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RISK-EFFICIENT FERTILIZER RATES: AN APPLICATION TO CORN PRODUCTION IN THE CERRADO REGION OF BRAZIL

By

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ABSTRACT

RISK-EFFICIENT FERTILIZER RATES: AN APPLICATION TO CORN PRODUCTION IN THE CERRADO REGION OF BRAZIL

By

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In agriculture, uncertainty permeates almost all types of decisions, a fact that greatly complicates the process by which choices are made.

This study develops a method that combines fertilization-response data with preferences of decision makers, to help research and extension workers improve their fertilizer-application recommendations. To prescribe preferred fertilizer practices tailored to the risk preferences of individual decision makers, this study adopted two objectives: (1) to estimate risk aversion coefficients for corn farmers in the Cerrado region of Brazil and to relate them to socio-economic variables, and (2) to measure how farmers' attitudes toward risk influence their adoption of alternative corn-production techniques.

To achieve the first objective, regression and discriminant analyses were employed to relate the measures of absolute risk-aversion coefficients, measured for 114 farmers in the Cerrado region, to selected socioeconomic variables, and to classify the farmers into different groups, based on their attitudes toward risk.

The results showed that there seems to be a strong relationship between risk attitudes and socioeconomic variables such as age, educational level, family size, size of farm, income, and sources of information, and that different tenure arrangements may reveal different attitudes toward risk. A significant percentage of the individuals studied displayed risk preferences at least for the situation analyzed.

To achieve the second objective, physical relationships, including the corn-response production function and the phosphorus carry-over function, were analyzed together with randomly generated weather patterns. A Monte Carlo program then was used to construct a large number of strategies that were evaluated by choice criterion stochastic dominance with respect to a function. This criterion provided sets of efficient choices for each class of decision makers.

Model results indicated that the introduction of farmers' preferences in the form of risk-aversion measures has an important influence on decision-making choices. Highly risk-averse farmers, for example, tend to make use of strategies that produce, in general, lower expected returns and lower probability of losses. This indicates that one should recommend strategies efficiently tailored to each class of decision makers.

To Dora, who, through her special love, has awakened within me a strong love for life.

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CHAPTER I

INTRODUCTION

Economic development requires an increase in agricultural productivity. Increased productivity is often associated with new technologies, as the green revolution demonstrated. But the generation of new agricultural technology is a complex process, as are its diffusion and adoption.[1] Because the new technology is often perceived as risky, small farmers are unwilling to switch to new methods of production when this means that they have to experiment with the very survival of their families. Wharton (1968), Schultz (1964), Mellor (1966), and Dillon and Anderson (1971), among others, supported the conclusion that risk discourages adoption of new practices.

The technological package needed for the achievement of higher crop yields includes inputs such as high-yielding varieties (seeds), improved water control, and the increased use of fertilizers. Although all inputs are related, fertilizer has been of particular importance in most developing and developed countries, as seen recently in Brazil.

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[1]The optimism about future world food supplies spurred by the green revolution during 1967-70 gave place to pessimism following relative food scarcity and high prices. Several factors went wrong with the green revolution, such as floods, droughts, diseases, etc., but the low rate of technology adoption by the farmers is a key element in that failure. (See Chapter I of Roumasset, 1976.)

The Importance of Fertilizer in Brazilian Agriculture

Most of Brazil's increase in agricultural production up to now occurred through the greater use of land and labor. Of the growth in output of 23 principal crops between 1948-50 and 1967-69, about 90 percent was due to expansion in area, and only 20 percent was attributed to yield increases, with a 12 percent decrease due to crop mix and changes in location. The main reason for this is that, if, on the one hand, modern imputs were very expansive in the last 20 years, the traditional imputs (land and labor), on the other hand, were relatively cheap because of both the high percentage of the country's manpower in the rural area (about 40 percent) and the abundance of agricultural lands.[2] As a consequence, the country's average yields have increased at a very slow rate, and most crop yields are below those obtained in other countries. (See Table 1.1.)

Until the 1950s, there was little chemical fertilizer use in Brazil. In the early 1960s, Brazilian farmers started expanding their use of chemical fertilizers. This increase in fertilizer use was a response to policy changes favoring its expansion. These policies included concessional import exchange rates and special subsidized credit. As a result, fertilizer use in Brazil increased 500 percent from 1960 to 1972. But fertilizer use in Brazil is still low when compared to the levels of other countries. (See Table 1.2.) One reason is that its use is limited to certain regions, in

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[2]More details can be found in Paiva et al. (1973) and Patrick (1975).

Table 1.1.--Production per unit of area and corresponding indices of 15 major Brazilian crops during different periods.

Products	Production in Kilos/Hectare				Indices (1947-49 = 100)		
	1947-49	1961-63	1964-66	1968-70	61-63	64-66	68-70
Cotton	442	554	482	490	125	109	111
Peanuts	1,004	1,347	1,286	1,286	134	128	128
Rice	1,552	1,634	1,536	1,464	105	99	94
Potatoes	4,779	5,758	6,294	7,098	120	132	149
Cacao	450	312	341	378	69	76	84
Coffee	411	415	771	811	101	188	197
Sugar cane	38,333	42,773	44,841	45,551	112	117	119
Onions	3,992	5,544	5,135	5,307	139	129	133
Beans	685	650	656	634	95	96	93
Oranges[a]	74,284	74,707	72,889	78,096	101	98	105
Castor beans	843	799	914	966	95	108	115
Manioc	13,347	13,404	14,120	14,662	100	106	110
Corn	1,256	1,311	1,283	1,365	104	102	109
Tomatoes	9,048	13,577	15,504	17,261	150	171	191
Wheat	789	658	833	945	83	106	120

Source: IBGE, Anuario Estastico do Brasil (various issues).

[a]In fruits per hectare.

Table 1.2.--Consumption of fertilizers per arable hectare in São Paulo, Brazil, and in other countries (in kg of nutrients).

Region	Year	Nitrogen	Phosphorus	Potassium	Total
United States	1964	23.83	17.99	14.57	54.51
Spain	1967	24.59	16.36	5.04	45.99
Italy	1967	31.53	30.53	11.73	73.79
Yugoslavia	1967	25.03	21.47	15.97	63.47
USSR	1967	12.76	7.01	8.83	28.60
Taiwan	1967	177.88	42.83	61.97	282.68
Israel	1967	68.89	28.66	15.38	112.97
New Zealand	1967	6.93	351.50	90.08	448.51
India	1965	3.33	0.83	0.55	4.71
France	1966	48.98	67.47	50.67	167.12
Chile	1965	7.33	13.98	2.88	24.19
Brazil[a]	1970	8.03	12.18	8.98	29.25
North	1970	2.60	0.32	2.72	5.65
Center	1970	11.38	13.52	11.52	34.42
South	1970	8.09	25.62	12.91	46.62
São Paulo	1970	22.72	27.07	23.04	72.85

Source: Syndicate of Fertilizer and Adhesives Industry, State of São Paulo, "Fertilizers: An Annual Review of World Production, Consumption, Trade and Prices" and "Production Yearbook," FAO. Cited in Ruy M. Paiva et al. (1973).

