integer programming option was used.

λ before the linear programming solution.[13] Since the linear programming solutions are identical for both technological patterns with limited credit, it seems to be a case in which the capital constraint is more important than risk, given that high risk levels have no effect on the optimal solution.

One other aspect that might be mentioned is the frequency of potato in the model solutions. For the case of open credit, small plots with potato are selected for farms under traditional technology. For farmers adopting the technical recommendations, potato is also selected especially for lower risk levels. When credit is restricted and improved technology is used, potato is not selected for upper risk levels, but it appears in the solutions for non-adopters with limited credit. These results are interesting provided that recommendations based on agricultural research have classified this specific area as marginal for potato, and technical improvements in potato are designed for land over 1800 m.o.s.l. (60).

In spite of agronomist's recommendations, the sample for this analysis recorded a number of farmers growing potato in this area equivalent to 34% of all exploitation units. It was noted that the level of activity as set in the solutions under those different conditions, seems to be just enough for family consumption as mandated by the nutritional diet.

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[13]This relationship should be understood as a comparison in relative terms. The selected values of λ are somewhat arbitrary. This is due to changes in the basis of the L.P. that were found for several points between any of the λ values presented in Tables 9 and 10, but they were not taken into consideration because the addition to expected profit was negligible, as were differences in activities of these solutions.

Some of the results for animal and animal-related activities are separate from the general pattern shown for the corn-tomato type of farm. Specifically, the level at which poultry is produced shows radical changes when farmers make no use of available credit. The highest level of this activity is reserved for the lowest level of risk that could be accepted by farmers, but if that risk level is increased (from $\lambda=2000$ to $\lambda=5000$), the number of animals drops dramatically, especially for those farmers under the traditional technology. These results create a sharp contrast with the results for farmers using open credit whose solutions indicate poultry production at the upper bound limit, regardless of the technology being implemented. In the case of traditional technology and limited credit, it seems to be a trade-off between poultry and cheese production, but this relation does not hold for solutions with recommended technology.

It is very difficult to provide an explanation of those facts with the information presented so far. This chapter looks at some economic comparisons among activities which could be helpful in understanding this point. However, the combination of activities for the total farm is intricate enough to be analyzed in part without incurring misconceptions; after all, the model is to produce a solution which maximizes the objective function at given levels of capital and risk measures.

Finally, a result that does not present a general pattern is the off-farm labor allocation for farms with limited amounts of credit. When technological change is introduced and farming becomes less diversified as risk levels increase, the total quantity of labor-days to be worked off farm does not decrease as in the case of the corn-tomato farm. The level of this activity actually shows a slight increment which is maintained by the linear programming solution. For farmers using traditional technology, changes in risk levels result in nonsystematic changes in the level of off-farm labor allocations, since it initially decreases but suffers a slight gain at the maximum risk level.

Production Activities on the Corn-Onion Farm

Activities selected by the model for the corn-onion type of farm are summarized in Table 2 for cases in which open credit is used by farmers, and in Table 12, credit is limited to Col. $5000.00. As in cases of the other two types of farms, the main point is the incorporation of the recommended technology, both corn-beans and corn into the optimal farms plan when it is available to farmers and they are willing to use all credit required to fulfill the demand of working capital needed to adopt the improved technology. However, in the situation of limited credit, production activities undertaken with traditional technology are preferred over improved techniques of cultivation.

It is worth noting that corn as a single crop is always chosen to be grown through improved techniques, on all types of farms. Given that there are no statistical differences between technical coefficients of the model for any of the types of farms, data presented in Table 8 could be used to explore the nature of the difference between productions obtained by the two technological patterns, given that variation measured by the values of standard deviations are not statistically different. To do so, a difference test between means was performed with the result that the production mean of corn cultivated with improved technology is greater than the production mean of corn grown with traditional technology, on a per hectare basis.[14] This is an indicator of the superiority of the improved technology in yields, since the variation is not inferior to the one obtained using traditional technology.

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[14]The hypothesis tested is: Ho: $\bar{X}ct = \bar{X}cr$ Ha: $\bar{X}ct < \bar{X}cr$ where: ct and cr stand for traditional and recommended corn, respectively. The statistics $t = \bar{X}ct - \bar{X}cr/S^2_p\ [(1/N_1) + (1/N_2)]^{.5}$ was used as the criterion for rejection of the null hypothesis. The estimated t value is 9.7504 and the t value at $\alpha = .05$ and 40 d·f is 2.021.

Table 11. Production activities for the optimal corn/onion type of farm with traditional and improved technology by different levels of risk and with open credit.

Activities	Improved Technology							Traditional Technology			
	---Level of Activities (Has.)---							---Level of Activities (Has.)---			
	λ=1000	λ=2000	λ=5000	λ=10000	λ=15000	λ=20000	λ=max	λ=2000	λ=5000	λ=10000	λ=max
corn-beans traditional	.04	.05	.10	.01	.000015	.000015	.000015	.03	.11	.17	---
corn-beans recommended	.10	.13	.30	.40	.78	.87	1.01	---	---	---	---
green peas	.10	.05	.06	---	---	---	---	.06	.02	.02	---
potato	.04	.04	.05	.04	---	---	---	.04	.04	.04	---
onions	.03	.007	.01	.08	.06	.13	.16	.04	.02	.11	.21
corn traditional	---	---	---	---	---	---	---	---	---	---	---
corn recommended	.07	.07	.12	.25	.12	.06	---	---	---	---	---
corn-beans-ahuyama, traditional	.21	.27	.50	.73	.55	.44	.35	.31	.51	1.09	1.30
pasture	.55	.59	.67	.67	.67	.67	.67	.55	.65	.67	.67
milk cows* (animals)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
hogs* (animals)	---	1.0	3.0	3.0	3.0	3.0	3.0	1.0	3.0	3.0	3.0
poultry* (animals)	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
milk by-products* cheese	149.0	145.0	126.0	69.0	68.0	73.0	76.0	133.0	140.0	80.0	74.0
off-farm work* (days)	157.0	158.0	133.0	135.0	134.0	131.0	114.0	175.0	157.0	141.0	141.0
renting land	1.06	.98	.37	---	---	---	---	1.15	.83	.08	---

* The level of these activities has been approximated to the nearest unit since no integer programming option was used.

Table 12. Production Activities for the optimal corn-onion type of farm with traditional and improved technology by different levels of risk with limited credit to Colombians $5000.00

Activities	Improved Technology				Traditional Technology		
	---Levels of Activities (Has.)---				---Levels of Activities (Has.)---		
	λ=1000	λ=2000	λ=5000	λ=max	λ=2000	λ=5000	λ=max
corn beans traditional	.04	.05	.10	--	.03	.12	.02
corn beans recommended	.10	.10	--	--	--	--	--
green peas	.10	.02	--	--	.06	--	--
potato	.04	.03	--	--	.04	.02	--
onion	.03	.01	.002	.002	.04	.002	.002
corn traditional	--	--	--	--	--	--	--
corn recommended	.05	.06	.03	--	--	--	--
corn-beans, <u>ahuyama</u>, traditional	.21	.25	.49	.60	.31	.47	.59
pasture	.55	.59	.66	.67	.55	.66	.67
milk cows* (animals)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
hogs* (animals)	--	1.0	3.0	3.0	1.0	3.0	3.0
poultry* (animals)	8.0	13.0	5.0	7.0	8.0	1.0	7.0
milk by-products* (cheese)	156.0	153.0	144.0	139.0	149.0	150.0	138.0
off-farm work* (days)	173.0	170.0	176.0	175.0	175.0	176.0	165.0
renting land	1.06	1.06	.90	.90	1.15	.91	.90

* The level of these activities has been approximated to the nearest unit number since no integer programming option was used.

Another feature concerning corn production on this type of farm, is the relative importance of traditional corn-beans in cases in which improved technology can be adopted and full credit is available. Table 12 shows this activity to be selected in all solutions, although its level decreases as risk increases, and for the upper values of risk and the linear programming solution, the level is nominal within the context of the entire farm. This fact could be linked with the increment in the level of onion production and the relative level of corn-beans-ahuyama. This could be the case of completion of the minimum corn family consumption by having a garden plot size cropping of traditional corn-beans.

A significant finding for this type of farm is the presence of onion in all solutions regardless of the technological pattern or the amount of credit. The impact of this activity is that farmers using the traditional technology and open credit or improved technology and limited credit, should replace corn-beans and corn with onions, even if the level of the activity is low for technology adopters. For farmers with improved technology and open credit, the amount of land to be planted with onions increases as they are willing to take higher levels of risk. These results are not surprising for the area in which onion is cultivated. A 1975 study of upper and lower quartils of the farmers' traditional technology showed that retruns to total capital expenditure were 350%, 189% and -3% for the high, medium, and low groups of net benefits in which a sample of 153 cases was stratified for all 6 municipios of the Caqueza Project (54).

Animal production activities are selected at the upper bounds assigned to the model for farms with open credit. One exception, which applies also to farms with limited credit, is the case of no hogs for farmers accepting the lowest level of risk at which the model was feasible. To be precise, this activity was selected in both solutions at a level of .49, but the criterion for approximation set that level to zero. There are, however, rough variations in the levels of poultry for farms operating under restricted credit, not only the activity is set at levels quite inferior from the bound, but an erratic pattern is shown for variations in the levels of risk. It is difficult to explain this type of change without the context of the entire farm plan for a given value of λ. As shown in this chapter, expected income increases as the risk to be undertaken is greater, which is the result of all combinations of production activities on the farm. It could be argued that the constraint in working capital forces this type of activity combinations, although this reasoning does not seem to apply to the typical corn-tomato farm.

Leasing land is taken into consideration for all types of farms even if it is not strictly a production activity. Leasing land represents an option to the small farmer to allocate his resources, and serves as a proxy for the opportunity cost value of land use in farming operations. There is however, a drawback to this activity: it is based on the assumption that demand for land to be rented is given at a per hectare price which is known and insensitive to size for the typical farmer. The reason for accepting such an assumption into the model is that the decision to lease land is, in general, a zero or one type of decision. That is, land can be leased once a year for the entire biological cycle, at a certain time during the year before the rainy season starts, and it is ordinarily, an irreversible decision.

The levels of the leasing land activity in Tables 11 and 12 follow the same general pattern found for the other two types of farms (Tables 6, 7, 9, and 10), which is the reason for looking at this aspect for all cases at the same time. It is common to all solutions that an inverse relationship between quantity of land to be leased and the level of risk required be accepted: the lower the risk, the higher the area to be leased. Only when the degree of farm diversification decreases to a greater concentration of fewer activities, does the value of the marginal product of land into production seem to be greater than the renting price.

The level at which this variable is selected by the solutions of the model is strongly affected by the disponibility of working capital, measured through credit use. For every type of farm, solutions under limited credit keep a good portion of land out of farming activities earned directly by the typical family.

Another factor affecting the level of land leasing is the type of technology used in the farm operation. Because traditional farmers attain the linear programming solution at lower levels of risk than the technology adopters, farmers using traditional technology should devote a higher proportion of land to leasing than farmers willing to adopt the improved technology. When the combination of traditional farming and open credit is solved by the model, the only occasion in which all land is allocated to production activities is at the linear programming solution for all types of farms. If a traditional farmer faces a credit restriction, he may lease a portion of his land, as much as 44% for the corn-tomato farmer.

These results are not surprising when compared to what farmers do in actuality. From the 1970 agricultural census it was learned that approximately 21% of the land was not in use (Chapter I). In addition, a study carried out in 1975 on frequencies of production and uses of land estimated percentages of land devoted to each different cropping activity. From here, "...it was calculated that 0.6 ha. on each farm was noncultivated land, including space for houses, buildings, paths, etc." (59, p. 139). This "rough" estimation seems to be consistent with the solutions of the model. It would be premature to speculate that this behvaior might be attributed to risk aversion, but the question could be formulated since former calculations are a riskless analysis.

Factor Use Under Traditional and Recommended Technologies

This section looks at the level at which resources are used under conditions of different patterns of technology, levels of credit, and degrees of risk at which the model has been evaluated. This is an ambitious task given the extent of disaggregation at which the model was set (Table 5). In order to be able to point out the most relevant aspects of factor use, inputs are aggregated into working capital, labor and land. Appendix B contains a detailed presentation of the use of inputs for all solutions of the model.

Due to the number of variables in which this analysis focusses, data are presented for each of the farms types. Comparisons among types of farms are of interest, but some of the details contained in the data will be mentioned only briefly in order to concentrate on the most relevant characteristics of the use of production factors. The reader must refer to Tables 13, 14 and 15 simultaneously when applicable. Finally, the use of these aggregated inputs for the activities at which the technical change is directed, will be presented in order to facilitate comparisons with the traditional technological procedures.

Factor Use on the Corn-Tomato Farm

Data of the level of factors used in the optimal solutions of the model by levels of risk for adopters and non-adopters under the established conditions of credit utilization are presented in Table 13. In addition, Table 13 contains calculations of labor and working capital use in per hectare basis, as well as changes in the use of the factors by risk level. These estimations are intended to provide a different view of factor usage, as well as a base for comparison.

As pointed out previously, there is a definite relation between land allocation to farming and the risk levels that farmers ought to undertake if a certain level of expected profit is seen as desirable. This direct relationship applies to all types of farms under analysis, as shown in Tables 13, 14 and 15. Even in cases in which a credit restraint is imposed, this relation is still true, although the maximum risk level is obtained before total available land is utilized for farm production.

Working capital is another variable with a clear relationship with the levels of risk selected for the solutions of the model: the higher the level of risk, the greater the amount of working capital to be used in farming. This relation holds for the corn-onion farm regardless of the type of technology applied to farming, and the level of credit used. This relationship is the general pattern for the other types of farms (Tables 14 and 15), except for a couple of risk levels in which a slight

Table 13. Factor use in the optimal corn/tomato type of farm with and without technical recommendations by levels of risk and credit.

Value of λ	Improved technology, open credit							Traditional technology, open credit						
	labor	working capital	land	labor/ha.	working capital/ha.	change labor	change capital	labor	working capital	land	labor/ha.	working capital/ha.	change labor	change capital
2000	166.56	6994.25	1.03	161.71	6790.53	---	---	156.41	6174.64	.904	173.02	6830.35	---	---
5000	192.35	9266.05	1.51	127.38	6136.46	-34.33	-654.07	164.48	7008.93	1.27	129.51	5518.84	-43.41	-1311.51
10000	178.22	12393.57	2.35	75.84	5273.86	-51.54	-862.60	189.94	9925.85	1.88	101.05	5279.71	-28.46	-239.13
20000	169.65	13123.11	2.35	72.19	5584.30	-3.65	310.44							
18203 (max)								152.98	10301.00	2.35	65.10	4383.40	-35.95	-896.31
28185 (max)	171.58	13544.55	2.35	73.01	5763.54	.82	179.34							
	Improved technology, limited credit to Colombians $5000.00							Traditional technology, limited credit to Colombians, $5000.00						
2000	166.48	7002.12	1.03	161.63	6738.17	---	---	156.41	6174.64	.904	173.02	6830.35	---	---
5000	138.99	7101.27	1.31	106.10	5420.82	-55.53	-1317.35	179.40	7442.64	1.25	143.52	5954.11	-29.50	-876.24
10000	136.10	7525.30	1.32	103.11	5700.98	-2.29	280.16	136.12	7472.42	1.32	103.12	5660.92	-40.40	-293.19
10938 (max)	134.62	7549.59	1.32	101.98	5719.39	-1.13	18.06	134.62	7549.59	1.32	101.98	5719.39	-1.14	58.47

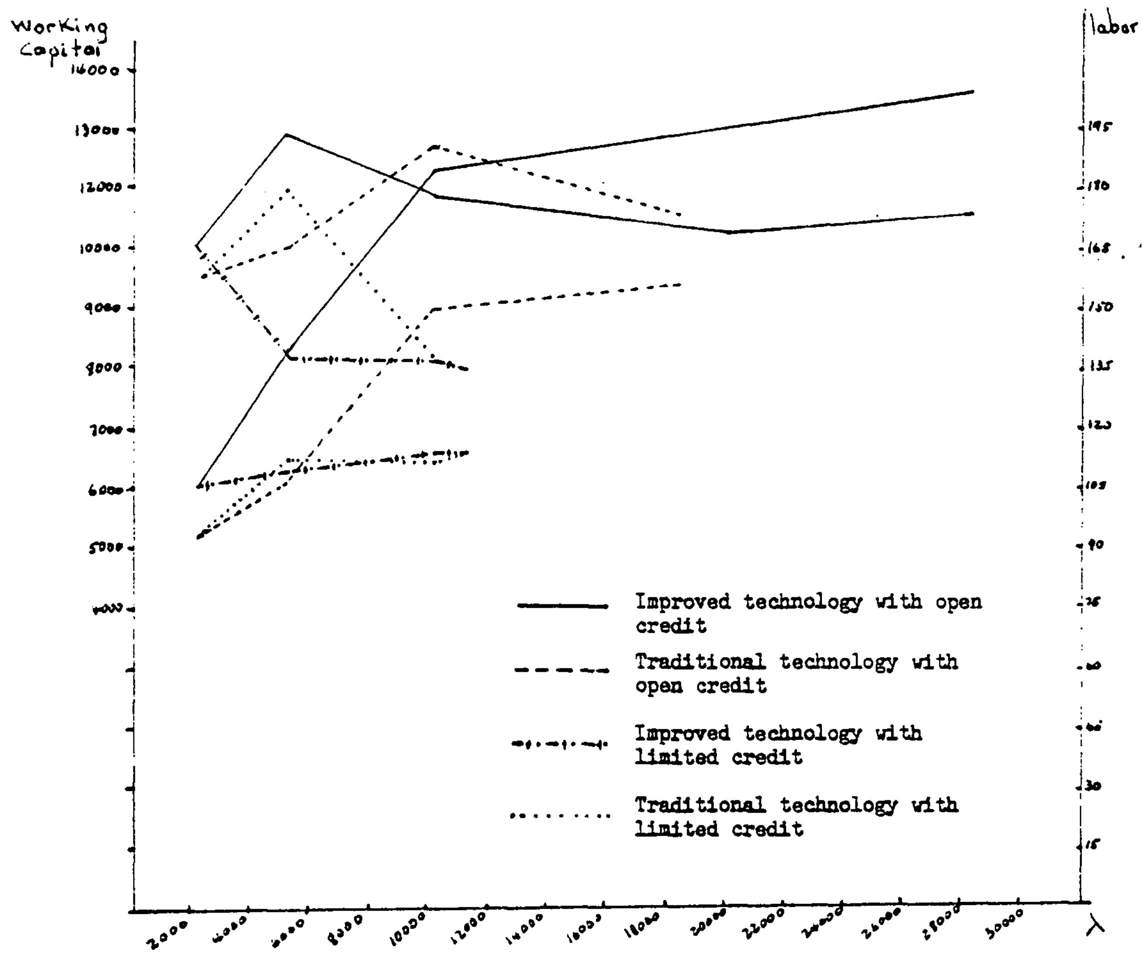
reduction in working capital takes place (i.e., corn-potato farm with improved technology and both open and limited credit). The use of labor, on the other hand, does not present any strict relationship with the levels of risk being considered. Table 13 shows signs of increasing and decreasing levels of labor for subsequent increases in risk. The same type of variation in the use of labor can be found for the other kinds of farms (Tables 14 and 15). Nevertheless, if the entire range of risk is observed at the time the use of labor seems to follow a tendency to diminish as land, working capital, and risk level are increased. An attempt to illustrate this relationship for the corn-onion farm is presented in Figure 4 (changes in land use are excluded in order to keep a two dimensional graphical representation).