[a]Figures for Brazil refer to the relationship between consumption of fertilizers and planted area, excluding pasture lands.

particular, the center-south and the south regions, because their soil and climatic conditions are more favorable. In fact, fertilizer use in these more developed regions accounts for almost 90 percent of the total fertilizer use in Brazil.

Two major factors suggest that fertilizer use in Brazil's growing agricultural output will be even more important in the future. First, the high-yielding crop varieties now being introduced are more responsive to applications of fertilizers than varieties used in the past. Therefore, fertilizer use can greatly increase the output of the agricultural sector. Second, in some states the limit to expansion of the agricultural frontier has been reached. As a result, the role of fertilizer in Brazil's growing agricultural output is becoming evident. The new lands, besides the fact that they are located far from the consumer centers, are deficient in several plant nutrients.

Many studies under both laboratory and field conditions have shown that yields in these new areas and the rest of Brazil can be increased through the use of fertilizer.[3] Although fertilization rates have increased rapidly, the information available on crop response to fertilizer at the farm level in Brazil is still almost nonexistent. And no one can really say that actual farm-level use of fertilizer is under, above, or around optimum levels. There are well-developed tools to select the optimal fertilization rates when

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[3]See, for example, FAO/ABCAR/ANDA (1973).

the goal is to maximize profit. But farmers also consider risk, which is now widely recognized as an important factor in a farmer's decision process. What is needed is a procedure that can properly account for risk and select an efficient fertilizer rate for different groups of farmers classified by their risk attitudes as well as their desire to maximize profits.

In this study, the central concern is with the development of a method that could combine fertilization-response data with preferences of decision makers and could, consequently, help research and extension select more effectively new practices and make more efficient the adoption of them by the producers. Particularly, the writer intends to develop fertilizer recommendations properly tailored to corn farmers, taking into consideration their attitudes toward risk. The area to which this study is applied is the central region of Brazil: the Cerrado. This region probably constitutes the largest contiguous mass of undeveloped agricultural land in the world.

Statement of Problem

Economic studies of traditional production in Brazil have focused little attention on the problem of risk and uncertainty in the decision-making processes. It is well known that risk generally has a significant impact on the way resources should be allocated--a result that raises serious questions about the relevance of any theory of production that specifically ignores risk.[4]

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[4]For excellent examples that make this fact evident, see Anderson, Dillon, and Hardaker (1977).

Because of uncontrollable climatic events and other factors, the physical outcome of fertilization is stochastic. Hence, the economic returns from fertilization are also stochastic. This fact makes it important to evaluate the level of risk that farmers are willing to assume when investing in fertilizers.[5]

Only in the south, and more precisely in the state of São Paulo, has there been rapid adoption of modern agricultural technology, mainly fertilizers. A higher proportion of large farms than small farms use it.[6] This may suggest that larger and more educated farmers understand more quickly; i.e., the cost of new information is less for them. It is also likely, as Pratt (1964) and Arrow (1964) pointed out, that attitudes toward risk and one's willingness to bear risk are related to one's wealth.

Fertilizer trials are scarce in Brazil. The farmers, when deciding upon fertilizer doses, must depend on their own experience and on the recommendation of fertilizer dealers. Moreover, in the absence of fertilizer-response data, the intensity of fertilizer use responds slowly to changes in factor and product prices, partly because changing fertilization rates, without adequate economic data, may be viewed as too risky. In such a situation, fertilizer use is largely a question of adopting fertilizer as a part of a production package rather than adjusting intensity of usage.[7]

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[5]See, for example, de Janvry (1972).

[6]See, for example, Adams et al. (1975).

[7]Ibid.

Research Objectives

The objectives of this study are:

1. To estimate risk-aversion coefficients for corn farmers in the Cerrado region of Brazil and to relate them to socioeconomic variables. The objective is to derive attitudes toward risk among farmers from interview results and then to relate this behavior toward risk to a set of socioeconomic and structural variables that characterize these farmers.

2. To measure how farmers' attitudes toward risk influence their adoption of alternative corn-production techniques. In this second phase, the impact of different degrees of risk aversion on optimal fertilizer rates will be examined; that is, this research will identify optimal levels of fertilizer application for different classes of decision makers categorized by their attitudes toward risk.

Using the method to be developed in this study, we can evaluate the effects of programs and policies such as price supports and concessional interest rates on credit, and which groups of farmers are likely to respond; that is, how these policies affect the efficient levels of fertilizer application when one is considering different categories of farmers based on their attitudes toward risk.

If it is verified that risk coefficients are related to some socioeconomic variables, the great contribution of the approach

developed in this research will be in the fact that: (1) one can identify sets of farmers based on a set of socioeconomic and structural variables that characterize them; (2) lower and upper bounds of the risk coefficients can be determined using direct approaches for representative farmers; and (3) the recently developed stochastic selection criteria can be applied to derive the optimum choice for each set of farmers. In summary, knowledge of the determinants of attitudes toward risk will be useful for the purpose of predicting the technologies best suited to particular categories of farmers.

Focus of This Study

The regional setting for this study, the Cerrado, occupies almost one-quarter of the area of Brazil. Despite its vast area, the Cerrado contributes little to the economy of the country at the present time, yet it has a tremendous potential for agricultural production, especially if proper fertilizer technology is used. It is believed that the results obtained from this study based on fertilizer experiments and survey data of a specific area can be generalized to a great portion of the Cerrado because of the similarities in soils and climate conditions in most of the region.

The commodity selected for this study is corn. This product has high significance in the agricultural sector of Brazil because it is planted on more hectares of land than any other crop. The center-south region of the country is responsible for 87 percent of the total produced.[8] Although Brazil is the third largest corn

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[8]The principal producing states are Minas Gerais, São Paulo, Rio Grande do Sul, and, more recently, Paraná.

producer of the world,[9] its average yield per hectare, at about 1.5 MT, is almost one-fourth the U.S. yield, due mainly to the low level of technology employed. There appears to be a great potential for increasing corn production in Brazil through technological improvement mainly in the form of fertilization and higher-yielding varieties.[10] Because of this potential, corn is one of the products that has been given special attention recently. During 1978, 38 researchers of the EMBRAPA[11] system conducted 103 research subprojects and 718 experiments with corn, several of them especially oriented to the adaptation process to soil and climate characteristics of the Cerrado.