The trends of labor use by traditional farmers regardless of the level of credit are the more realistic representation of such a diminishing tendency. The use of labor increases as the risk level moves from the lowest level upwards, but it soon decreases as higher levels of risk are accounted for. This tendency can be observed on the corn-potato farm, as shown in Figure 5. Figure 4 helps visualize the labor-working capital relationships for all levels of risk in the optimal solutions for the corn-tomato typical farm. In general, the trend of working capital increases, and the use of labor diminishes as higher levels of risk are allowed in the solution of the model. These general relations, however, include variations in the use of land, not shown in Figure 4. To correct this, Table 13 presents the per hectare estimations of land and working capital use. These generated data allow for generalizations among the different types of farms considered in this study.

Factor Use on the Corn-Potato Farm

Data relative to the use of factors in the typical corn-potato farm for different levels of risk are summarized in Table 14. As explained before, the general relation between land use and risk levels holds for this type of farm. There is, however, the exception of those farmers

Figure 4. Labor and Working capital use in the Corn-tomato type of farm with and without improved technology by levels of risk and credit.



using limited credit: the linear programming solution of the model requires less land than the previous risk level at which the model was evaluated (λ=5000). In this instance, the relaxation of the constraint on the total variations seems to produce a substitution of land for both labor and working capital, since the level of these two inputs is increased in relation to the solution at which more land was used. There are many factors that could bring about a set of production activities and levels such that expected profit could be increased, and a less specific input could still be used. In looking at Table 10, it can be noted that the level of an activity which was land saving, but capital and labor using, was doubled, e.g., poultry.

Table 14 also illustrates some exceptions to the tendency of working capital to increase with the level of risk. When the value of λ changes from 15000 to 20000 for improved technology, for adopters working with open credit, total working capital decreases slightly. Data in Table 9, shows that solutions at those values of risk differ in agricultural production activities: an activity with the recommended technological pattern is increased approximately 26% to the expense of reducing an activity produced under the tradtional technology at about 28%, and discharging from the solution another activity, even if its previous level was very small.

A more notable exception is the case of a technology adopter using limited credit. For those farmers, the use of working capital decreases and then increases when more risk is taken into account, but the highest values of the factors is at the lowest level of risk for which the model had a feasible solution. Although Table 10 is useful in explaining these differences as to the amount of working capital used on the farm, a quick view is enough to conclude that combinations of selected production activities and their levels could satisfy an explanation of almost any combination of factor use.

The general trends of labor and working capital use are graphed in Figure 5. Although specific cases already mentioned do not conform to some of the tendencies of variation in the use of those inputs, the

Table 14. Factor use in the optimal corn/potato type of farm with and without technical recommendations by level of risk and credit.

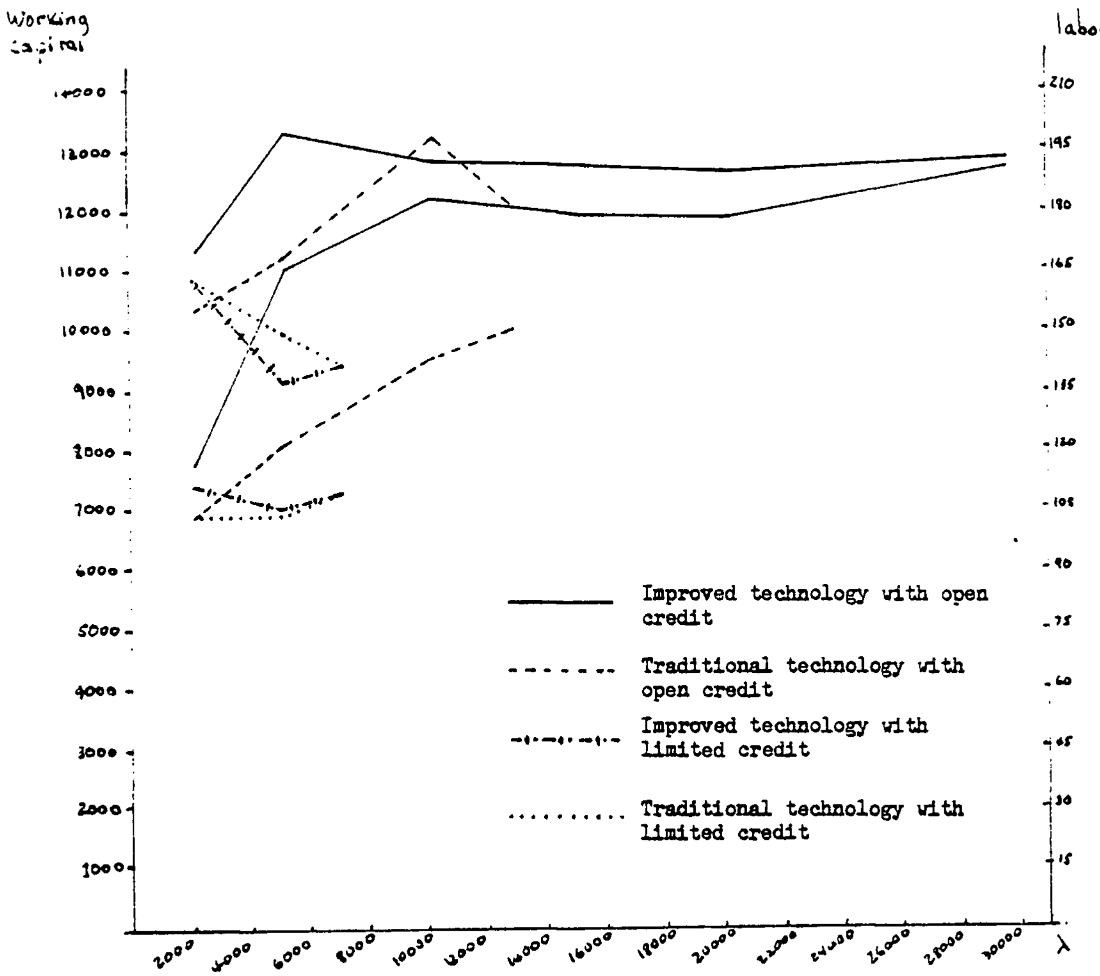
Value of λ	Improved technology, open credit							Traditional technology, open credit						
	labor	working capital	land	labor/ha.	working capital/ha.	change labor	change capital	labor	working capital	land	labor/ha.	working capital/ha.	change labor	change capital
2000	170.76	7776.24	1.14	143.79	6821.26	---	---	156.66	6785.03	1.01	155.11	6717.85	---	---
5000	201.84	11089.58	1.80	112.13	6160.88	-31.66	-660.38	170.31	8039.96	1.28	133.05	6281.22	---	-436.63
10000	194.35	12123.42	1.98	98.16	6122.94	-13.97	-37.94	197.19	9671.00	1.78	110.78	5433.15	-22.06	-848.07
12367 (max)								181.70	10047.76	1.98	91.77	5074.63	-22.07	-358.53
15000	192.05	11914.63	1.98	96.39	6017.49	-1.17	-105.45						-13.01	
20000	193.42	11903.64	1.98	97.67	6011.94	1.30	-5.55							
29404	193.79	12773.68	1.98	97.87	6451.35	.20	439.41							
	Improved technology, limited credit to Colombians, $5000.00							Traditional technology, limited credit to Colombians						
2000	164.90	7442.56	1.09	151.28	6828.04	---	---	156.66	6785.03	1.01	155.11	6717.85	---	---
5000	138.56	7056.48	1.31	105.77	5386.63	-45.51	-1441.41	148.61	6843.88	1.27	117.02	5388.88	-38.09	-1328.97
7074 (max)	141.49	7345.44	1.29	109.68	5694.14	3.91	307.51	141.49	7345.44	1.29	109.68	5694.14	-7.34	305.26

factor use in this type of farm appears to fit into the general description of labor decreasing and working capital increasing as the level of risk is changed from low to high. This trend can be observed in Figure 6 also.

Estimation of labor and working capital by hectare results in a series of different patterns. Calculations presented in Tables 13, 14, and 15 seem to follow a pattern according to which the use of both labor and working capital decrease as higher levels of risk are incorporated. This is due to the steady increase in land use that accompanys all incremental changes in the levels of risk. There are however, cases in which the production factors do increase as the model is evaluated at higher values of λ. This is especially true for the linear programming solutions when farmers adopt the recommended technology. The most interesting cases are solutions for adopters using open credit since in all types of farms, full land utilization is reached for at least three different levels of risk. Changes in both labor and working capital (Tables 13, 14 and 15) illustrate not only the sense of the change, but the quantity. In the case of corn-potato, open credit users have four solutions in which all available land is used. When this stage is reached, labor and working capital decrease but final changes become positive, indicating increments in the use of both factors. For the solutions at which land is fully utilized, a discussion of factor substitution does not have much economic significance, given that such substitutions occur in front of a given level of λ instead of an isoquant or a production possibility curve. In this vein, columns showing changes in labor and working capital cannot be taken as indicators of discrete marginal changes toward increments in production.

In spite of the relation of changes in the use of factors by changes in the value of the risk indicator, the absolute magnitude of those changes seems to support the possibility that changes in working capital are more severe than the changes in labor. This is especially true when the changes are positive in all farm types under analysis. This is in accordance with the trends described before according to which working capital tends to increase at a higher rate than labor decreases.

Figure 5. Labor and working capital in the Corn-potato type of farm with and without improved technology by levels of risk and credit.



These labor-working-capital ratios will be formally discussed in Chapter V.

Factor Use on the Corn-Onion Farm

Data concerning factor use for the typical corn-onion farm by levels of λ and credit are presented in Table 15. Although the use of factors on this type of farm generally conforms to the characteristics pointed out throughout this section, this is without doubt, the farm with more differences or rather exceptions to the general trends of factor use.

Farmers using improved technology with and without limitations in credit seem to have an opposite schedule for factor use: a rapid increment of working capital followed by declining levels as the risk value is increased, and a sustained increment in the use of both inputs associated with high levels of risk.

Farmers using traditional technological patterns and limitations on credit follow a scheme of using working capital very close to the one pointed out for adopters who are also limited in credit but belong to the corn-potato farm: the use of this factor goes up and down as risk varys from low to high.

Another interesting difference of the solutions for this type of farm is given by positive changes in the use of labor when farmers adopt the technological recommendation. This tendency can be seen by contrasting the trend of the curves for labor presented in Figure 6 against the same curves graphed for the two other types of farms, shown in Figures 4 and 5. For solutions associated with improved technology (with or without credit constraints), lines showing the use of factors tend to run parallel to each other, rather than in opposition as has been indicated for the other types of farms under analysis.

One final comment regarding all types of farms concerns the similarity of the level of inputs used in farming. The range in which labor and working capital change at different points of solution is different for each farm, but total expenditure and total man-days are very close.

Table 15. Factor use in the optimal corn/onion type farm with and without technical recommendations by levels of risk and credit.

Value of λ	Improved technology, open credit							Traditional technology, open credit						
	labor	working capital	land	labor/ha.	working capital/ha.	change labor	change capital	labor	working capital	land	labor/ha.	working capital/ha.	change labor	change capital
1000	177.63	7271.29	1.21	146.80	6009.33	---	---							
2000	176.15	7908.30	1.59	110.79	4973.77	-36.01	-1035.56	159.55	7091.72	1.03	154.90	6885.22	---	---
5000	201.53	10802.17	1.81	111.34	5968.05	.55	994.28	178.20	8162.88	1.35	132.00	6046.58	-22.90	-838.64
10000	186.73	12293.53	2.18	85.66	5639.23	-25.68	-398.82	185.97	10869.06	2.10	88.56	5175.74	-43.44	-870.83
15000	185.68	12237.88	2.18	85.17	5613.71	-.49	-25.52							
15034 (max)								187.96	11320.07	2.18	86.22	5192.69	-2.34	16.95
20000	194.30	12806.39	2.18	89.13	5874.59	3.96	260.78							
25126 (max)	198.88	13145.18	2.18	91.23	6029.90	2.10	155.41							
	Improved technology, limited credit to Colombians, $5000.00							Traditional technology, limited credit to Colombians, $5000.00						
1000	159.00	6843.55	1.12	141.96	6110.31	---	---							
2000	158.10	6962.52	1.12	141.16	6216.54	-.80	106.23	159.55	7091.78	1.03	154.90	6885.22	---	---
5000	145.40	6811.03	1.29	112.71	5297.87	-28.45	-936.67	144.72	6701.68	1.27	113.95	5276.91	-40.95	-1608.31
6951.99 (max)	143.91	6890.08	1.27	113.31	5425.26	.60	145.39							
10000 (max)								143.25	6888.51	1.27	112.80	4224.02	-1.15	147.11

This is not a surprising result since the farm typification is given for a fairly homogeneous geographical area, and there are no major differences in technical coefficients. Of course, there are notable differences between farm plans for which introduction of technical change has been accounted for and those plans carried out under traditional technology conditions. Nevertheless, differences among types of farms are not severe for each of these categories.

Factor Use in Activities Subject to Technological Change

As a way to gain some understanding about differences between farm plans incorporating changes in the technology of production and plans without those changes, average values derived from the sample and calculated on per hectare basis, are shown, in Table 16. Physical outputs are included as well in order to provide a better idea of the possible impact of the improved technology, and to make this table suitable for further analysis.

Table 16 is self explanatory as to the differences in factor use and output of the technology that has been developed and recommended to corn farmers in the Caqueza Project. These differences are due to the level of inputs used in each case. Fertilizer, pesticides and output to be harvested are responsible for the differences in both labor and working capital expenditures. Increments of about 40% in labor use, and approximately 165% in the amount of working capital are to be met by farmers wanting to adopt the recommended technological pattern to grow corn-beans on one hectare.

These significant arguments in factor use explain discrepancies in total labor and working capital between farm plans when technical changes are considered, since production activities with the new technology are selected by the model over the same activities with traditional technology (Tables 6, 7 and 9), total farm factor use should be greater for solutions which include improved technological practices as reflected in Tables 13, 14 and 15.

Figure 6. Labor and working capital in the Corn-onion type of farm with and without improved technology by levels of risk and credit.

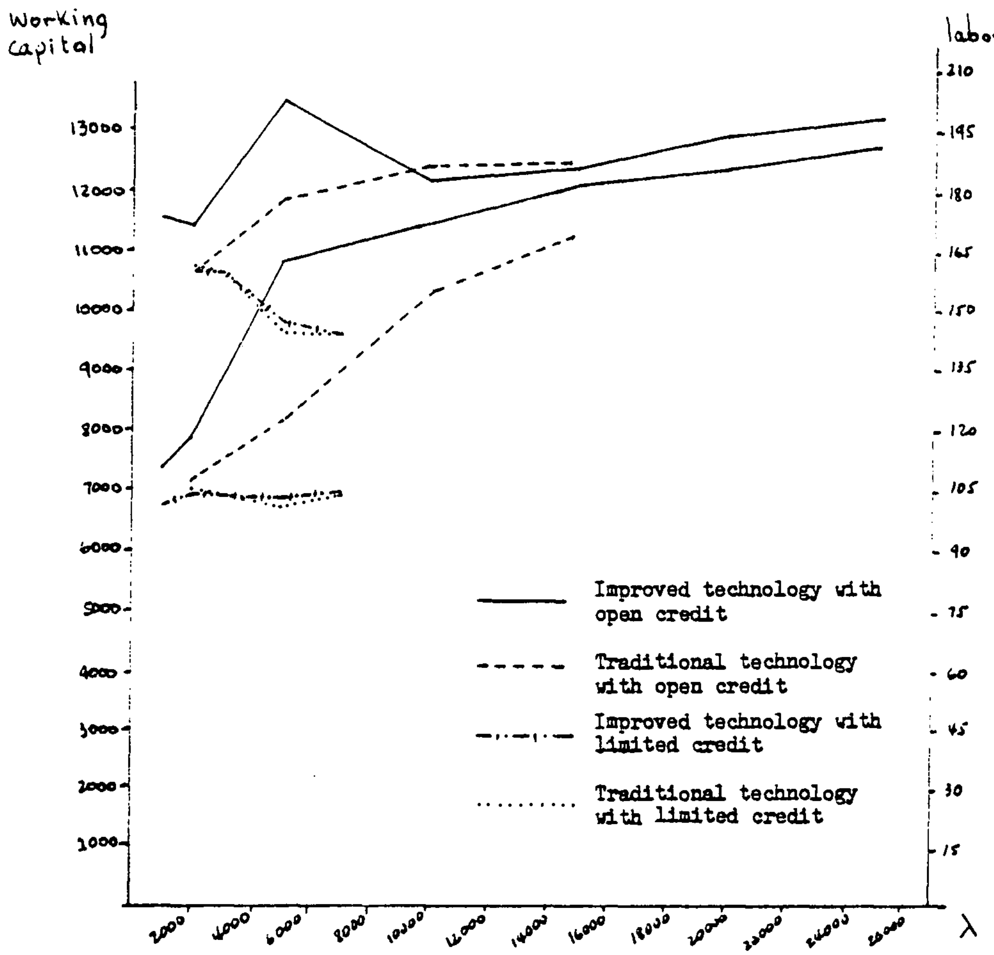


Table 16. Average factor use/ha. in crops under traditional and improved technology.