This study will combine data from an experiment carried out on the CPAC[12] station with results from a survey conducted in the county of Unai, located about 100 km from the experimental area.

The major objective of this study is the provision of an efficient tool to help agricultural researchers select the set of best alternatives to continue experimenting with and/or making recommendations to farmers. One example of this application is in the selection of new crop varieties from nursery trials conducted sometimes

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[9]Behind the U.S.A. and the People's Republic of China.

[10]See Thompson and Garcia (1978).

[11]Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) is an agency whose responsibility is to establish and maintain agricultural research activities throughout the country in accordance with the policies of the federal government.

[12]Centro do Pesquisa Agropecuaria do Cerrados (CPAC) is one of the EMBRAPA's regional research centers. The CPAC center concentrates efforts on the major problems of the Cerrado region.

in different regions. The EMBRAPA system, through its 16 national research centers and other centers, conducts annually thousands of experiments including selection of varieties, control of insect pests, the development of new technologies based on more intensive use of fertilizers, new seed varieties, and irrigation, among others. Unfortunately, in most cases, only statistical tools such as comparisons of mean yields are used to try to identify the optimum alternative. It is believed that the procedure developed in this study will be useful in the interpretation of agricultural research because it allows the consideration of attitudes of farmers toward risk.

Organization of the Study

Several studies dealing with subjects of risk are reviewed in Chapter II. The review is divided into two parts, one showing evidence that risk influences farmers' decisions and the other focusing on studies related to the selection of optimal rates of fertilizer use.

The data to be used in this dissertation, more precisely the experimental and sample data, are described in Chapter III. The decision model used in this analysis is explained in detail in Chapter IV. The presentation and analysis of the results are discussed in Chapter V. Chapter VI includes the summary, conclusions, and recommendations for further research.

CHAPTER II

LITERATURE REVIEW

This chapter reviews research related to the present study. The first part of the review is of evidence that farmers make decisions according to the expected utility hypothesis (EUH). The second part is of studies dealing with the problem of optimal use of fertilizer.

Risk and Decision Making

Although the Bernoullian decision theory is more extensively discussed in Chapter IV, a brief introduction to it is necessary here. This theory is based on an individual's utility function, from which utilities or index numbers can be associated with each of the different outcomes of a risky prospect. These utilities, weighted by the probability of occurrence of the corresponding outcome, are summed for each risk prospect, producing the expected utility of that prospect. When an individual is offered a set of alternatives, the preferred alternative maximizes expected utility. Several researchers believe that risk attitudes of farmers are reflected in their utility functions and that decisions are made according to the expected utility hypothesis. Among these researchers, Officer and Halter (1968), in their study of Australian wool producers, concluded that

Bernoullian utility maximization explains actual farmer behavior more accurately than it does profit maximization (cost minimization).

Dillon and Anderson (1971) also showed that farmers consider risk when making their decisions. In addition to the data analyzed, the authors cited two other studies, one in Chile and the other in Australia, in which most of the farmers interviewed had nonlinear utility functions. The authors concluded that those farmers were not indifferent to risk. The study by Lin et al. (1974) supported this conclusion. Analyzing six large California farms, the authors developed after-income-tax expectation-variance boundaries (E-V) for each farm and determined utility and profit-maximizing crop plans for each. Using a goodness-of-fit criterion, they showed that models that take risk into account, that is, Bernoullian and lexicographic utility, are more accurate predictors of farmer behavior than is profit maximization.

Although Mellor (1977) did not argue explicitly with the expected utility hypothesis, he said that low-income farmers tend to avoid risk, i.e., avoid actions with a possibility of variation in results. Hence, risk affects the distribution of benefits and the adoption of innovation. For example, Mellor, citing Schuter's work, showed clearly that lower-income farmers in the Surat District of India prefer lower profit and less labor-intensive but more certain enterprises. These farmers tend to choose cropping patterns with a smaller deviation in income.

Dillon and Scandizzo (1978), in an empirical study of peasant risk attitudes in Northeast Brazil, concluded that:

> First, most but not all peasants are risk averse; second, risk aversion tends to be more common and perhaps greater among small owners than among share croppers; third, in a expected utility context, the distribution of peasant risk attitudes is diverse and not necessarily well represented by an average population value; fourth, level of income and perhaps other socio-economic variables influence peasant's attitude to risk (p. 434).

This study concluded that risk should be considered in any agricultural decision-making model.

Now, we turn to the problem of determining optimum rates of fertilizer use, taking risk into consideration.

The Selection of Optimal Rates of Fertilizer Use

Two approaches can be defined that include risk in productive processes. Anderson, Dillon, and Hardaker (1977) called these approaches analytical and gross. In the analytical model, the emphasis is on valuation of information rather than on resource allocation; and, in the gross approach, the opposite is true.

The Analytical Approach

In the analytical model, the advantage is that valuation of added information may be possible. According to Anderson, Dillon, and Hardaker (1977), the analytical approach to risk specification of the production process can be thought of as a two-step procedure; i.e., first the production or response function is measured, and, second, the joint probability function associated with the stochastic variables is estimated. Because there are so many stochastic variables influencing the agricultural production processes, this approach is difficult. Despite this, several studies attempted to follow this line.

Byerlee and Anderson (1969) developed a method for evaluating information in a response process that involves interaction between controlled and uncontrolled factors. Using data from the South Australian wheat belt, they determined the empirical relationship for wheat response to nitrogen and growing-season rainfall. The authors illustrated the method through an analysis of the value of a rainfall predictor in determining optimal applications of nitrogen to wheat. Their study defined the conditions under which the predictor is most valuable and suggested types of predictors that may be of greater value.

In a similar approach, Tollini (1969) studied the response of corn to nitrogen in North Carolina. The central objective of his study was to analyze some possible explanations for high rates of return to fertilizer; that is, Tollini tried to find some theoretical reasons for the actual use of fertilizers to be lower than the level considered optimal. Considering weather as a source of uncertainty, Tollini thought this variable could be used to approximate the risk model since one has some accumulated knowledge about the distribution of weather over the years.[1] A comparison was made of three decision rules, assuming a given weather distribution: (1) maximizing expected net revenue; (2) minimizing maximum regret; and (3) maximizing utility, which is assumed to be a function of the mean and the variance of net revenue. To analyze the effect of weather uncertainty, an experimental production function relating corn yield to

[1]Another study similar to this one is by Fonseca (1976).

nitrogen inputs and to an index of moisture deficiency was used. The author concluded that corn producers in North Carolina were correct in their use of nitrogen. Tollini found that weather uncertainty leads farmers to be conservative in their use of fertilizers because crop responses to fertilizers depend on weather conditions. Hence, farmers use conservative decision rules as a sort of insurance against adverse weather. The most probable explanation is that farmers may be maximizing expected utility, which can be approximated with a function which has variance of net income as its argument. The crop-yield variability and, therefore, net-revenue variability increase with the level of fertilizer applied because of the existence of a negative interaction between nitrogen and soil moisture deficiencies. Tollini concluded that this fact could explain about 70 percent of the gap between optimal and actual use of nitrogen.

One study that contributed to this analytical approach was by de Janvry (1972). Using corn and wheat fertilizer response data from the Argentina Pampa, the author developed a method to assess the production conditions under which uses of fertilizers are economical. Because economic returns from fertilization are stochastic, de Janvry concluded that it is important to assess, as precisely as possible, the level of risk that farmers assume when they invest in fertilizer, especially in less-developed countries. He defined the risk of fertilizer use as the probability that the internal rate of return to fertilizer is less than or equal to zero. The method developed involved obtaining the frequency distribution of the internal rates of return that can be obtained under several possibilities of investing in fertilizers. Of particular interest is what de Janvry called the "fertilization possibility frontier," which describes the set of relative nitrogen prices and soil fertility combinations for which fertilizer costs are just covered at the specified level of risk aversion. Below this curve, profits are positive, and above it they are negative. The risk-aversion level is an arbitrary measure that "corresponds to a statement about a probability level that characterizes the chances with which an individual wants to cover at least the cost of fertilizer use in any particular year" (p. 4). Under alternative price policies, this study permitted estimates of economic returns from fertilization.

Another work similar to de Janvry's is that of Teixeira Filho (1974), in which the basic data deal with corn production in the Brazilian Northeast in the semiarid region of the State of Pernambuco. The basic difference between these two studies is the relationship assumed between rainfall and fertilizer response. De Janvry used amounts of rain with an exponent equal to the regression coefficient. Teixeira Filho's analysis included rainfall as one of the variables used in the production-response function. The argument used for this modification is that rainfall distribution and not total rainfall is the important variable. With soils of average acidity and with rainfall that can be expected 75 percent of the time, the author concluded that any farmer, in the region studied, can be sure to obtain a 30 or 40 percent return on the application of fertilizer. Within the price variations analyzed, the most favorable

return one could expect from reductions in fertilizer prices is about 65 percent.

The major problem with the above studies is that all sources of uncertainty are confined to a single factor. Tollini (1969), for example, used a single moisture index as a combination of several weather variables. The same occurred in other studies. It is also possible to miss an important variable in the model. These and other problems may contribute to the underestimation of the importance of risk in the production process.

The Gross Approach

One alternative to the analytical model is what Anderson, Dillon, and Hardaker (1977, pp. 174-75) classified as the gross approach. In this case, the emphasis is on resource allocation instead of on valuation of information. All the variation is compounded, and the effect of individual sources is not identified. The composite probability distribution is quantified and functionally related to the decision variables. One of the first attempts to use this approach was by Colyer (1969). Using data from a time series of experimental data, he quantified the mean and variance of product fertilizer response.

Moscardi and de Janvry (1977), assuming that the safety-first model holds,[2] presented an economic approach in which the

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[2]According to the safety-first rule, "an important motivating force of the decision maker in managing the productive resources that he controls and, in particular, in choosing among technological options is the security of generating returns large enough to cover subsistence needs" (Moscardi & de Janvry, 1977, p. 710).

degree of risk aversion manifested by peasants in Puebla, Mexico, can be derived from observed behavior. This method derived a risk-aversion measure for each farmer from knowledge of the production function, the coefficient of variation of yield, product and factor prices, and observed levels of factor use. This indirect approach is easier to implement empirically than the direct approach (the elicitation of preference or utility function), but it has the great inconvenience that risk aversion is measured as a residual from a behavioral equation; i.e., it is based on the difference between optimal (risk neutral) and actual factor use. As the authors noted, the data have to be screened carefully to eliminate discrepancies between optimal and actual resource allocation that are not due to risk in production, which seems to be difficult in practice. Another criticism lies in the fact that, even though nitrogen is the most important input for increasing yields in the analyzed area and is also the largest component of variable costs, all the emphasis is put on its marginal productivity, derived from farm experiments, in order to calculate the risk-aversion coefficient for each farm household. The authors concluded that risk aversion is indeed responsible for substantial differences between the demand for fertilizer without risk and actual demand. Risk premiums are high, discouraging the use of high rates of fertilizer under safety-first behavior.

Studying decision making among low-income Philippino rice farmers, Roumasset (1976) investigated the problem of estimating expected profits and the risk of using nitrogen fertilizer for purposes of making fertilizer recommendations and explaining farmer

decisions. He developed a new method in which production functions, based on experimental plot data, are combined with cross-section data on crop damages at the field level. The criterion used was the safety-first principle, which implies a lexicographic ordering of preferences. The model includes de Janvry's definition of risk as the probability that the internal rate of return to fertilizer is less than or equal to zero. For the situation and locations studied, it appeared to the author that using the amount of nitrogen fertilizer that maximizes expected profits does not substantially increase the risk above low nitrogen levels. Roumasset concluded that "risk aversion does not play a significant role for the situations studied." It could be that the farmers were in fact risk neutral, but Roumasset's tests were insufficient to certify this conclusion.

A significant contribution to the approach of setting up risky decisions on resource use in the context of utility maximization was given by Anderson, Dillon, and Hardaker (1977, pp. 160-83). Considering the classical production function in a unidimensional utility context, the authors derived some economic implications of production risk: "If a producer is risk averse, risk acts as friction to production and induces a lower level of resource use than would otherwise prevail; if a producer prefers risk, the reverse occurs." The authors made use of a one-factor, one-product case of expected utility maximization (or Bernoulli's principle) with uncertain product price and uncertain yield response to exemplify how the optimal level of factor use is less than the value of the marginal expected product of the factor. They illustrated the model empirically

with a maize-nitrogen example of a farmer whose relevant risk preferences for profits are approximately encoded in a quadratic utility function. The term REDQ (risk evaluation differential equation), which is the negative of the marginal rate of utility substitution between the expectation and the variance of profit, is inserted in the model in order to show how risk affects the optimal factor and output levels. The authors extended the model to explain how several decision variables can be introduced in the analysis and, also, how alternative utility functions can be used.

The model described above requires knowledge of the farmers' utility for income and their subjective probability distribution functions. Nothing was said, however, about eliciting farmers' subjective probabilities and encoding their preferences in utility functions. This is a difficult task, mainly when the sample is large.

Discussing the difficulties related to eliciting data to construct utility functions, Roumasset (1976) commented:

> Since analysts and consultants face resource limitations in conceptualizing, programming, and solving problems, it may be, for example, that it is not rational from the analyst's point of view to follow an expensive procedure for estimating utility functions for each farmer in order to generate recommendations for farm inputs (p. 27).