Crop or Crop Combination	Labor (man days)	Working capital (Col.$)	Yields (kgm). corn	beans
Improved corn/beans	76.04	3804.47	2268.53	395.83
Traditional corn/beans	53.70	1438.97	1030.16	339.47
Improved corn	62.60	4051.28	2628.73	
Traditional corn	59.90	1287.76	1107.72	

The Impact of Risk on Family Income

This section surveys the production side of farm plans as estimated by the model under the conditions at which it was evaluated. This aspect of the production process takes all the weight of the risk measure, since yields and prices are affecting expected profit, given that prices of production factors have been considered to be riskless. In this sense, this section also complements the two preceding sections of this chapter, provided that the analysis of output and profit will complete the view of the entire production cycle.

To demonstrate how the expected income will be related to the different values of the total deviation from net revenue, a summary of results is presented in Table 17. To facilitate comparisons with other tables, Table 17 includes the use of technology, credit limitations and risk values for each type of farm. As would be expected, there are conspicuous differences in farm plans under different technologies, and among plans with different credit levels. This is apparent from the information provided in prior sections of the chapter (Tables 6, 7, 9, 10, 11, 12, 13, 14, 15 and 16).

Farm plans considering the adoption of the recommended technology and full use of credit, yield higher expected profits at each level of risk than plans keeping the traditional technological pattern, even if all required credit is used. This statement applies to all kinds of farms. This pattern can be further qualified by pointing out that at low levels of risk, the difference between expected profit is more

Table 17. Expected income from optimal farm solutions with and without technological change by types of farms, levels of risk and uses of credit.

Value of λ	Improved Technology Open Credit	Traditional Technology Open Credit	Improved Technology Limited Credit to Colombians $5000.00	Traditional Technology Limited Credit to Colombians $5000.00
	E(π) Corn/Tomato Farm (in Col. pesos)			
2000	10581.37	6251.00	10581.37	6251.00
5000	18516.49	14770.45	16171.64	14684.00
10000	23863.80	20775.40	16660.36	16660.36
10938 (max)			16661.19	16666.19
18203 (max)		24387.95		
20000	26202.32	(23151.34)		
28135 (max)	26594.79			
	(35846.86)			
	E(π) Corn/Potato Farm (in Col. pesos)			
2000	8889.50	3284.76	8654.14	3284.76
5000	16156.24	11429.77	11893.79	10417.87
7075 (max)			12513.79	12513.79
10000	19418.12	16634.84		
12367 (max)		18047.10		
		(15585.49)		
15000	19713.38			
20000	19666.61			
29404 (max)	20367.22			
	(37056.62)			
	E(π) Corn/Onion Farm (in Col. pesos)			
1000	6983.89	-----	5696.29	-----
2000	10364.24	5013.48	8867.90	5013.48
5000	17723.24	12885.00	12065.91	11870.19
6952 (max)			12423.33	
10000	22069.66	19132.00		13238.65
15000	22553.14			
15034 (max)		21382.59		
		(19070.72)		
20000	22812.05			
25126 (max)	22921.30			
	(31872.49)			

accentuated than the same differences at higher risk levels. For the corn-potato and corn-onion types of farms, expected profits of technology adopters experience more than twice the expected profit of non-adopters at the lower risk level. These differences continue to decrease up to the point at which the maximum risk level is reached.

Following the former pattern of change in the expected profit, it seems worthwhile to note that at the highest risk level, after which expected profit will not increase regardless of the willingness to take more risk, the absolute difference in expected profit is not as substantial as it could be with regard to the difference of the risk value that has to be undertaken by farmers. In order to comprehend the differences in the risk indicator, the work by Hazzell is pertinent to approximate the M measure (the λ value in the model) to the standard deviation of the population, since M is an unbiased estimate of the population variance (3, 25).[15] For the maximum values of λ for adopters and non-adopters using all required credit, the corresponding estimations of the standard deviations appear in parenthesis in Table 17. One point that might be distinguished, is that for technology adopters to obtain the maximum expected profit, they have to accept a level of variation such that the standard deviation will always be much greater than the expected profit. If farmers keep the traditional technology to obtain the maximum expected profit, they also have to accept a significant variation, but the standard deviation is less than the profit which is expected.

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[15] Anderson, Dillon and Hardaker (3) report that $V=M^2[\pi s/2(s-1)]$ where s is the sample size. This is true when the population is normal or approximately normal. It may be recalled from Chapter III that the risk factor was the result of multiplying a normal distributed sample (prices) times a triangular distributed sample (yields). Although the sample size was 100 cases, there is no evidence that the resulting distribution is normal or approximately normal. For this reason, only the maximum risk values are subject to analysis and they should be accepted as an illustration.

Farm plans including the restriction in credit availability present a distinct view: differences in expected profit are substantial at the lowest level of risk, but soon adopters and non-adopters will find fairly equal values of expected profit, until finally reaching the maximum values of λ which is the same for both categories of farmers and yields identical expected profits. One exception is the corn-onion farm in which adopters of technological change obtain the linear programming solution at a lower λ value than non-adopters. This implies that traditional farmers with limited credit could secure higher expected incomes than innovative farmers if they are willing to take the risk associated with that level of profit.

In addition to the characteristics presented in Table 17, one of the most important effects of the relevant differences in expected profits that could be attributed to availability of working capital, is represented by the use of credit. An analogy of the second and third columns with the extreme left columns of Table 16 provides an idea of these differences. While the introduction of the improved technology makes a difference in expected profits for farmers who can afford the technical recommendations, the technology factor becomes secondary when restrictions in working capital are taken into consideration.

Results contained in Table 17 depict the E-M efficiency frontier for every type of farm. As pointed out in Chapter III, this efficiency locus shows the trade-off between risk and expected income, indicating how much risk (deviation from the mean net revenue) is necessary to accept for a desired income level. The corresponding curves are presented in Figures 7, 8, and 9 which are graphical representations of data in Table 17.

There are a few interesting aspects derived from those graphs as far as adoption of the technological change is concerned. If farmers face a credit constraint of the type imposed in the model, after a relatively low level of risk, they cannot attain technological patterns that are available to those without credit constraints.

On the other hand, introduction of new technology results in superior expected profit everywhere along the efficiency frontier. The only element to take into consideration is the trade-off between variation and net gain in expected income for high levels of risk, as pointed out earlier. If farmers are willing to accept only small or relatively limited levels of variation, the adoption of the recommended technology could be significant in order to improve the familys' income. There is, however, an important exception for farmers whose farms are suitable for growing onions: the traditional technology is more appropriate if they face limitations in working capital and are willing to take medium to high levels of risk. This is the only case in which the two efficiency frontiers of the same characteristics cross each other depicting the ranges in which each one is relevant to farmers.

Another facet is the range of possibilities for farmers who will accept only small variations in risk. Their expected income, after accomplishing basic family food needs, will be relatively low. Figures 7, 8 and 9 show that credit limitations are the crucial factors, but technological change could be as important as the availability of working capital. It is evident that for all types farms, new technology adopters could do better than farmers who keep the traditional patterns even if innovators have limited working capital and traditionalists do not have that restriction. In essence, the efficiency frontiers shown in Figures 7, 8 and 9 depict a clear path only for those farmers who have no restrictions in working capital and are able to incorporate the recommended technology into their farm activities. In other instances, a variety of strategies could be used to maximize expected profit. The strategy selected will depend on availability of capital, willingness to introduce technical changes and risk attitudes toward rejection or acceptance of variations affecting the certainty of a given level of income. Finally, it may be recalled from Table 17, that after certain levels of risk, the relative increments in expected income are smaller than the increments in variation. This relationship causes the efficiency frontier to rise sharply in contrast to the generalized curvature presented in Figure 2.

Figure 7. E-M efficiency frontier. Traditional and improved technology. Corn-tomato farm type.

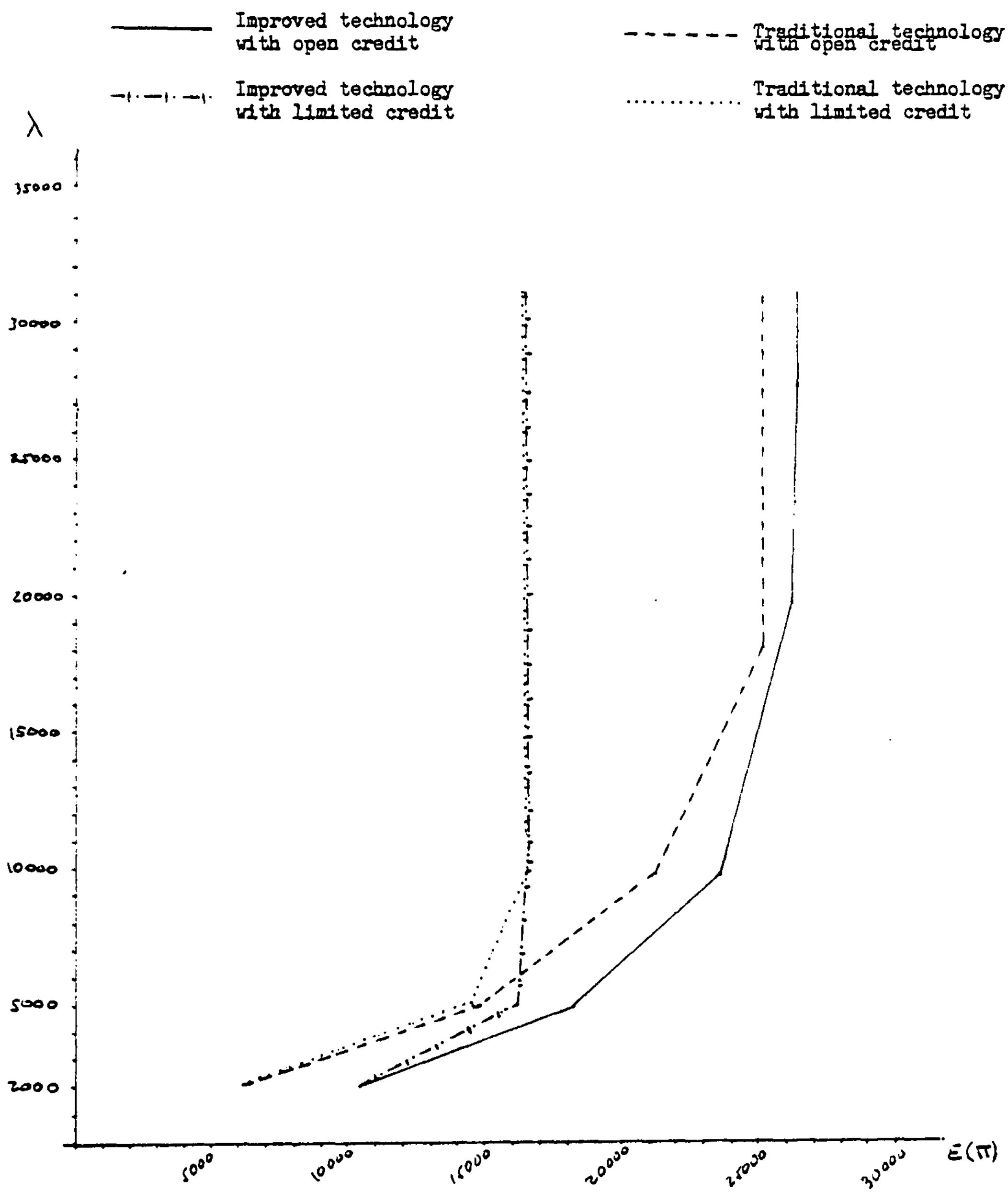


Figure 8. E-M efficiency frontier. Tarditional and improved technology. Corn-potato type of farm.

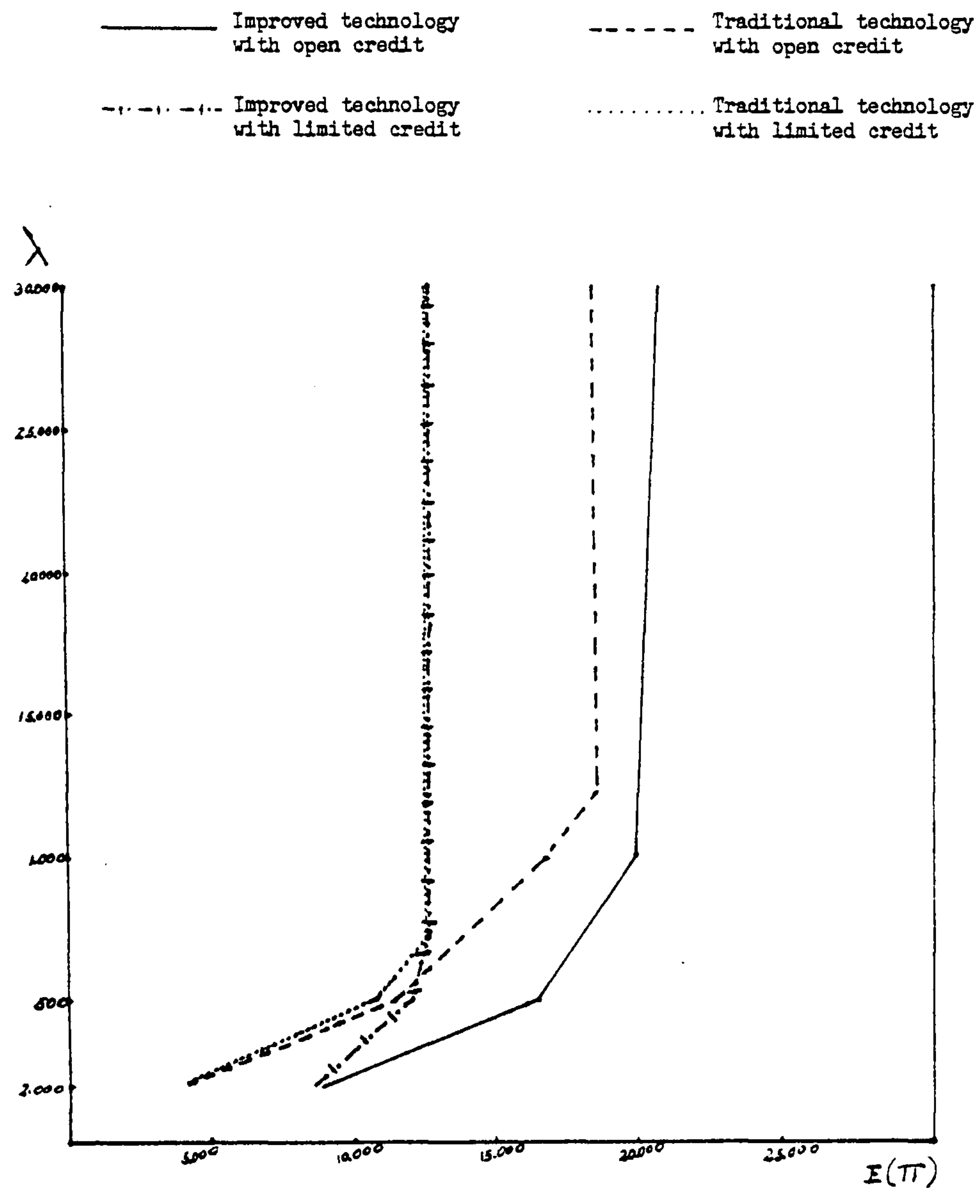
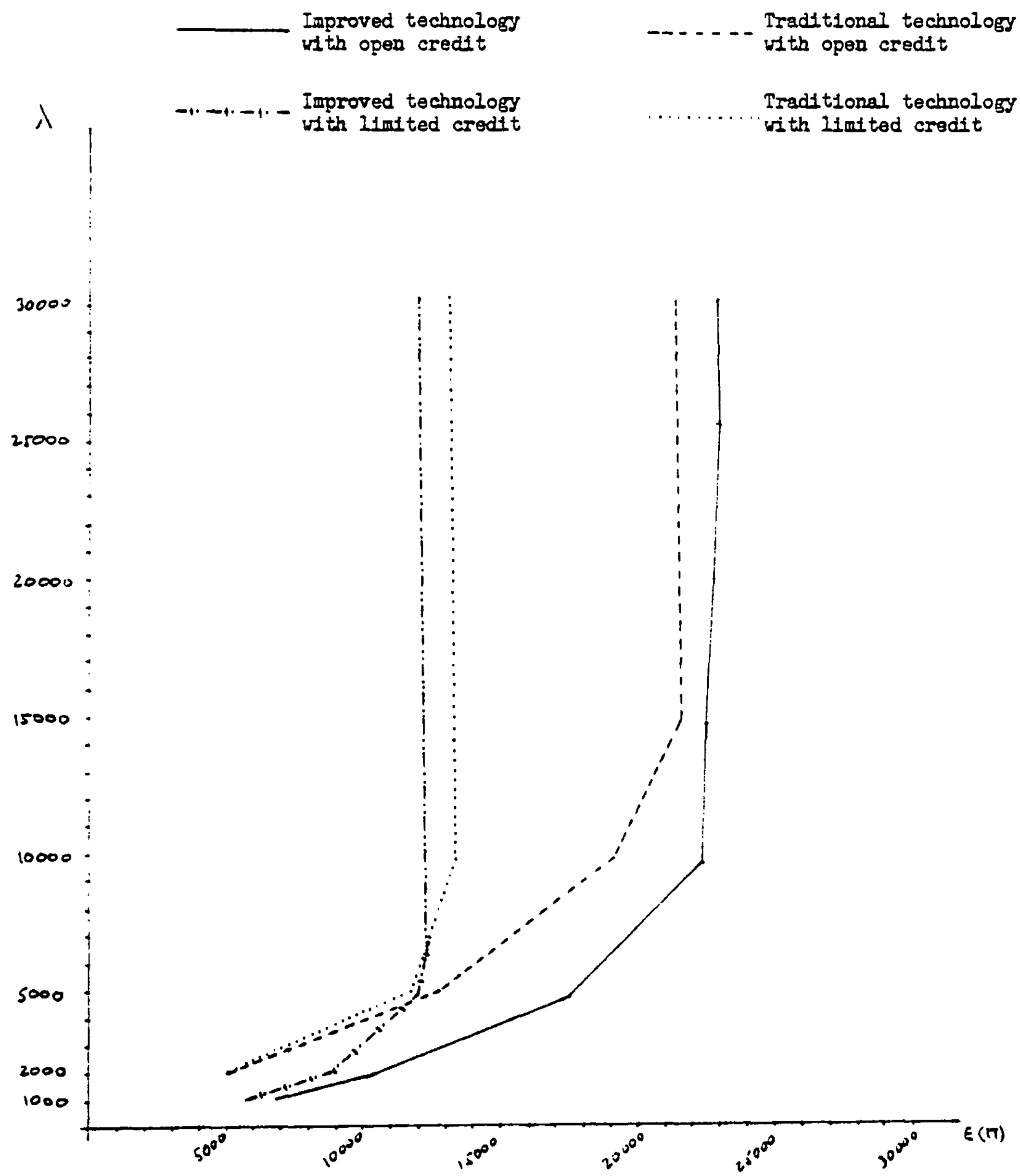