Not only the difficulties and costs related to obtaining the utility function are taken into consideration but also the methods used. Moscardi and de Janvry (1977), for example, stated that in these methods

> the subject is asked to make decisions in reaction to a large number of randomly arranged hypothetical bets and insurance schemes. This approach has serious difficulties resulting from the fact that subjects have different degrees of utility or disutility for gambling (the very method used to reveal their preferences) and that the concepts of probability are by no means intuitively obvious (p. 710).

Thus, one can see that, for several reasons, adequate elicited preferences are difficult to obtain. Given the above difficulties, the ideal would be an approach that allows for the consideration of risk and does not require the direct estimation of a farmer's utility function.

The solution for the above problem is the criterion called stochastic dominance, presented in two independent works by Hadar and Russell (1969) and Hanock and Levy (1969). These authors developed an approach in which the large number of risky prospects could be reduced without knowledge of the expected value for each investment alternative. The only thing needed is the probability distribution of outcomes for each investment strategy. The great advantage of this criterion is that it is consistent with the expected utility hypothesis; that is, the advantage is in its general and simple presuppositions about the algebraic form of the farmers' utility functions.[3]

There are several works[4] dealing with the determination of optimal fertilization rates in which the model used is based on the principle of stochastic dominance. Here we review the work by

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[3]Stochastic dominance is discussed further in Chapter IV.

[4]See also Moutinho (1977), Teixeira Vieira (1977), and Garcia and Cruz (1978).

Anderson (1974a), perhaps the most complete of them. In his study, one can find several examples of crop-fertilizer problems. The great advantage of the approach used is that one can filter out inefficient technological packages with no specific assumptions about the algebraic form of farmers' preference functions. This approach, for ordering uncertain action choices, is claimed to be superior to the methods based only on moments, notably, the mean and variance method. Anderson explained that his interest in stochastic dominance (of first, second, and third degrees) was "to explore how far one can go in risk planning" in the absence of utility functions. Anderson believed that stochastic dominance is useful because it permits "orderings of risky prospects that are as complete as is theoretically possible without knowing more (and much more) about the attitudes to risk of millions of farmers than will ever be possible" (p. 179).

Despite all the benefits presented by this study, there are some criticisms. Anderson made use of several estimation procedures, and, if one adds the measurement error to the possible errors in the various steps of estimation, this could lead to doubtful results. In one of the cases analyzed, 36 probability distributions of irrigated wheat yield, estimated for each design point of a 6 x 6 complete factorial, were used and not the original data. Because Anderson worked with sparse data, he had to use a smoothing procedure. In order to locate more precisely "bounds on efficient levels of fertilizer rates," he decided to interpolate among the data. He did this interpolation in two steps: relating sufficient parameters of the estimated distributions to the decision variables and "fitting

[interpolated] distributions by use of the parameters predicted for any specified combinations of fertilizer nutrients." This procedure allows an analysis of levels of the continuous variable, amounts of nitrogen and phosphorus in this case, other than the original observations.

Two points should be observed here. First, the author's intention of making the discrete[5] stochastic dominance approach to approximate, as much as possible, a continuous process should be viewed with care because of the risk involved in the estimation procedures, mainly when interactions among the analyzed factors can be present. This indicates the emphasis that researchers must place on making the range of observations (combinations of amount of fertilizers in this case) as wide as possible. Second, the only advantage in fitting distributions to the response data is in making the approach simpler; that is, only few parameters are necessary to conduct the analysis. However, as Anderson, himself, showed, the efficient sets are very sensitive to the location of the lower tails of the fitted distributions. It is even possible that the several distributions of a particular problem do not belong to the same family.

The great disadvantage in employing the stochastic-dominance theory lies in the fact that all farmers, with no exceptions, are considered risk averse. In Roumasset's (1976) opinion, this approach in a wide range of cases

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[5]Pairwise comparison of cumulative probability is involved here.

> only allows us to rule out techniques which are more risk intensive than the risk neutral solution. . . . Thus stochastic dominance theory is typically not sufficiently discriminating to facilitate predictions or recommendations about the optimal technique (p. 154).

Even if the stochastic-efficiency criterion is one of the most suitable tools one can have in practice to deal with risky decisions, this does not mean one will have good results. If the set of efficient outcomes has a wide range, this means the predictions or recommendations will be widespread, inappropriate, and not effective. The best one can do is to advise the use of the same set of efficient techniques to all groups of farmers, independent of the degree of risk aversion each one has. It is necessarily an approach in which risk attitudes of different groups of farmers can be taken into consideration; then advice according to the characteristics of individual groups can be given. This is what we intend to do in this research, utilizing the recent and useful developments in stochastic-dominance theory.

This new and promising method was developed by Meyer (1977a). He suggested a new efficiency criterion called stochastic dominance with respect to a function. This method allows the identification of a class of decision makers whose risk-aversion measures lie between some upper and lower bounds. Robison and King (1978) demonstrated the power and usefulness of this approach as the evaluative criterion in a Monte Carlo procedure. These studies, and others more directly related to this dissertation, are discussed in Chapter IV with the presentation of the decision model.

Chapter III presents descriptive information about the area and data used for the present study.

CHAPTER III

DATA DESCRIPTION

This chapter presents a descriptive background of the Cerrado region of Brazil. This descriptive background includes a discussion of: (1) the agricultural production potential of this vast area, together with the economic policy needed to support this agriculture; (2) a description of the experimental area in which experiments were conducted on the response of corn to fertilizer; and (3) a general description of the farms sampled.

Background

In order to guarantee increasing internal demand and to have a growing surplus of agricultural products for export, the agricultural sector of Brazil must use more intensively yield-increasing technology and an expanded cultivated area. One vast and available region is the Amazon; but, according to several authors, it is too early to start to explore that area because very little is known about it. Therefore, years of research will be necessary before that immense area is incorporated into the agricultural production process. The alternative is, doubtless, Brazil's Central Plateau (Cerrado), covering almost one-quarter of the area of the country. The Cerrado[1] occupies

[1]The savannah vegetation of the Cerrado has its own characteristics. In Portuguese, "cerrado" means "closed" or "enclosed." The vegetation is enclosed in the sense that tortuous trees and low

approximately 180 million hectares, and it is located mainly in the states of Minas Gerais, Mato Grosso,[2] and Goiás. (See Table 3.1 and Figure 3.1.)

Table 3.1.--Distribution of Cerrado region in Brazil.

State or Territory	Cerrado Area (in millions of hectares)	Percentage of Area of State	Percentage of Brazil
Goiás	55.5	88	30
Mato Grosso	47.9	39	26
Minas Gerais	30.8	53	17
Piaui	11.5	46	6
Bahia	10.5	19	6
Maranhão	9.8	30	5
Roraima	4.4	19	2
São Paulo	4.1	17	2
Pará	3.9	3	2
Amazonas	2.0	1	1
Amapá	1.9	14	1
Federal District	.6	100	1
Others	..	..	1
Total	182.9	..	100

Source: Mario G. Ferri, IV Simpósio Sobre o Cerrado--Bases Para a Utilização Agropecuária, Brasília, 1976.

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shrubs of varying densities cover the grassland. Detailed information on this vegetation is found in Eiten (1972).

[2]In 1978, the state of Mato Grosso was subdivided into two new states: Mato Grosso do Sul and Mato Grosso do Norte.

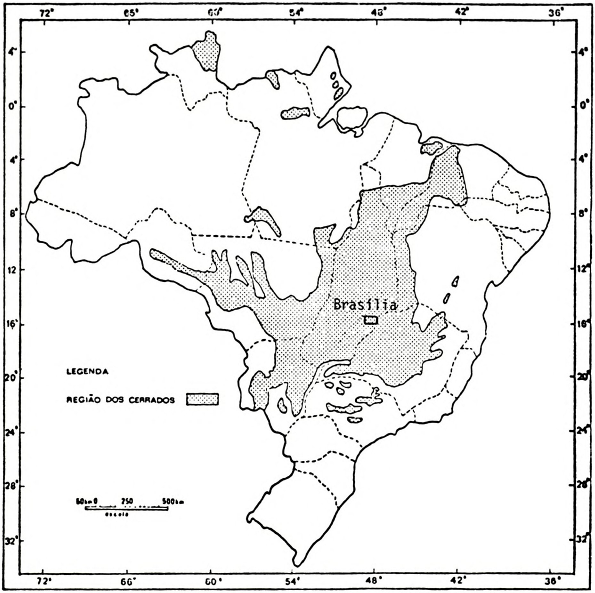

Figure 3.1.--Distribution of the Cerrado region of Brazil, including the transition areas.

Source: CPAC, 1976-77.

It is an accepted hypothesis that one-third of the Cerrado area, i.e., 55 million hectares, can be transformed into cultivated land. Should this occur, the current cultivated area in Brazil, i.e., 34 million hectares, would increase by 162 percent. It is also assumed that 15 percent of the total area of the Cerrado, or 27.5 million hectares, does not have economic use, and the remainder, 100.5 million hectares, can be used only for pasture and forestry (see Silva, 1978).

The Cerrado, in contrast to the Amazon region, is an area that has been studied for several decades, primarily in work dealing with its ecology (see Ferri, 1976). It was in the last decade, however, that the agricultural aspects of the Cerrado, spurred by increasing global food demands, were studied more intensively with an aim to utilizing fully its agricultural potential. Its enormous potential for agricultural production led the Brazilian government in 1976 to establish the Cerrado Agricultural Research Center (CPAC), which became part of the earlier established Brazilian Corporation for Agriculture Research (EMBRAPA). The purpose of CPAC is to explore specifically the agricultural problems of the Cerrado region.

The Center's research program is composed of three projects: (1) the Inventory Project, which determines the Cerrado's natural resources and its potential for agriculture; (2) the Natural Resources Utilization Project, in which problems of low soil fertility and water shortage are studied; and (3) the Farming System Development Project, which tests improved farming systems compared to traditional ones (see CPAC Reports, 1976-78).

The evolution of the CPAC Center can be demonstrated by the following indicators:

Indicators	January 1976	January 1979
Number of researchers	33	99
Center area (Ha)	1,400	2,140
Experimental area (Ha)	720	1,700
Budget (million cruzeiros)	29	150

Several national centers, state research systems, and universities collaborate with CPAC in order to develop, adjust, and disseminate technologies that will make the agriculture of the Cerrado efficient and productive.

Innumerable aspects of the Cerrado related to agriculture need to be more thoroughly studied. At present, something is known about the ecology of the Cerrado, its flora, mineral and hydrologic resources, soil characteristics, and agricultural capability. This knowledge allows commodities such as corn, soybeans, wheat, rice, beans, cassava, coffee, forages, eucalyptus, and pinus to be grown.

Some Limitations to the Agricultural Development of the Cerrado

Geographic and Demographic Aspects

The Federal District of Brazil, Brasilia, is located in the center of the Cerrado region (see Figure 3.1), and it is the nucleus for the development of this immense region. The construction of Brasilia started in 1957. The Capital and satellite cities of the Federal District today have a population estimated at over one million.

To serve this population, infrastructural services were built. Highways were established to several state capitals such as Belo Horizonte (720 km), Rio de Janeiro (1,204 km), São Paulo (1,015 km), Goiânia (202 km), Cuiabá (1,144 km), and Belém (2,110 km). These roads link important markets, an essential element for the economical exploration of the Cerrado. Farm roads need to be built, but the soils of the Cerrado offer good conditions for the construction of such roads because of good drainage and topography. Railroads are still limited in the Cerrado region. Unfortunately, this deficiency is common to most of the country.

Although the population of the Federal District grew very quickly, development is still limited, and the remainder of this vast area is sparsely populated. There is low density of rural workers in the region. There is no migration from urban to rural areas, and the distribution of workers is unequal in geographic terms. The inelastic supply of rural labor necessitates development of technologies that are labor saving (Vilas, 1979).

The Physical Environment: Climate and Soils

The Cerrado region has a climate marked by two well-defined periods: the wet season, between October and April, having more than 90 percent of the total precipitation; and the dry season, from May until September, with an almost total absence of rainfall causing a drastic decline in the production of native grasses and hindering extensive cattle-breeding development. The Cerrado region, in general, receives ample but not well-distributed rainfall. Most crops

can be cultivated in these climatic conditions. However, a great problem is the phenomenon called "veranico" or little summer--that is, the existence of two or three weeks or more without rain during the wet season, which decreases the production directly by water deficiency or indirectly by influencing insects and diseases. Table 3.2 shows the frequency of dry spells found in a study of 42 years of climatological data recorded for Brasilia. The effect of these dry days is intensified with the small water-holding capacity of the Cerrado soils. On the basis of experimental results, it is predicted that there is no available water for plants located to a depth of 50 cm in the soil after 8 successive days without rain and no yield of corn after 22 consecutive dry days. In order to alleviate this problem, options exist such as varietal selection, deep incorporation of amendments, supplemental irrigation, and different planting periods.

Table 3.2.--Frequency of wet-season dry spells (veranicos) for Brasilia, based on 42 years.

Dry Spell (Days)	Frequency
8	3 per year
10	2 per year
13	1 per year
18	2 in 7 years
22	1 in 7 years

Source: Wolf (1975), p. 34.