Figure 9. E-M efficiency frontier. Traditional and improved technology.
Corn-onion type of farm.



The Nutritional Objectives

As previously explained, optimal plans for each type of farm are set by the model once all constraints have been met. It includes the nutritional constraints expressed through minimum consumption of proteins and calories. There are, however, other sources of information that were considered in order to shorten the nutritional analysis of this study. In 1973, a consumption survey of 259 families from the entire area of the Caqueza Project, indicated that families from the entire corn growing zone had a less adequate consumption level of calories, protein, calcium, Vitamin A, riboflavin and niacin, as measured by the standards of the United States Interdepartmental Nutrition Committee for National Defense (ICNND) as illustrated in the first column of Table 18.[16] The same study provided data claiming that protein and calorie consumption was directly related to food expenditure, while consumption of calcium, vitamin A and riboflavin was more related to regional food habits (55). These conclusions suggested that augmenting family income through a more productive technology and implementing a nutritional education program, would substantially contribute improvements to family nutritional status.

Moreover, data on family consumption obtained through the two samples drawn for the purpose of this study, have been analyzed by the Harvard Institute for International Development (HIID). The last two columns of Table 18 present a summary of the results. The standard requirements used to estimate adequacy were those recommended by the Colombian Welfare Family Institute (26). Conclusions of that study suggest that most families were reasonably well fed, and that on the average, family consumption of all nutrients is above the requirements except for Vitamin A, among families farming with the traditional technology. However, the authors add, because the intakes are so near to the requirements, they can be considered as adequate (22).

[16] The ICNND regards 86% of the Colombian National Nutritional Institute recommendation as acceptable (55).

Table 18. Average family nutrient consumption in 1973 and 1978 as percent of total requirements.

Nutrient	Corn area[1] 1973	Corn area 1978[2] Recommended Technology	Traditional Technology
calories	89	115.9	108.8
protein (gr)	99	110.3	105.2
calcium (mgr)	64	123.9	114.7
iron (mgr)	117	158.3	144.5
vitamin A (IU)	68	137.2	96.9
thiamin (mgr)	143	179.8	167.6
riboflavin (mgr)	98	120.7	110.6
niacin (mgr)	82	103.9	109.5
ascorbic acid (mgr)	295	310.9	330.0

Sources: 1. Adopted from Swanberg, K.G, and E. Shipley, "The Nutritional Status of the Rural Family in East Cundinamarca, Colombia," Food Research Institute Studies, v. XIV, No. 2, 1975 Table 6, p. 120.

2. Adopted from Goldman, R.H., and C.A. Overholt. " Agricultural Productivity and Nutritional Goals." Nutrition Intervention in Developing Countries: v. VII, Harvard Institute for International Development. December, 1978, Table 13, p. 77 (cited with permission from the authors).

Differences between levels of nutritional adequacy of groups classified by the level of technology seem to support the conclusions of the pioneer 1973 study, since the program of education in nutrition has been implemented and there is evidence of net income gains for adopters of the recommended technology (59). Alternatively, the HIID study presents estimations of calories and protein consumption behavior. It was found that demand for calories is not strongly explained by the level of per capita income and the estimates of income elasticity for protein demand are also low. Farm milk production however, has a strong relation to both calories and protein consumption and technology adoption indicates a higher consumption of protein over families who continue with the traditional technological pattern, even when corn production appears to have no direct influence on consumption of nutrients (22).

As far as the present analysis is concerned, the single most important result of the inclusion of nutritional requirements is that farmers in the corn growing zone of the Caqueza Project are in the position to adopt a variety of farm plans, any of which will allow them to fulfill the minimum family consumption requirements and generate a new family income to be used to attain other family needs. These plans include a choice in technology of production, a choice in the level of debt, and a relative vast choice of risk level associated with level of income.

Solutions of the optimization model estimate the kind and amount of food items to be consumed by the family. As related in Chapter III, most of these consumption activities are restricted by upper and lower bounds to force food consumption within the customary diet of families in the area. Since several options to fulfill the nutritional constraints were included, it is tedious to report items and quantities set by each solution for each type of farm. One way of providing a general illustration is to convert food items to monetary values which allows a break down of expenditures on food to be consumed by the family. In doing so, it was discovered that there exists no virtual difference between the various farm types. For this reason, Table 19 contains data for all solutions for the corn-onion type of farm as an illustration of the subject. This type of farm was chosen because it provides solutions at a lower level of risk than any other farm type.

In order to estimate the proportions of Table 19, market prices were used for all food items consumed by the family regardless of their source for consumption (i.e., if farm produced, non-farm produced or purchased when items could have been produced on the farm). This generalized pricing does not conform to prices as used in the model, since farm produced food goods were priced at their production cost in the original matrix of technical coefficients. Nevertheless, as this is an illustration, the market value pricing provides a better base for comparison.

From the data contained in Table 19, it could be said that approximately 80% of the value of food consumption comes from their own farm production; about 20% of that value is direct cash expenditures to buy

Table 19. Proportion of family food expenditure for the corn/onion type of farm, by sources of consumption, type of technology use of credit and levels of risk.

Value of λ	Improved technology, open credit			Traditional technology, open credit		
	VFPF[1] / TVFC	VNFPF[2] / TVFC	VFBCBFP[3] / TVFC	VFPF / TVFC	VNFPF / TVFC	VFBCBFP / TVFC
1000	.731	.198	.071			
2000	.795	.197	.008	.592	.197	.211
5000	.803	.197	----	.801	.197	.002
10000	.791	.199	.010	.803	.197	----
15000	.727	.199	.074	.709	.212	.079
20000	.727	.199	.074			
25126	.727	.199	.074			
	Improved technology, limited credit			Traditional technology, limited credit		
1000	.703	.223	.074			
2000	.745	.230	.025	.592	.197	.211
5000	.729	.198	.073	.672	.257	.071
6952	.730	.197	.073			
10000				.730	.197	.073

1. value of farm produced food/total value of food consumed
2. value of non-farm produced food/total value of food consumed.
3. value of food bought, but capable of being farm produced/total value of food consumed.

food items which are basically processed food, and less than 1% of the total value of food consumption corresponds to items that are bought, but could have been produced on the farm, since in all cases those are agricultural products which are actually part of the production activities undertaken at the farm. This generalization applies to families on each type of farm under analysis.

It is interesting to note that only two solutions in Table 19 show zero expenditures in food items that are capable of being produced on the farm. The fact that less than 1% of the total market value of food consumption should be bought at the retail market is an indication of the higher marginal cost per unit of edible food items purchased at the retail market. As soon as the marginal cost becomes greater than the item market price, farmers should obtain the product at the retail location. The same conclusion could be reached if prices for farmers per unit of edible items happened to be greater than the retail market price. This is an open possibility in this analysis due to the risk measures on prices and yields. Again, those comments are valid for all farm types, since Table 19 is not seriously different than tables that could have been presented for the remaining types of farms.

Finally, it is of some interest, especially for the Caqueza Project team, to have detailed information of the items and the quantities consumed by the family as recommended by the solutions of the model. Appendix B presents such information. All other solutions were not included because variations between them were not significant. There are, however, relations between production activities and consumption of farm produced goods, which is not surprising due to the pricing system introduced into the model.

CHAPTER V

> "Linear programming is mainly a procedure for providing normative answers to problems which are so formulated. By normative we refer to the course of action which ought to be taken by an individual, business, area, or other economic sector when a) the end or objective takes a particular form and b) the conditions and restraints surrounding the action or choice are of a particular form."
>
> Earl O. Heady and Wilfred Chandler
> "Linear Programming Methods."
> Iowa State Univ. Press, 1960.

Model Validation

In spite of the normative character of the model used in this analysis, such a model is an abstract representation of reality. In this sense, solutions of that model should delineate reality accurately, or at least within certain margins that allow a degree of confidence such that real application to actual situations becomes a realistic issue.

There are several factors by which a model may not perfectly represent either actual scope of the problem or the economic situation which is supposed to be simulated: 1) there may be errors in the specification of the model in both the constraints and the activities to be accounted for; 2) inaccuracies in numerical data could lead to wrong representations of the market or the production side of the problem; 3) the objective function to be maximized does not conform to a real farmers' objective; 4) interrelations between farms, and conditions of homogeneity have been violated, and 5) the normative nature of the model causes numerical results to differ from real economic behavior because rational choice is bounded by individual knowledge which is assumed perfect by normative models (11, 21, 52). All of these potential sources of discrepancies between the real world and the solution of the model have been categorized in errors in specification and aggregation bias affecting programming models (11, 32).

Buckwell and Hazzell (11) provide a symbolic representation of the problem as follows: Let $\dot{x}_{ht}$ be the j x 1 linear programming solution vector of the h^{th} group of farms in the t^{th} period, where j denotes the number of activities of farms, and K_{ht} is the number of farms in the group. The aggregate supply from all groups is the vector

$\sum_h \dot{x}_{ht} \cdot K_{ht}$. If the vector of actual farm supply is represented by $\sum_h \sum_k \bar{x}_{ht}$, a discrepancy will be found whenever the following expression holds:

$$\sum_h \dot{x}_{ht} \cdot K_{ht} \neq \sum_h \sum_k \bar{x}_{ht} \qquad [24]$$

As simple as the explanation contained in [24] appears to be, validation of programming models, applied to a farm or the entire economy, is seldom discussed beyond its conceptualization. This fact could be attributed to a virtual absence of methodology and techniques to implement the validation process of a multiple-response model (32). Reliability of programming models has been established by testing hypotheses about the pricing system of the market in relation to the predictive ability of the model (44). Others have made use of the goodness-of-fit measures that are generally applied to econometric models (32), and some others have set the example by avoiding potential problems of internal consistency (11) and aggregation bias when working with a representative farm (11, 21, 52).

This chapter does not pretend to discuss the methods used to validate multivariable models, nor is it aimed at further examination of the validation process of this model. The reason for this analysis is to provide some indication of the reliability of the solutions as they compare with what farmers in the Caqueza region are actually doing, and to analyze both the consistency and potential of adoption of the model solutions.

Internal Consistency

One of the sources of error of specification in building models is the lack of self-consistency due to poor formulation of the problem or an inadequate set of data. For the specific case of this model, coefficients, objective function, prices, restrictions, activities and bounds are the elements that provide the consistency of the model. Such a consistency should be evaluated from the economic point of view, which in turn, relies on the economic theory explaining the production process of the typical farm in the Caqueza Project Area. From the theoretical point of view, a simplistic checking of internal consistency is based on economic rationale of the solution of the model. That is, decisions tending to maximize the objective function should exhibit relationships between available resources and prices of both inputs and final products, given a set of restrictions imposed by the structure of the model.

To perform a test for internal consistency of the present model it is sufficient to recall that all activities, their technical coefficients, prices and bounds are exogenously determined. The selection and levels of activities, and their combined impacts are the endogenous variables that must be found by the solution of the model within a given range of variation in net revenue which is to be minimized by the model. Other endogenous variables, e.g., labor use, credit use, family diet composition, off-farm work, land renting and food consumption items bought at the retail market level, are dependent on the set of the earlier mentioned endogenous variables. Thus, these are mere consequences of the initial solutions. This quick recall of the model is guaranteed by construction. Actual tests of this consistency were performed by increasing the average price of the off-farm work. This resulted in zero farming activities.

The available data, on the other hand, may be subject to errors in the recording process, and in the memory of the farmers. A process to counter check each interview against farmer data collected in the same area was undertaken, and an effort to prevent major distortions in the data was made by using interviewers who had years of experience working with those particular farmers.

Validation of the Full Model

As dictated by the construction of the model, the set of endogenous variables is the focus of the validation process. There are, however, considerations to take into account due to the lack of methods to complete such a validation. In the first place, there is no need to try a validation procedure for each type of farm for which the model was solved, since there are no variations in the model for each type of farm. Therefore, if the model for one type of farm could be analyzed, this result could be generalized for all cases. Following this reasoning, the corn-potato type of farm was selected for the validation analysis, since it represents a greater number of farmers within the area of study.

Secondly, there exists a major problem of comparison between the model solutions, which are evaluated for the typical farm, and each individual farm. This incompatibility is due to the parameterization of the risk-factor λ used for the typical farm, since the level of risk is not known for each farm. If a comparison of the type shown by expression [24] is to be accomplished, it is necessary to adopt a criteria by which a farmer can be assigned to a specific level of risk, in order to conform his actual behavior with that recommended by the model. In other words, it is required to locate the farmer in the λ-$E(\pi)$ space in which the efficiency frontier found by solving the model has been represented. The method used to solve this problem is the subject of the next section.

Finally, even if the former problem can be solved, the number of farmers conforming to the corn-potato type of farm is 91 which makes the analysis not only time consuming, but more difficult to perform. In order to make the problem manageable, a subsample of 30 farmers was drawn at random from the 91 farmers conforming to this group which was considered as the universe. The underlying assumption is that if the validation method could be set for a subsample of 30 cases, its procedures and results could be generalized to the entire group of farmers. In order to keep this power of generalization, the proposed model was solved for the typical farm of the subsample by using the distributions found for the 30 farmers.

The Farm-Risk Allocation Process

Allocation of individual farms into a specific risk level has been accomplished by parameterizing a risk-aversion coefficient and choosing the one that minimizes the difference between the actual farm plan and one of the plans estimated by solving a linear programming model (9). In spite of the ingenuity of this method, it would require a set of transformations to the λ values for it to be applied to the present problem and in order to express them in terms of risk-aversion coefficients, as well as the evaluation of the model for each individual farm.

In order to avoid the involved calculations and to try to keep the process focussed on the evaluation of the model for a representative farm, the efficiency frontier of solutions of the model for the subsample was standardized to a λ-$E(\pi)/ha$ space. This allows a comparison of the $E(\pi)/ha$ for the entire set of solutions with the actual π/ha of each individual farm. With this common factor, the minimum difference criterion was adopted, which results in the allocation of a λ value to each farm, based on the smallest difference in profit/ha between the actual farm plan and the model solution. This process could be represented as follows:

$$\min \left(E(\pi)/ha_{ht} - \pi/ha_{kt}\right) \rightarrow \lambda^*_{ht} \qquad [25]$$

where $E(\pi)/ha_{ht}$ = expected per hectare profit of the h^{th} group of farmers in the t^{th} period.

π/ha_{kt} = actual per hectare profit of the k^{th} farm in the t^{th} period.

λ^*_{kt} = assigned λ value to the k^{th} farm for the t^{th} period.

The implementation of expression [25] can be graphically represented for each level of technology and credit usage. Figures 10 and 11 show the cases of limited credit for both improved and traditional technology, since these two cases contain nearly 70% of the subsample.