The most serious and limiting factor to intensive agriculture in the Cerrado is doubtless the soil, which is very poor in nutrients and high in aluminum concentration. For cropping, these soils are deficient in available phosphorus in their native state because of their enormous ability to fix this nutrient and render it unavailable for plants. Further, these soils require large amounts of fertilizers and limestone when they are first brought into production. The limestone is used to solve the toxic aluminum concentration problem of Cerrado soils and consequently its acidity. Fortunately, there are many deposits of high-quality limestone in the region, which make this corrective relatively cheap. The low soil fertility can be corrected through the use of fertilizers. One of the difficulties of intensive agriculture in the Cerrado is the small holding-capacity of the soil for potash and nitrogen, necessitating frequent applications of these nutrients. Atmospheric nitrogen fixation through Spirillun spp. has been observed and shown to be an important nitrogen supply in corn production in Cerrado soils (see Silva, 1978, p. 5).

Large amounts of nutrients are required per hectare, mainly of phosphorus, with initial applications varying from 40 kg P_2O_5/ha to 2,000 kg P_2O_5/ha, depending on the crop. Fertilizers are very expensive, and the large amounts required make the ratio of the price of nutrients to the price of agricultural products a limiting factor in efficient utilization of the Cerrado. It should be mentioned here that the most phosphate mines in Brazil are located in the Cerrado area, a positive factor in terms of transportation cost.

Fortunately, these serious limitations to the agricultural development of the Central Plateau can be resolved or at least alleviated. Positive factors in the Cerrado development are its location relative to markets, a topography favoring mechanized farming systems, and the low cost of the land. Fertile land in other areas sells for as much as 50 times the price of raw land in the Cerrado area. Although a large amount of money is needed for initial investments such as clearing of the area and soil infertility and acidity correction, this expenditure is at least partly offset by the low cost of the raw land.

The Government Action

Besides creating CPAC for agricultural research on the Cerrado, the government also has been collaborating with the agricultural development of this region through the program called Polocentro[3] (Programa de Desenvolvimento dos Cerrados). The main objectives of this program are: (1) to integrate research and extension services in order to offer adequate agricultural technology for the rational and systematic occupation of the Cerrado; (2) to provide financing that induces farmers to clear the land, prepare the soil beds, construct grain elevators, houses and other facilities, and acquire limestone, seeds, fertilizers, and other factors of production. The program also attempts to develop the infrastructures necessary to the development of the agricultural sector of the region, such as road construction, warehousing, and the provision of electrical energy.

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[3]This program was created by a decree--Law Number 75.320--on January 29, 1975.

The intention of the government, through Polocentro, was to add three million hectares of the Cerrado to the national agriculture sector in the period 1975-79. In the first three years of the program, about 2,300 rural credit projects were approved, with 1,900 undertaken utilizing 7.5 billion cruzeiros on 1.2 million hectares. Also, 970 thousand hectares indirectly benefited from the support provided by the program in the form of technical assistance, access to the productive areas (roads), warehousing, facility in the attainment of factors of production, and energy (see Alencar, 1979).

Following is a description of some general and major financing conditions offered by Polocentro (see Banco Central, 1978). The government and private extension services participate in all phases of the projects, helping the farmers to set up loans and giving technical assistance. The costs related to these services vary from 4 to 6 percent of the total amount borrowed, depending on the loan limit and time of repayment.

For the initial investments, such as clearing of the land, plowing, and acquisition of limestone, farmers will pay an annual interest charge of 10 percent on a value up to 2,000 MVR,[4] 12 percent on a value from 2,000 MVR to 5,000 MVR, and 14 percent on a value over 5,000 MVR.

The borrower has up to 12 years to repay. No principal or interest has to be paid during the first 6 years. After that period,

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[4]MVR (Maximo Valor de Referencia), fixed at 1,150 cruzeiros at this date, is a reference value that is corrected annually.

the capitalized interest due is divided by the number of desired installments and integrated into the principal.

For operations such as purchasing of insecticides, bags, fertilizers, seeds, and all operations necessary to the continuation of the cultivation of the land, the program offers a three-year credit for the first financing. The annual nominal rates are 13 percent for a value up to 50 MVR, 15 percent for a value more than 50 MVR, and no charge for fertilizers if that is all that is purchased.

The farmer has to repay 50 percent of his debts after the first harvest and the remaining 50 percent in two equal parts in the two following years. After the first year, operating loans must be repaid a month after the harvestime.

For fertilizers in general, the government offered a 40 percent price subsidy for the two years 1975-76. After that, Polocentro began offering credit for fertilizer devoted to the correction of soil infertility--phosphorus in this case, with no interest and up to five years for repayment, no payment being required during the first two years.

In general, interest rates on all loans have been negative in real terms in recent years because the inflation rate is higher than the nominal interest rate. (See Table 3.3.) Despite favorable interest rates, small farmers in general are not benefited because, in most cases, they do not have enough collateral to secure a loan.

Table 3.3.--General price index and inflation rate for the period 1974-78.

Year	General Price Index (1969=100)	Inflation Rate (%)
1974	480	28.7
1975	613	27.7
1976	866	41.3
1977	1,236	42.7
1978	1,714	38.4
Average	..	35.82

Source: Fundação Getúlio Vargas, Conjuntura Econômica, Brazil, various issues.

It is assumed that the lack of agricultural credit at reasonable interest charges is one of the most serious limitations in the adoption of new technologies. Based on this assumption, the financing conditions offered by the government, i.e., the low interest rates associated with low administrative costs, will favor the utilization of necessary factors of production in the intensive agricultural exploration of the Cerrado.

Description of Soils and Fertilizer Applications in the Experimental Area

In order to evaluate different phosphorus fertilization strategies and the residual effectiveness of the phosphorus fertilizer, an experiment was begun in 1971 at the CPAC Experiment Station, located approximately 40 km northeast of Brasília. This study examined crop responsiveness to alternative methods of applying

fertilizer. Eight consecutive crops of corn have now been raised in this experiment. As was seen before, phosphorus deficiency is one of the most serious limitations to crop productivity in oxisols; in the case of corn, for example, there is no production at all without the addition of phosphorus. This nutrient is the only varying factor in this experiment.

The experimental sites were located on a soil described as a Dystrophic Dark Red Latosol, clayey texture, cerradão phase (Yost, 1977; Lobato, 1978). Some chemical properties of this soil are given in Table 3.4. This table shows how these soils, in their native state, are deficient in available phosphorus and have high aluminum concentrations.

Table 3.4.--Some chemical properties of the Dark Red Latosol used in the phosphorus rate experiment.