Aggregate Supply Comparisons

Due to the nature of the endogenous variables determined by the model, the validation process can be concentrated on the comparison of total farm supply and total regional supply as forecasted by the solution of the model, and as stated by the expression [24]. To complete the parameters of comparison, the points of the model efficiency frontier to which each farm is to be compared, are summed to obtain the overall farm supply. This process is repeated for the production figures. Tables 20 and 21 contain the summary results of aggregation processes of both model solutions and actual farm production, as recorded by the subsample, according to the different credit levels. It should be noted that animal production activities have been excluded from the analysis. This is due to the fact that these are bounded activities at low levels and their use results in the loss of meaning of the comparison.

Data presented in Tables 20 and 21 are clear in showing the products for which the model forecasts are definitely off the actual aggregate production figures. Specifically total estimated production of potato and ahuyama are quite different from the actual volumes of production. These results are, however, consistent with findings reported in Chapter IV, since potato is considered by agronomists to be a marginal activity for the altitude of the area, and ahuyama production is estimated to be increased as farmers are expected to devote more land to the association of corn-beans-ahuyama.

The judgment concerning the acceptability or reliability of the model, based on this simple exercise of validation is of course, a subjective response and further discussion would be deviating from the

Figure 10. Farm-risk allocation. Improved technology. Limited credit.

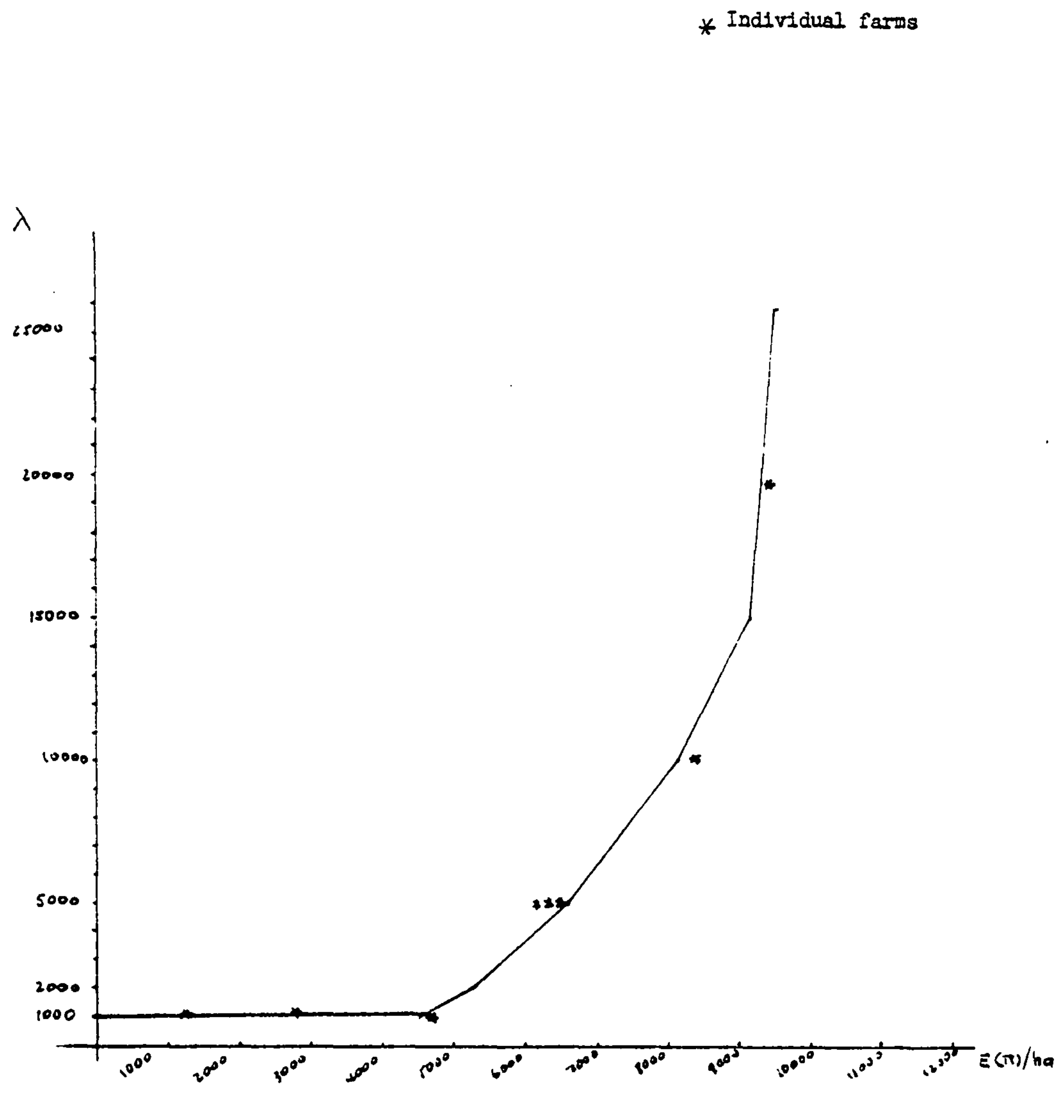
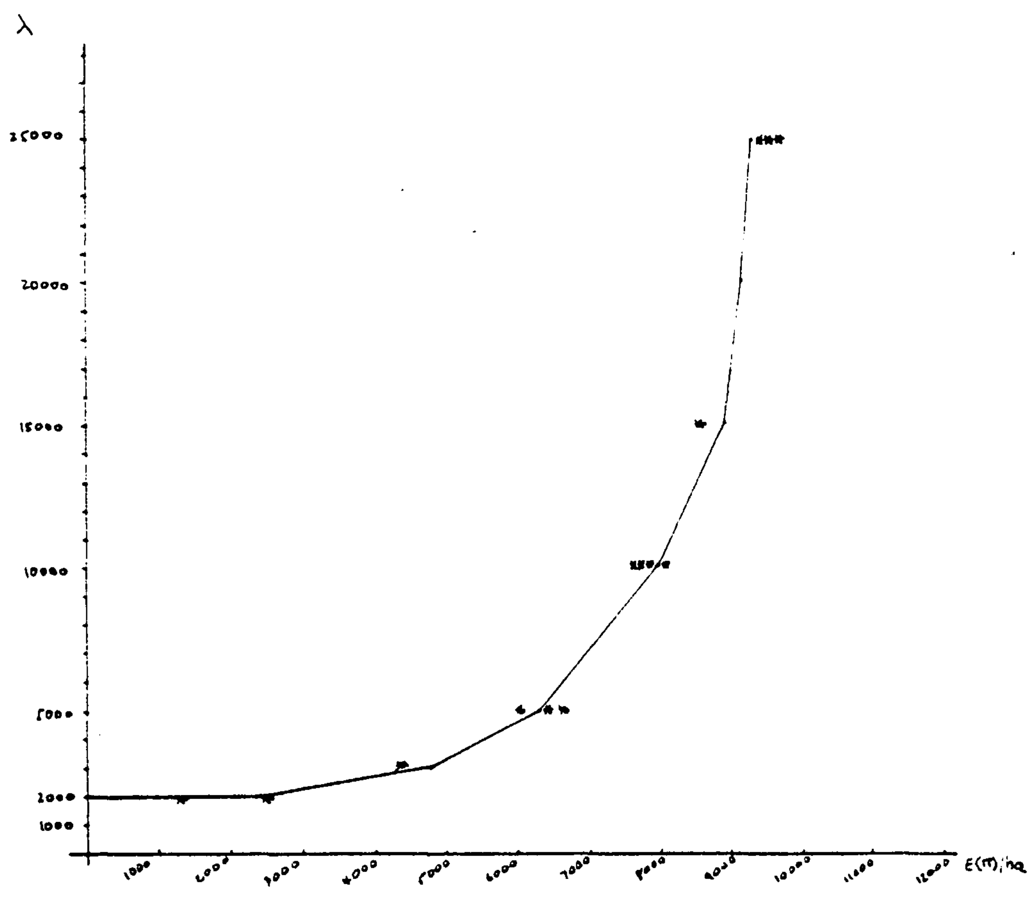


Figure 11. Farm-risk allocation. Traditional technology. Limited credit.

* Individual farms



content of this study. It is important to emphasize that the model forecasts are normative in nature, but can be feasibly applied as shown by the solutions of the model to different risk levels which state the activities and their levels that are attainable if farmers either adopt the technical recommendations, use more credit, are more willing to accept a higher risk level, or any combination of these factors.

There are several goodness-of-fit measures that could be applied to the raw data presented in Tables 20 and 21. One of those measures concentrates on calculations of the error between the actual and simulated data. Kost (32) explains some of these tests, and recommends the evaluation of errors relative to the average size of the variables, expressed in percentage terms. Following his terminology, Table 22 illustrates the mean absolute relative error (MARE) which he defines as follows:

$$\text{MARE} = \frac{\Delta}{T} \sum_{t=1} \left(\frac{|Y_t - Y_t|}{Y_t}\right)$$

where T = number of periods

$\hat{Y}_t$ = the estimated level of the variable in period t

Y_t = the actual level of the variable in period t

Of course, in every case, the smaller the MARE value, the better the fit.

Table 22 illustrates the size of the errors calculated from data in Tables 20 and 21. A value judgement is again made regarding these results. It is worth mentioning though that values on Table 22 compare much better with identical measures presented by Kost (32).

Final Comments on the MOTAD Model

Results presented in Chapter IV are based on the assumption that the version of the MOTAD model used to obtain the solutions is adequate to analyze the problem, otherwise a different model would have been selected. Data shown from the results of the validation procedure could be used to confirm or deny this basic assumption, but the only certain conclusion that can be obtained is that there exists an aggregation

Table 20. Estimated and Actual Aggregated Production. Improved Technology by Credit Levels.

Products	Open Credit (4 farmers)		Limited Credit (8 farmers)		All Improved Technology (12 farmers)	
	Actual Production (Kgrs)	Estimated Production by the Model (Kgrs)	Actual Production (Kgrs)	Estimated Production by the Model (Kgrs)	Actual Production (Kgrs)	Estimated Production by the Model (Kgrs)
Corn, traditional	3584	3233.16	3576	6402.34	7160	9635.50
Corn, improved	4585	3075.78	3243	2308.36	7828	4456.45
All corn	8169	6308.84	6819	7783.01	14988	14091.95
Beans	1042	573.29	1181	1380.67	2223	1953.96
Peas	---	---	904	---	904	---
Potato	---	1512.86	2700	1781.44	2700	3294.30
Ahuyama	85	229.50	120	464.15	205	694.65
Pasture	2.10(has.)	2.52(has.)	4.780(has.)	4.784(has.)	6.88(has.)	7.30(has.)

Table 21. Estimated and Actual Aggregated Production. Traditional Technology by Credit Levels.

	Open Credit (5 farmers)		Limited Credit (13 farmers)		All Traditional Technology (18 farmers)	
	Actual Production (Kgrs)	Estimated Production by the model (Kgrs)	Actual Production (Kgrs)	Estimated Production by the model (Kgrs)	Actual Production (Kgrs)	Estimated Production by the model (Kgrs)
Corn, traditional	6499	6777.25	14681	16888.71	21180	26662.96
Beans	1424	1301.96	3203	3470.07	4627	4772.03
Peas	---	81.27	150	---	150	81.27
Potato	10084	2806.45	8860	2477.56	18944	5284.01
Ahuyama	---	568.14	120	1258.51	120	1826.65
Pasture	6.32(has.)	3.27(has.)	8.08(has.)	8.04(has.)	14.4(has.)	11.31(has.)

Table 22. Mean Absolute Relative Measurement of Error Between Actual and Estimated Aggregated Supply

	Traditional Technology			Improved Technology		
	Open Credit	Open Credit	All Trad.	Open Credit	Open Credit	All Improved
Traditional corn	.0423	.1503	.1172	.0978	.7903	.3457
Improved corn				.3291	.5742	.4307
Beans	.0857	.0833	.0313	.4498	.1690	.1210
Peas	---	1.0	.4582	---	1.0	1.0
Potato	.7216	.7203	.7210	---	2.8679	4.7804
Ahuyama	---	9.4875	14.2220	---	2.8679	4.7804
Pasture (has.)	.4825	.0094	.2145	.2000	.0008	.0610

bias problem which may or may not be of paramount importance to the results of this analysis. An attempt to clarify this point of uncertainty requires an addition of other elements of judgment added to the validation process, even if they are intuitively based.

Although factor usage resulting from the model appears to follow expected behavior as compared to previous research (18, 59, 60), the distinction between family and hired labor was not well captured by the model, even if total use of labor per land unit is insured by construction. There are, at least two factors that might be responsible for this: the timing of labor utilization, and the setting of hired labor as an endogenous variable. The nine labor utilization periods were given a length as close as possible to a month in order to gain facility to estimate labor availability. It is possible, however, that a month period is long enough to perform most of the activities by using family labor, while in reality the operation period for certain tasks (i.e., harvesting) could be much shorter.

Another aspect which could be the most important to analyze as to the appropriateness of the model, is the role of the credit restriction exogenously imposed on the model. It was previously mentioned that in spite of institutional arrangements providing no virtual limitations on credit available to farmers, the observed farmers behavior in the Caqueza region was different (Chapter II). If the model is estimated exclusively with an open credit option, all solutions show that at any point, the recommended technology will produce superior results which implies that there is no point in dealing with the traditional technology anymore. It has been found however, that on the contrary, a massive adoption of the improved technology is a problem which remains to be solved (15, 16, 59, 60). Only when constraints in credit are imposed, does the set of efficiency frontiers become closer to empirical observations. This is confirmed by the allocation of farmers into risk levels: 70% of the cases in the subsample were closer to points in the efficiency frontiers depicted for limited credit, as shown in Tables 20 and 21.

These results reinforce the fast adoption rate of farmers participating in the risk-share corn plan which provides credit to farms in kind that does not have to be repaid if certain minimum levels of production are not obtained (59). The same type of interaction between credit and uncertainty has been reported to affect technological change in India among small farmers (47).

If credit or any other factor constitutes a prospect of risk for farmers in the Caqueza Project region, the version of the MOTAD model used for this analysis is not a complete representation of reality. The basic implication is that the measure of risk based exclusively on yields and price variations does not capture all relevant risk factors affecting farmers. It is, indeed, an interesting challenge to empirically test the validity of this hypothesis by either modifying the MOTAD model, or using a different model to estimate farm plans and the introduction of technological changes among peasants with similar characteristics of those in the Caqueza region.

CHAPTER VI

Selective Comments on the Results

This chapter is a discussion of some of the issues and results presented in Chapters IV and V. Having provided a direct report of the most relevant relationships of the optimal farm plans, there are several aspects suitable of being further interpreted in relation to the economics of production, and policy implications. Only a "select" number of issues have been chosen for further comment. This is not meant to slight any of the other points, but for practical reasons only those which seem more relevant to the objectives of this study and/or provide room for further research are taken into consideration.

It should be kept in mind also, that these comments do not present an exhaustive critique. They are intended to point out either weaknesses in the present analysis or some aspects to which questions can be raised, such that they become a challenge for more research efforts. The specific issues selected for discussion refer to the nature of the technological change which has been offered to farmers in the Caqueza Project, and some of the policy factors linking the present family nutritional status and the National Nutritional Plan.

The Nature of the Technological Change

Data presented in Table 16 and the direct implications of the difference in factor use explained in Chapter IV merit further elaboration on the nature of the technological recommendation being offered to small farmers of the Caqueza Project since useful clues could be found to assist in the understanding of the adoption process of technological change.

Economic theory is powerful in demonstrating that changes in factors of production will be given, among other things, by the cost of those factors which in turn depends on their scarcity. That scarcity value, including the social cost of factor adjustment, must be taken into account for both policy decisions and evaluation of the change to be introduced (19, 46). The case of the Caqueza Project presents some interesting issues in relation to factor endowments: results show a considerable proportion of labor not being used on farm production activities, land is to be rented if farmers are not willing to undertake a high level of risk, and credit seems to be a crucial factor representing working capital availability.

The estimates of Table 16 are self-explanatory of the dramatic changes in factor use that farmers wishing to introduce the technical recommendations have to perform. However, because those changes are due to both labor and working capital, it is difficult to infer the nature of the technical change from that data. In order to shed some light upon the nature of the technological change, several steps of analysis could be performed, but for the purpose of this section, the simple factor-factor ratios will be discussed, as well as some additional evidence reported in former research.

From Table 16, corn-beans figures seem appropriate for this illustration, since corn is not a very important production activity for the farm plans. The capital/labor ratios are 26.796 and 50.023 for traditional and recommended technology respectively, which indicates a percentage differential of 186.71% between adopters and non-adopters. This ratio is consistent with a former estimation in money value at 1975 prices which yield a difference of 295.0% between recommended and traditional technological patterns (51). The meaning of these ratios indicates that for an extra unit of labor, non-adopters require 50.032 units of capital.

Another indicator which is often used to determine the nature of the technological change is the shares of capital and labor. An analysis completed in 1979 of a set of the data used in this study permits the determination of shares for labor and capital, since production elasticities were estimated using a Cobb-Douglas production function for corn-beans growers (14). Table 23 presents factor share estimates for 1975 and 1977 which were derived from cross-sectional samples of farmers of the corn-growing area of the Caqueza Project (14, 51). Figures in Table 20 reinforce the nature of the input ratios: the relative change in capital share is .0633 and .07 while the relative change in labor share is .0545 and .035 according to 1975 and 1977 estimates, respectively. This relation of the factor shares indicates that the technological change is capital biased.

Table 23. Labor and Capital Shares in Corn-Beans Production With and Without Recommended Technology in the Caqueza Project.

Factor	Traditional Technology* 1975**	Recommended Technology* 1975**	Traditional Technology*** 1977	Recommended Technology*** 1977
Capital	.1499	.2132	.139	.209
Labor	.2559	.3104	.137	.172

Sources: * Sepulveda, S., "The Impact of Modern Technologies upon Factors Shares and Employment in Integrated Rural Development Districts in Colombia." Unpubl. Ph.D. Thesis, Cornell University, 1977.

** Production functions were estimated in money values.

*** Escobar, G., "Technological Change Among Small Farmers: The Case of Corn-Beans Production in the Caqueza Project, Colombia." Unpubl. paper presented at Oregon State University, May 1979, 10 pp.

One further step towards the analysis of the nature of the technological change is reported in (14). Following the Hicksian approach to technical change classification, it was found that the marginal rate of substitution of labor for capital decreases when the recommended technology is introduced due to a drop in the marginal product of labor. This means that less labor is required to substitute for one unit of capital, holding the level of output constant (14). This is a very significant result since the analysis was performed with the same data used in this study, and because there are other indicators working in the same direction that support the claim that the change in technology which is being introduced to farmers in the Caqueza Project corn-zone, is capital biased.

The confrontation of the analysis on the nature of the technical change and the results presented in Chatper IV are not very promising in the light of economic theory postulates. Not only is the recommended technology more demanding of the scarce resource, but there seems to be factors affecting the operation of institutional arrangements in providing the capital required to insure the adoption of the improved technology as shown in Chapter V. These findings link with the early comments on the validation of the model and the analysis of the E-M efficiency frontiers. Moreover, the biasness of the recommended technology raises several questions on the expected rate of adoption of such technology, not only among the Caqueza farmers, but among farmers of the other IRD districts since the adaptation of technology for those districts follows the method developed in Caqueza. Also, the bias of the improved technology imposes a heavy penalty upon the entire national agricultural policy as stated in the nutritional plan: a failure to increase basic food supply prevents massive urban increase in consumption.

The implications of a capital biased technology on the national agricultural development are complex to analyze. This "green revolution" type of technology could be one of the results of the dualism in the Colombian agricultural sector which has been traditionally reinforced by policies mainly directed toward the commercial subsector. That policy has encouraged the introduction of capital using technology through mechanization with subsidized prices by overevaluating the exchange rate and lowering interst rates (5). Additional legislation on minimum agricultural and urban wages, and the lack of land reform and basic rural services have contributed to a significant rural-urban migration which, in turn, has created political pressure to continue the introduction of capital intensive technology. This issue is not tangential to small farming in the nation. Peasant agriculture is facing unequal competition in the market and has been traditionally put aside from national plans until recent years. Yet, if the agricultural research effort directed toward small farmers is to produce a capital biased technology, an enrichment of the dualism can be foreseen, which implies a further deterioration of the tradtional subsector.

Some Comments on Nutritional Policy Prospects

Data presented in Chapter IV and the results of the HIID study analyzing the same set of data used in this research work (22) provide a clear vision of the family nutritional status, and the relationship between production and food consumption since the optimization model links them in a solution in which minimum nutritional requirements are satisfied. In spite of the possible negative effects that the nature of the technological change could bring about in farm production, it seems reasonable to claim that Caqueza farm output is market oriented with a potential for growth, if the IRD plan can overcome problems in operating institutional arrangements. It is thus appropriate to comment on the immediate prospects of the contribution of the IRD districts to the nutritional plan.

Unfortunately, the formulation of the nutritional plan on hand is not supported by relevant economic data to allow any inference of the results of this study. There exists, however, an interesting article analyzing the impact of increasing food supply on human nutrition in Colombia which considers different income strata in urban centers (40). Table 24 presents some of the figures reported in the study that seemed more relevant to the present analysis, since they refer to items that are produced in the area.

One aspect that looks attractive to increase supply is the possibility of a change in quantity demanded by the lowest income strata groups, as far as corn and beans are concerned. Those estimations could introduce important changes in prices, provided those groups in urban areas actually increase demand of those food items. Moreover,

Table 24. Selected summary information on food consumption of items being produced in the Caqueza Project.

	Direct Price Elasticity			Change in per capita calorie intake caused by a 10% increase in supply. Deficient strata.			Change in per capita protein intake caused by a 10% increase in supply. Deficient strata.			Reduction in calorie and protein caused by a 10% increase in supply.[4]		
										Calories	Proteins	
Product	Stratum I[1]	Stratum II[2]	Stratum III[3]	Direct	Indirect	Net	Direct	Indirect	Net	Stratum I	Stratum II	Stratum III
Eggs	-1.343	-1.227	-1.262							.33	1.21	3.46
Milk	-1.788	-1.621	-1.21	6.17	-3.04	3.13	.42	-.08	.34	6.33	1.49	4.13
Corn	- .630	- .548	- .441	38.21	.07	32.28	.94	-.02	.92	.92	16.22	5.46
Beans	- .812	- .778	- .649	7.77	.29	8.06	.57	.01	.58	3.42	2.99	6.15
Peas	-1.132	-1.128	- .757	.23	- .67	-.44	.06	-.02	.04	-.19	.17	.48
Potato	- .410	- .417	- .312	10.86	4.21	15.07	.24	.06	.30	6.39	2.24	2.02
Tomato	-1.169	-1.247	- .997							-.15	0.0	.01

1 Stratum I corresponds to families with an average income of U.S. $ of 353.88/year.

2 Stratum II corresponds to families with an average income of U.S. $ of 676.32/year.

3 Stratum III corresponds to families with an average income of U.S. $ of 1,073.88/year.

4 Reductions in calorie and protein deficiencies are given as % of total deficiency.

Source: Adapted from: Per Pinstrap-Andersen, Norha-Ruiz de Londono and Edward Hoover, "The Impact of Increasing Food Supply on Human Nutrition: Implications for Commodity Priorities in Agricultural Research and Policy." American Journal of Agricultural Economics. v. 58, n. 2, May 1976, pp. 135-140.

if the policy goal is to improve the poorest urban people, products like corn, beans and potato will have the greater contribution in providing calories and proteins to the most degraded income groups, given their consumption habits for basic staple foods. It is also reflected in the estimated figures on deficiency reduction based on the hypothetical case in which supply is increased 10%. The former considerations are used to propose research and policy production priorities. In so doing, the study considers different relative costs of research and policy measures. In all cases, corn and beans are counted among the first five priorities if the goal is to improve calorie and protein nutrition (40).

If the findings of that analysis are reflective of the true situation, farmers of the IRD districts and in particular, farmers in the Caqueza Project would make important contributions to the national nutritional plan. One significant drawback to these prospects is the dependency on demand increase of those low income groups. Critical to such demand expansion is the income change that these groups would experience which in turn, is a function of the labor absorption capacity of the urban economy. This aspect is not explicitly considered in the nutritional plan. What the nutritional plan has designed is a system of subsidies to increase food consumption among the poorest urban centers. This system, which has been operated as a pilot project up to now, could be equivalent to an increase in real income, provided that other sectors of the economy can generate the value of the subsidies.

In a hypothetical situation where urban demand is increased, farmers response in terms of production is not easy to predict. If the prevailing circumstances are described in Chapters I to III, the type of response presented in Chapter IV could be a good approximation of what farmers could do. However, if that demand expansion brings about significant price changes, supply reaction would take place not only among small farmers, but the entire agricultural sector would be trying to take advantage of the favorable price changes. This type of supply change could seriously affect small farming on a long term basis, especially if farmers actively enter the credit market attracted by favorable prices.

Supply increase in eggs and milk products are favored by a high price elasticity of potential consumers. For significant changes in production in the Caqueza Project area, the constraints imposed on the model prevent further analysis. Nevertheless, the option is not appealing from the technical point of view, particularly for livestock. Egg production could have a high potentiality, but again, any significant expansion of production requires a relative important lump sum of capital expenditure, as well as technical expertise capability.

Despite the factors that have been mentioned that have an effect on farmers supply response, possibilities of government intervention to increase urban consumption among the poor could act as a powerful stimulant for small farmers to increase total output. Given the limitation of the land, farmers would face the decision of adopting the recommended technology and fully utilize the credit available to them. This will induce them to accept a higher level of risk which could require very favorable prices to be off-set.

CHAPTER VII

Summary and Conclusions

The objective of the present research work was to develop a principle programming model to typify the "average farm" within the corn-growing zone of the Caqueza Project to determine the effectiveness of technological change in increasing family income and fulfilling nutritional requirements under conditions of risk. A version of the MOTAD model, modified to account for nutritional constraints, was used to perform the analysis. Production, factor use, income generators, food consumption, and financial activities were defined for the model in which a distinction was made between activities with and without the introduction of technological change and credit use levels.

Cross-sectional sample data of 168 farmers, experimental results and 28 years of monthly prices were used to estimate the model's technical coefficients to all activities included. Risk measures were estimated as deviations from the mean net revenue by each production activity. Based on the farmers' estimations of the most likely, lowest and highest yields in a ten year period, deflated prices, and probabilistic combinations were simulated using a Monte Carlo distribution generator to obtain fourteen observations of revenue variations. Nutritional requirements were annually estimated by the typical family, according to age, sex, physical environment, and number of children (including expectant mothers). Both nutritional requirements and calories and protein contents of consumption items were set according to Colombian nutritional equivalents.

Based on geographical location and altitude above sea level, the corn-growing zone was found to have three different types of farms, all of which grow corn and corn with other crops, but differ on other single crops that can only be produced on specific climatic locations. The model was applied to each type of farm. Each of those farms is to represent "the average farm" for which the most common production activities recorded in the sample were incorporated into the programming model to allow the optimal solutions to set the activities that conform to the "average farm" and to set the levels at which those activities are to be undertaken.

Solutions of the model for each type of farm are given by the type of technology, the level of credit used, and the risk measure values which are varied parametrically from minimum to maximum within the relevant range. Those solutions include information on activities, factor usage, profit maximization levels, and the E-M frontiers which describe the trade-off between expected profit and the level of risk that is attached to it. Each solution has the satisfaction of the food consumption requirements built-in and provides information on specific goods and quantities to be consumed by the family.

Chapter IV presents all sets of solutions for each type of farm. The most significant results can be summarized as follows:

(1) Farm plans are characterized by a fairly high degree of diversification in both agricultural and animal production activities. There exists in the model an inverse relationship between farm diversification and the values of the risk measure: the higher the level of risk, the less diversified the farming activities.

(2) Cropping activities for which improved technology is available are preferred by the model over the same activities performed with the traditional technology pattern in all types of farms. Among those activities with recommended technology, associated crops are selected over single crops, i.e., improved corn-beans over improved corn. Solutions of the model that do not consider the introduction of technological change, select double and triple crop associations over single cropping activities, i.e., traditional corn-beans and corn-beans-ahuyama over traditional corn.

(3) Income generation activities such as land renting and off-farm labor play an important role in maximizing expected profit. The area of land to be rented, according to model solutions, varies inversely with the value of the risk: the lower the level of risk, the higher the proportion of land to be rented. There is not a definite pattern of allocation of off-farm labor, since it is closely related to the

total set of activities on the farm.

(4) Availability of working capital represented by levels of credit to be used by farmers is of paramount importance in planning farm activities under the conditions of the model used in this study. Farmers using all credit required by the model will not only obtain higher expected profit for a given risk level as compared with farmers operating under limited credit, but will allocate more land to farming activities, use more labor, and concentrate on improved technology activities when available.

The level of credit makes a significant difference in the range of solutions to be found according to the parametric variations of the risk value. That is, farm plans in which credit is limited will reach the maximum risk level (after which no changes in expected profit will be produced) very rapidly as compared with farm plans considering open credit. If in addition to credit levels the type of technology is considered, farm plans with open credit and improved technology have a much longer range of solutions than farm plans with traditional technology and credit limitations.

(5) The value of the expected profit varies not only with the level of risk, but with the type of technology and the level of credit used in each type of farm. Shown by the E-M efficiency frontiers presented in Chapter IV, for farmers with open credit, the introduction of technological change yields higher value of expected profit than for farmers with traditional technology for any level of risk. However, when credit is restricted to $5000.00 Colombian pesos, the introduction of the recommended technology brings about higher levels of expected profit at low levels of risk, but it produces the same level of profit as the traditional technology when the risk levels increase to medium and large values. One significant exception is the case of the corn-onion average type of farm in which traditional technology is superior in generating profit rather than the improved technology where farmers face limited credit and are willing to accept either a medium or a large risk level.

An interesting characteristic of the relationship between risk and expected profit is that the bigger profit increments are obtained by increasing risk from the minimum to relatively low values. After this range, additions to risk values increase expected profit at a decreasing rate. For farmers adopting the recommended technology and using all credit required by the solution, expected profit increments are obtained at the expense of large increments in the risk levels, after the low risk values have been reached.

(6) Minimum family nutritional requirements are satisfied in all solutions of the model. Measuring food consumption by total expenditure approximately 80% of that value corresponds to farm produced goods, and about 20% of the total expenditure is actually devoted to purchasing food items in the market for processed food goods. In all cases, less than 1% of total food expenditure corresponds to items that are bought but could have been produced on the farm.

(7) Further analysis permits us to establish that technological change introduced among the farmers of the Caqueza Project is capital biased.

Several conclusions can be derived from the results that have been summarized in these pages. Given the amount of information generated by solving the model and the considerable research reports on the Caqueza Project, conclusions could be extended to almost all aspects of the small farming economic activities taking place in the region. For the purpose of this study, only the data generated in this analysis will be considered in the statement of conclusions, most of which have already been mentioned in Chapters IV and V. For this reason, what follows is a succinct summary of conclusions derived in view of the objectives of this study.

1. Technological change as represented by the technical recommendation for corn and corn associated crops seems to be a key factor in substantially increasing family income after nutritional requirements are met. There are however, several factors that encourage questions as to the success of the technological change as far as the adoption by farmers is concerned. Working capital requirements, the willingness of farmers to become indebted and the remarkable increase in

risk for modest increments in expected profit are factors that could prevent farmers from adopting the recommended technology en masse.

2. The use of credit is a crucial element in increasing rural income via introduction of technological change. The results of the present analysis support the claim that if credit is restricted or farmers are reluctant to use it, as indicated by former research, the type of technology used in the farm production process has no effect on the level of income that could be expected to be obtained. If such is the case, farmers behave indifferently to the adoption of technical recommendations or will keep their traditional technological patterns. Under these circumstances, adoption of technological change is not a predictable behavior.

Farmers response to credit use in view of the present institutional arrangements for the IRD districts, is an area where further research is needed. The determination and the effects of farmers' perception of risk due to indebtedness should be clearly understood and incorporated into the programming tool, either by modifying the MOTAD model or by using another model allowing the incorporation of risk attached to the use of credit.

3. The effects of risk on farm plans are reflected not only on the adoption of the improved technology, but in the allocation of production resources on the farm, land, labor and working capital vary with the levels of risk that farmers must accept in order to obtain a given level of expected profit. Solutions of the model provide evidence that farm diversification is an immediate response to risk minimization and only with the relaxation of a minimum risk will the input demand for land and working capital expand and farm plans become more specialized.

Due to the fact that crop associations are superior in increasing expected profit as compared to single crops, the present results could be taken as a formulation of crop research priorities to technical teams and experiment station researchers working for small farms in Colombia. It is however, essential to concentrate all research efforts on generating improved technology suitable to peasant agriculture as opposed to concentrating resources in producing a capital biased technology which may have no impact on small farmers due to resource endowments, factor prices, and risk attitudes of the decision makers.

4. Although minimum family nutritional requirements can be met regardless of the technological pattern and limitations on credit, the policy goals contained in the national nutritional plan may be affected if small farmers do not substantially increase output entering the urban market. It is apparent that failure to adopt the recommended technology will have a strong effect on the expected supply increase. It is possible, on the other hand, that market conditions may develop such that urban groups with high price demand elasticity enter the basic staple food market to precipitate favorable prices for farmers resulting in a rapidly increasing farm supply. The analysis of farmers response to this type of market change goes beyond this study. It is left to future research to evaluate possible effects of positive skewed price distributions on the mode, the trade-off between risky prospects due to credit use and the possibility of obtaining higher output level at higher market prices, and what would be the supply response of other farming subsectors in Colombia if food demand actually increased in urban areas.

5. The model used in this analysis could also be used by ICA as an instrument of analysis for the entire production unit to permit the evaluation of technological change, and the formulation of farm plans in other areas with similar characteristics. This model is characterized by its simplicity, such that repeated applications should not present a major difficulty to technical teams in IRD districts. Notice is made nevertheless, of the possibility that the model does not capture all sources of variability that face lower income level farmers. This could be an important deficiency of the model if further research shows evidence and measurement instruments of variability sources other than deviation from the mean expected revenue. It must be kept in mind that the model used in this study is but one of the known approaches that deal with risk in production, and there exists much room for modifications and adaptations of these types of instruments to specific farming situations.

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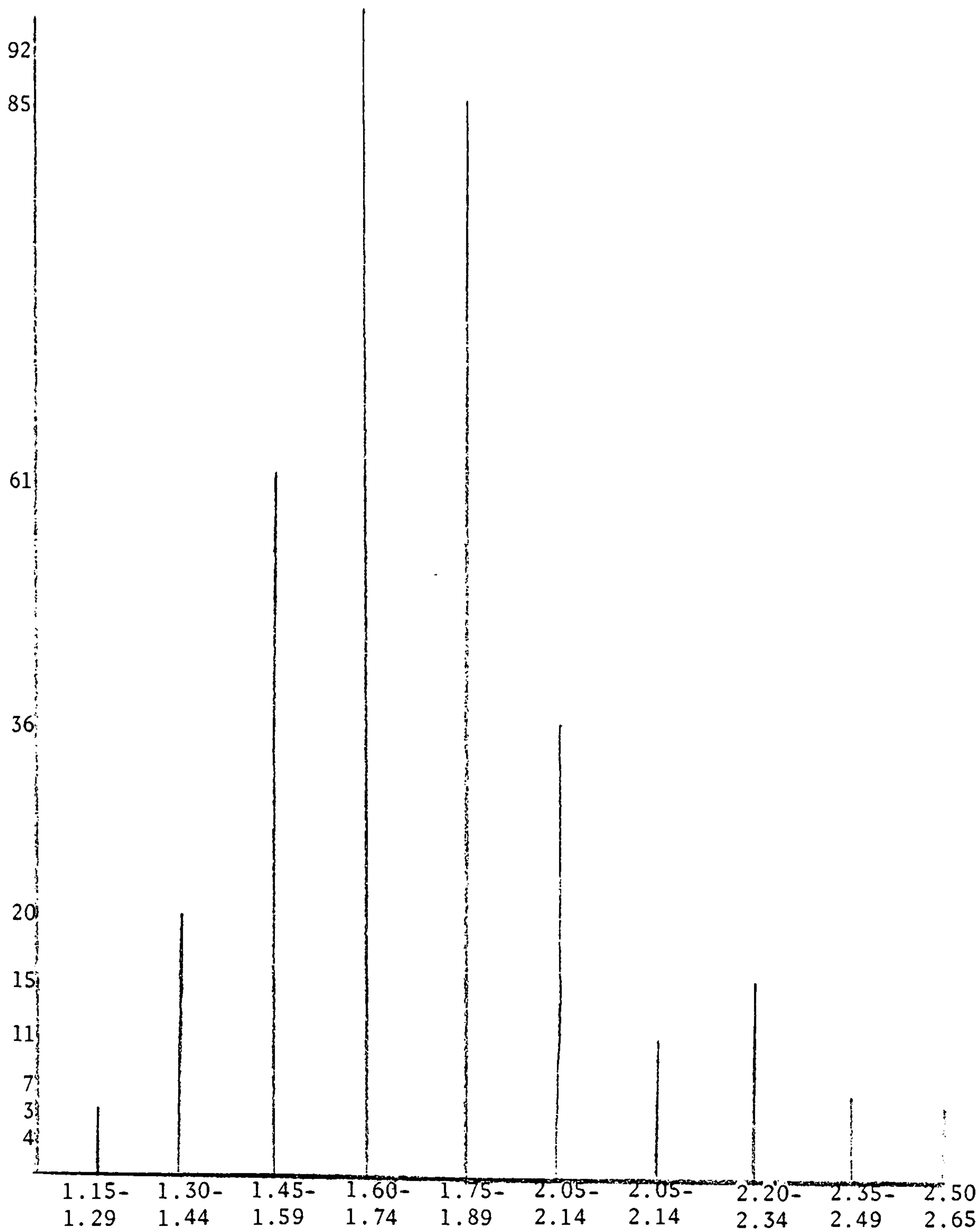
APPENDICES

Appendix A. In this appendix, a sample of prices and yield distributions is presented as an illustration.

Figure A.1. Approximated yellow corn price distribution. 1949-1975 monthly prices deflated by the Colombian food vector price index.



Prob.

.014	.060	.182	.274	.253	.108	.033	.045	.020	.011

Figure A.2. Approximated bean price distribution. 1949-1975 monthly prices deflated by the Colombian food sector price index.

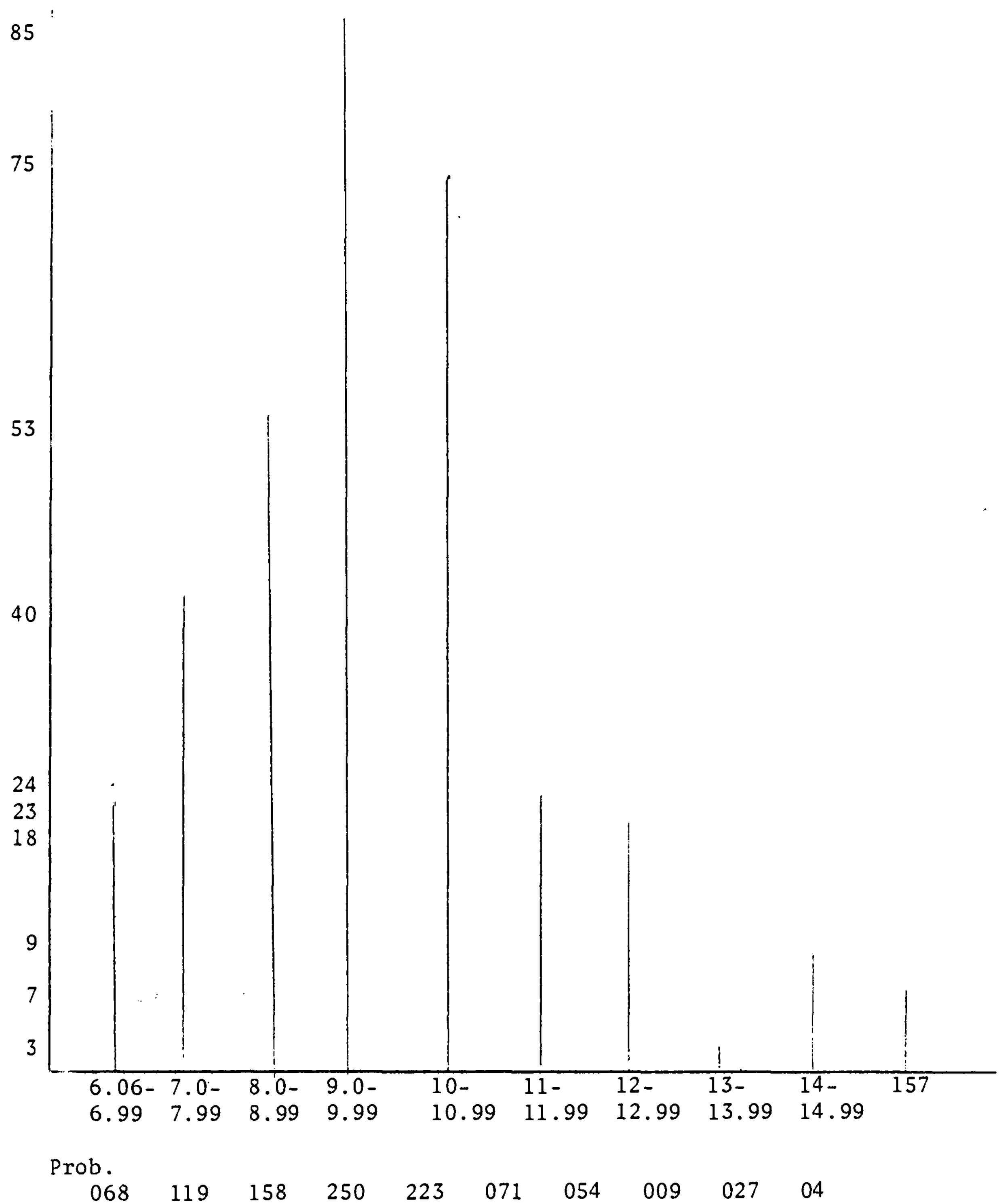


Figure A.3. Approximated potato price distribution. 1949-1975 monthly prices, deflated by the Colombian food sector price index.

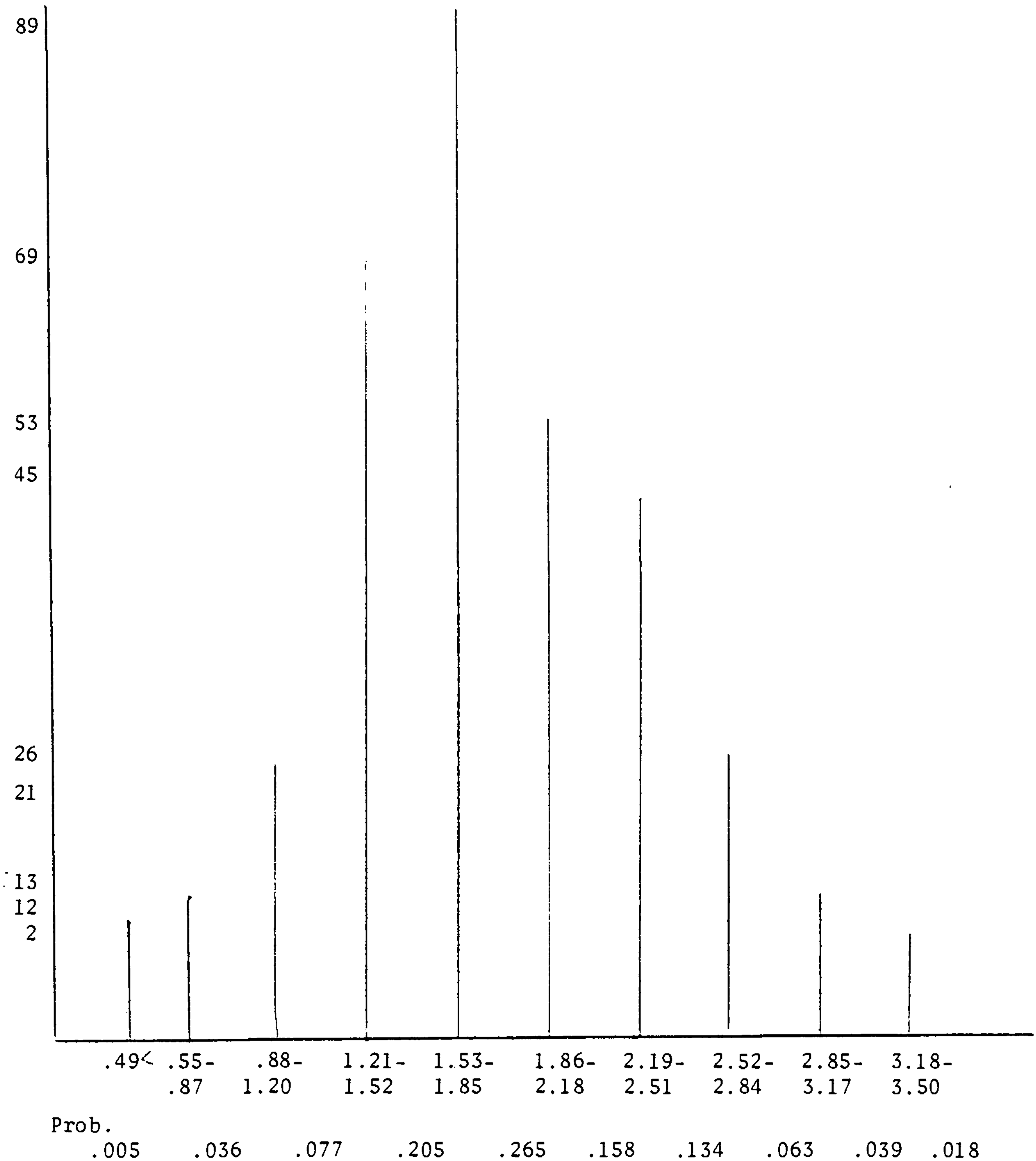


Figure A.4. Approximated improved corn yield distribution in association with beans.

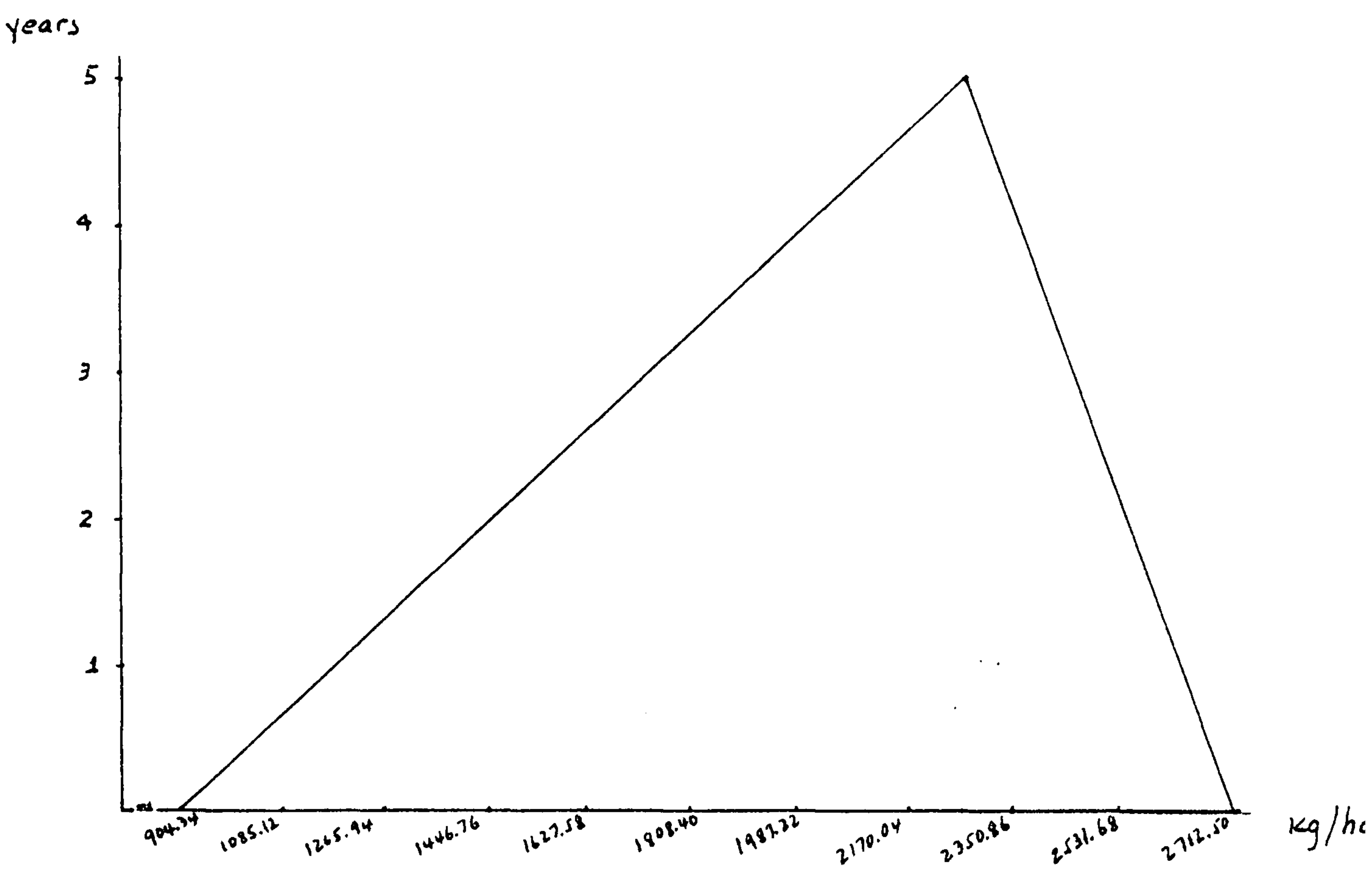


Figure A.5. Approximated bean yield distribution in association with improved corn.

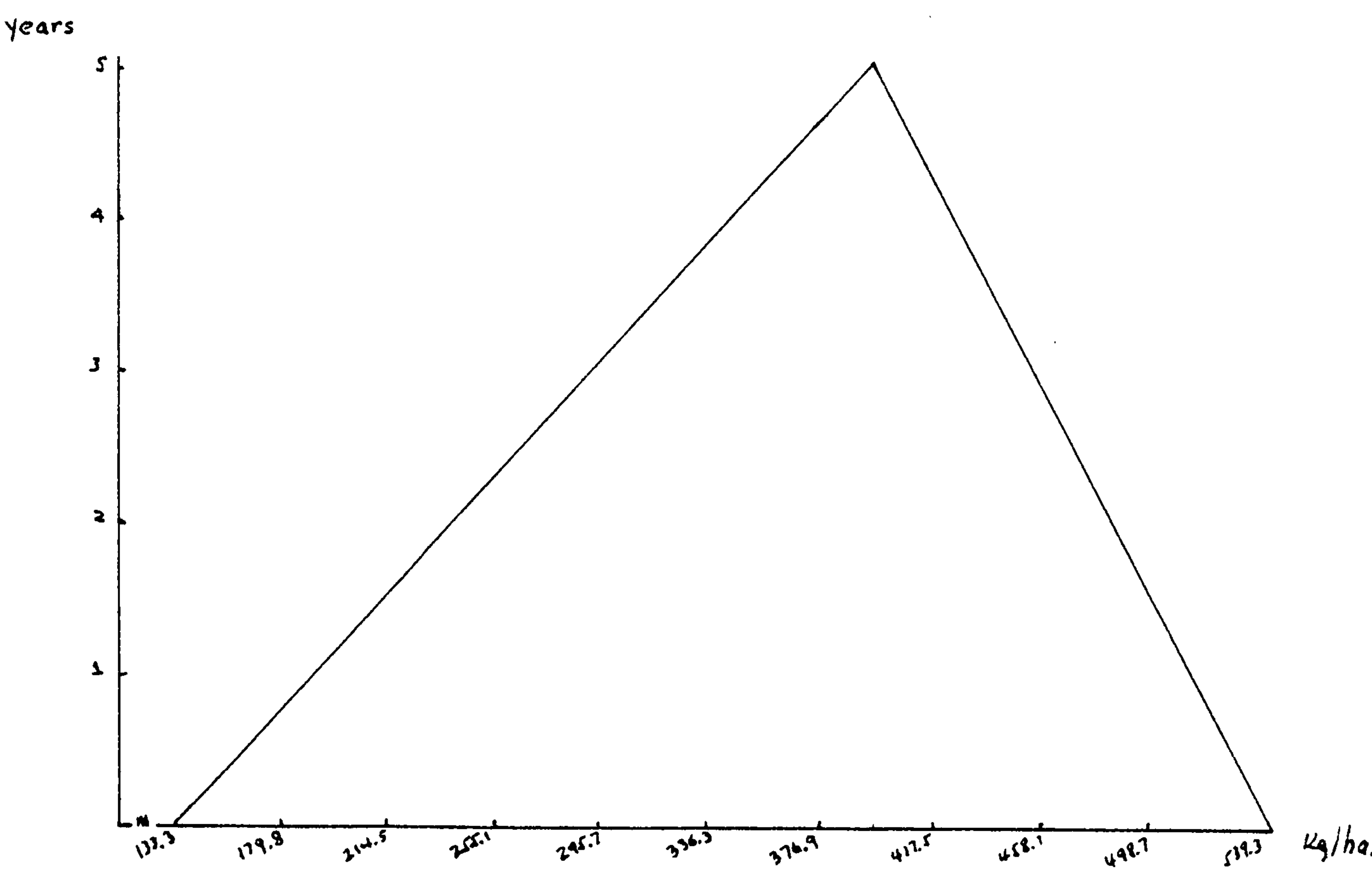


Figure A.6. Approximated traditional corn yield distribution in association with beans.

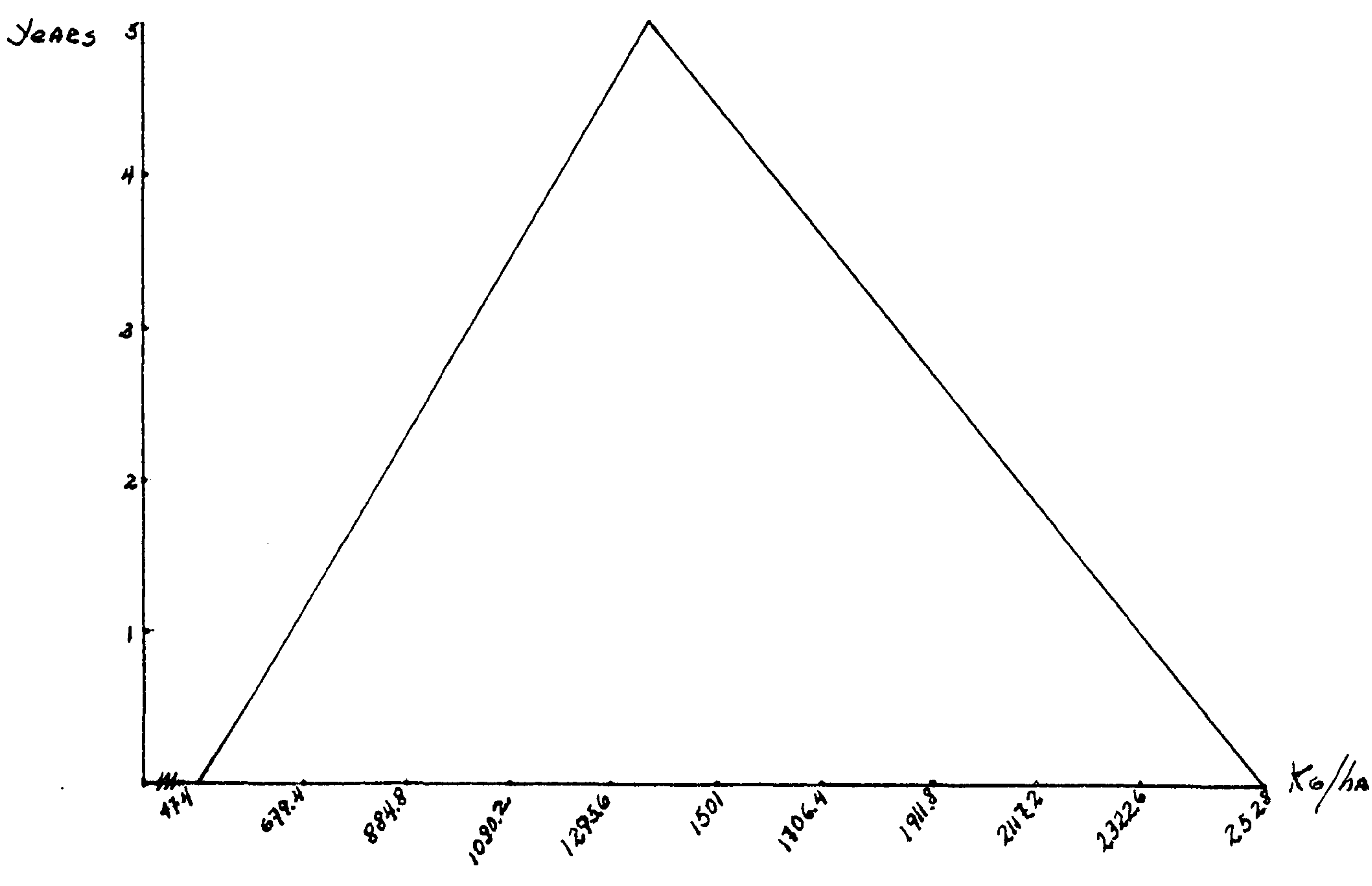
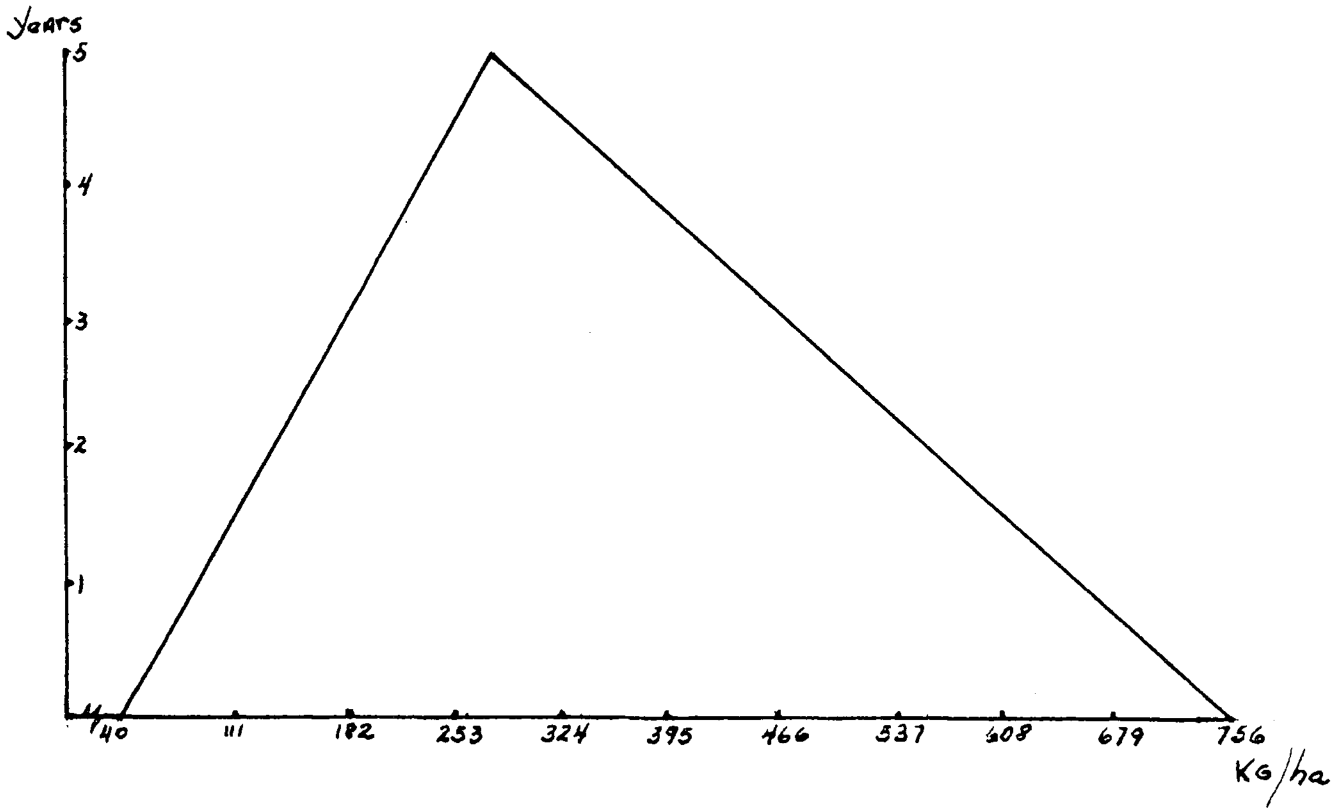


Figure A.7. Approximated bean yield distribution in association with traditional corn.



Appendix B. Complete results of the programming solutions are shown in this appendix for the corn-potato type of farm. Information presented in Tables B.1 and B.2 are complementary to the data provided in Chapters IV and V.

APPENDIX B.

Table B.1. Summary of results. Optimal solutions for the corn-potato type of farm. Traditional and improved technology. Limited credit to col. 5000.00.

	λ=2000	λ=5000	λ=7074	λ=2000	λ=5000	λ=7074
Variables	Improved technology			Traditional technology		
Seeds (Kgr):						
Trad. Corn	3.36	14.78	15.32	3.36	12.82	15.32
Improv. Corn	3.74	1.51	---	3.74	---	---
Beans	6.72	11.01	11.56	6.62	10.53	11.56
Peas	.34	---	---	.34	---	---
Potato	23.20	---	---	23.20	18.24	---
Ahuyama	.44	.93	1.04	.44	.88	1.04
Fertilizer (Kgr)	60.66	54.34	49.40	60.66	61.02	49.40
Urea (Kgr)	37.00	31.96	23.42	37.00	20.72	23.42
Pest Control ($)	201.33	60.83	23.28	201.33	106.31	23.28
Drugs ($):						
Cows	9.75	9.75	9.75	9.75	9.75	9.75
Hogs	23.44	20.53	22.23	23.44	21.04	22.23
Chicken	129.70	53.12	108.55	129.70	4.80	108.55
Supplements ($)						
Cows	9.66	9.66	9.66	9.66	9.66	9.66
Hogs	10.67	45.93	43.74	10.67	47.08	43.74
Chicken	68.82	27.50	56.34	68.82	9.24	56.34

Table B.1. (Continued)

Variables	$\lambda=2000$	$\lambda=5000$	$\lambda=7074$	$\lambda=2000$	$\lambda=5000$	$\lambda=7074$
	Improved technology			Traditional technology		
To the Market (Kgr):						
Improv. Corn	---	---	---	---	---	---
Trad. Corn	---	---	---	---	---	---
Beans	133.03	203.57	208.12	133.03	196.20	208.12
Peas	6.12	---	---	6.12	---	---
Potato	---	---	---	---	---	---
Cows (heads)	1.0	1.0	1.0	1.0	1.0	1.0
Calves (heads)	1.0	1.0	1.0	1.0	1.0	1.0
Hogs	448.24	950.73	1026.90	448.24	970.93	1026.90
Milk (bottles)	27.28	51.61	64.03	27.28	17.81	64.03
Cheese	392.85	315.01	275.24	392.85	423.17	275.24
Eggs (units)						
Chicken (heads)	23.00	---	---	23.00	---	---
Ahuyama	51.98	109.93	122.53	51.98	103.02	122.53
Home Consumption (Kgr):						
Eggs (units)	2064.00	1655.00	2711.06	2064.0	116.0	2711.06
Milk (bottles)	238.61	238.61	238.61	238.61	238.61	238.61
Cheese	75.00	75.00	75.00	75.00	75.00	75.00
Corn	768.83	883.17	768.83	768.83	720.06	768.83
Beans	19.08	19.07	19.08	19.08	19.08	19.08
Potato	161.08	---	---	161.08	126.67	---
Ahuyama	---	---	---	---	---	---

Table B.1. (Continued)

Variables	λ=2000	λ=5000	λ=7074	λ=2000	λ=5000	λ=7074
	Improved technology			Traditional technology		
Purchased for Consumption: (Kgr/year)						
Meat	29.70	29.70	29.70	29.70	29.70	29.70
Bread	50.37	50.37	50.37	50.37	50.37	50.37
Fruits	32.0	32.0	32.0	32.0	32.0	32.0
Coffee	12.34	12.34	12.34	12.34	12.34	12.34
Sugar	6.20	6.20	6.20	6.20	6.20	6.20
Brown Sugar	8.22	8.22	8.22	8.22	8.22	8.22
Cooking Oil (bottles)	35.0	35.0	35.0	35.0	35.0	35.0
Rice	97.90	31.88	31.88	97.90	297.02	31.88
Chocolate	7.68	7.68	7.68	7.68	7.68	7.68
Potato	39.79	200.88	200.88	---	74.20	200.88
Onion	14.0	14.0	14.0	14.0	14.0	14.0
Tomato	20.0	20.0	20.0	20.0	20.0	20.0
Corn	---	---	---	---	48.77	---

Table B.2. Summary of results. Optimal solutions for the corn-potato type of farm, improved and traditional technology, open credit.

Variables	λ=2000	λ=5000	λ=10000	λ=15000	λ=20000	λ=29404	λ=2000	λ=5000	λ=10000	λ=12
	Improved technology						Traditional technology			
Seeds (Kgr):										
Trad. Corn	6.50	11.80	9.20	9.20	6.80	---	6.0	11.56	21.36	25.20
Improv. Corn	3.77	8.77	16.63	16.47	19.30	26.19	---	---	---	---
Beans	7.23	15.11	17.45	19.98	20.28	18.35	5.43	10.53	20.31	24.49
Peas	1.28	2.63	---	---	---	---	6.02	---	---	---
Potato	26.17	43.35	28.92	18.89	---	---	13.77	19.29	28.92	28.92
Ahuyama	.48	.95	.87	.87	.64	---	.43	.87	1.85	2.27
Fertilizer (Kgr)	68.83	136.29	146.81	140.50	132.49	142.25	56.54	61.81	107.51	123.84
Urea (Kgr)	38.32	84.69	137.81	137.23	152.39	187.61	10.59	20.74	41.89	50.87
Pest Control ($)	237.45	550.76	467.77	364.01	299.72	388.50	202.24	111.07	173.67	181.49
Drugs ($)										
Cows	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66
Hogs	10.30	22.23	22.23	22.23	22.23	22.23	7.18	21.11	22.23	22.23
Chicken	144.50	144.50	144.50	144.50	144.50	144.50	144.50	144.50	144.50	144.50
Supplements ($)										
Cows	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75
Hogs	23.04	49.47	49.74	49.74	49.74	49.74	16.08	47.25	49.47	49.47
Chicken	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
To the Market (Kgr)										
Improv. Corn	---	222.23	817.17	802.84	1125.06	1906.21	---	---	---	---
Trad. Corn	---	743.34	591.94	595.68	439.65	---	---	---	575.25	841.65
Beans	139.66	318.19	390.11	461.07	490.70	499.26	93.42	196.23	677.21	454.50
Peas	23.04	47.53	---	---	---	---	108.66	---	---	---
Potato	---	100.20	---	---	---	---	---	---	---	---
Cows (heads)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Calves (heads)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Hog	477.45	1026.90	1026.90	1026.90	1026.90	1026.90	331.64	977.96	1026.90	1026.90
Milk (bottles)	28.66	44.54	71.70	74.87	73.19	79.65	41.42	34.69	35.28	76.24
Cheese	388.45	337.61	250.72	240.56	245.95	225.26	347.59	369.15	367.26	236.17

Table B.2. (Continued)

Variables	λ=2000	λ=5000	λ=10000	λ=15000	λ=20000	λ=29404	λ=2000	λ=5000	λ=10000	λ=12
	Improved technology						Traditional technology			
To the Market (Kgr) (Continued)										
Eggs (units)	---	405.00	4384.00	4384.00	4384.00	4384.00	---	---	367.26	236.17
Chicken (heads)	25.00	15.00	---	---	---	---	---	---	1401.49	1788.93
Ahuyama	56.78	111.43	102.02	102.66	75.77	---	51.64	103.07	218.38	267.59
Home Cunsumption (Kg/year)										
Eggs (units)	2250.00	2711.00	116.00	116.00	116.00	116.00	2250.00	2250.00	2711.00	2711.00
Milk (bottles)	238.61	238.61	238.61	238.61	238.61	238.61	238.61	238.61	238.61	238.61
Cheese	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00	75.00
Corn	809.79	768.83	1064.45	1064.45	1064.45	1064.45	374.90	720.07	768.84	768.84
Beans	19.08	19.08	19.08	19.08	19.08	19.08	19.08	19.08	19.08	19.08
Potato	181.75	200.88	200.88	131.20	---	---	95.62	133.97	200.88	200.88
Ahuyama	---	---	---	---	---	---	---	---	---	---
Purchased for Consumption (Kgr/year)										
Meat	29.70	29.70	29.70	29.70	29.70	29.70	29.70	29.70	29.70	29.70
Bread	50.37	50.37	50.37	50.37	50.37	50.37	50.37	50.37	50.37	50.37
Fruits	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00
Coffee	12.34	12.34	12.34	12.34	12.34	12.34	12.34	12.34	12.34	12.34
Sugar	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20	6.20
Brown Sugar	8.22	8.22	8.22	8.22	8.22	8.22	8.22	8.22	8.22	8.22
Cooking Oil (bottles)	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00	35.00
Rice	42.24	31.88	31.88	31.88	31.88	31.88	78.98	78.98	31.88	31.88
Chocolate	7.68	7.68	7.68	7.68	7.68	7.68	7.68	7.68	7.68	7.68
Potato	19.12	---	---	69.67	200.88	200.88	105.25	66.90	---	---
Onion	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Tomato	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Corn	---	---	---	---	---	---	393.93	48.65	---	---
Credit Used	5226.22	8005.62	8926.67	8735.29	8778.23	9480.31	4334.99	5418.49	6750.82	7061.20