Depth	C	N	Exchangeable Cations Ca + Mg	Exchangeable Cations Al	Al Saturation	Soluble P (Double Acid)
cm	%		me/100g		%	μg/gm
0- 10	1.8	0.21	0.4	1.9	83	1
10- 35	1.2	0.08	0.2	2.0	91	1
35- 70	0.9	0.05	0.2	1.6	89	1
70-150	0.7	0.05	0.2	1.5	88	1

Source: Yost (1977).

The area was initially disc plowed to 20-25 cm depth. Lime at the rate of 4 ton/ha (100 percent $CaCO_3$ equivalent) and micronutrients (11 kg Zn/ha and 1 kg B/ha) were applied initially, being disc incorporated. Blanket applications of 150 kg/ha of N (in the form of urea) and 150 kg/ha of K_2O (KCl) were made for each crop.

The rates of phosphorus applications are indicated in Table 3.5. There were ten treatments arranged in five replications in a random block design. All phosphorus was applied as simple superphosphate. In the broadcast treatments, appropriate amounts of phosphorus were incorporated by rotovation at the beginning of the experiment. For the banded treatments, the amounts of the nutrient were placed below the seeds before each planting. After each crop, the soil was plowed and disced, and there was a change of about 15-25 cm in the position of the row from that of the previous year's crop. It was decided to stop further banded phosphorus applications after the fourth crop except for treatment number 10 (80 broadcast plus 80 banded). It is possible, then, to compare different treatments at the same levels of total phosphorus applied. The nitrogen and potassium nutrients continued to be applied.

Cargill-111 hybrid corn was planted in the 80 cm rows and averaged 6,000 plants/ha.

The results of this experiment show that it is possible to get high corn yields in Cerrado soils when one has proper fertilization and crop management. (See Table 3.6.) Several questions, however, arise from these results. How long will these initial and

Table 3.5.--Application of phosphorus in a Dark Red Latosol experiment.

Treatment No.	Method	Crop 1	2	3	4	5	6	7	8	Total
		kg/ha								
1	Broadcast	160	..	..	..	..	..	..	..	160
2	Broadcast	320	..	..	..	..	..	..	..	320
3	Broadcast	640	..	..	..	..	..	..	..	640
4	Broadcast	1,280	..	..	..	..	..	..	..	1,280
5	Broadcast[a]	2,000	..	..	..	..	..	..	..	2,000
6	Band	80	80	80	80	..	..	..	..	320
7	Band	160	160	160	160	..	..	..	..	640
8	Band	320	320	320	320	..	..	..	..	1,280
9	Combination[b]	320+80	80	80	80	..	..	..	..	640
10	Combination	80+80	80	80	80	80	80	80	80	720

[a]Eighty kg/ha was band applied before the first crop, and 1,920 kg/ha was broadcast prior to the second crop.

[b]Three hundred twenty and 80 kg/ha broadcast applied and 80 kg/ha band applied preplanting.

Table 3.6.--Corn grain production in a Dark Red Latosol experiment.

Treatment No.	Total Phosphorus Applied (kg/ha)	Grain Yield (metric ton/ha)							
		Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6	Crop 7	Crop 8
1	160	5.23	3.27	0.87	1.78	1.65	1.19	0.45	0.72
2	320	6.27	5.68	2.20	3.42	3.02	1.79	0.88	1.54
3	640	6.79	7.48	2.97	6.43	4.82	4.41	1.55	2.55
4	1,280	7.96	8.53	3.86	9.09	6.25	6.70	4.67	4.88
5	2,000	2.26	9.54	4.56	9.02	6.60	6.42	5.32	6.40
6	320	2.42	5.08	3.08	6.03	4.49	2.83	1.33	1.53
7	640	3.85	6.57	3.41	8.07	5.86	5.24	2.71	2.94
8	1,280	4.79	8.42	4.19	9.03	6.89	6.76	4.86	4.65
9	640	6.65	7.32	3.33	7.22	5.40	4.24	2.47	2.73
10	720	4.56	6.00	2.56	6.48	5.79	5.41	4.19	4.65

large applications of phosphorus continue to supply sufficient nutrient for adequate plant growth? Which of the treatments is the most efficient? We will try to answer these and other questions, taking into consideration attitudes toward risk revealed by farmers as described in the following section.

Description of the Area and the Farmers Studied

The Area

Farms included in the study were located in the state of Minas Gerias, more precisely, in the county of Unai. This area was selected because it has the same soils and climate conditions and is relatively close to the experimental area. In addition, there is a large number of farmers growing corn in fertile soils or Cerrado soils or both occurring side by side in the region. The purpose of this study was primarily to collect information about attitudes toward risk from farmers who have had contact in any way with the Cerrado. It was thought that farmers in the area would be suitable for the analysis of this study.

The county of Unai has an area of 9,749 square km. Its population in 1975 was estimated at 62,250, 69 percent of whom live in the rural area. This city is considered one of the greatest corn producers of the state of Minas Gerais, which is the largest producer of corn in Brazil. The gross product of the "municipio" originates mainly from agriculture, primarily corn, cattle, beans, and rice. (See Table 3.7.)

Table 3.7.--Major agricultural products in Unai, Minas Gerais, Brazil, 1977.

Product	Producers (no.)	Area (ha)	Heads (no.)	Production (tons)	Productivity (kg/ha)	Value of Production (Cr$ 1,000)
Corn	1,978	37,000	..	88,000	2,400	160,308
Cattle	2,120	800,000	264,000	9,345	..	112,248
Beans[a]	1,618	33,000	..	10,000	360	119,000
Rice	200	6,097	..	5,487	900	14,652
Hogs	16	..	270	345	..	5,875
Soybeans	8	2,700	..	1,620	600	6,000
Cotton	3	80	..	84	1,050	616
Wheat	2	300	..	360	1,200	1,000
Others	15	16	..	..	..	320
Total						420,019

Source: IBGE (1977).

[a]Practically all beans are interplanted with other crops, mainly corn.

Much of the land in this region that is used for corn is composed of fertile soils, but recently the Cerrado soil is being cleared and incorporated into the cultivated area. The factor market is satisfactory to serve the producers. Institutional credit is extensively used, mainly by large farmers. There are a fair number of rural workers. The producers of the region seem to be in the initial stage of adopting new technologies.

The Farmers Studied

The sample farmers were randomly chosen from the land rolls of Instituto Brasileiro de Reforma Agraria (IBRA) and subjected to the following criteria: (1) more than 50 percent of the land under control and in condition to be cultivated is operated; (2) more than 50 percent of the operated land is devoted to the production of corn. Interviews[5] were carried out during October and November 1978. One hundred thirty interviews were conducted, of which 114 are included in this study. Sixteen questionnaires were not considered because they were not completed (13) or were not in accordance with the above criteria (3).

The size distribution of the farms is shown in Table 3.8. It was hypothesized that small, medium, or large farmers might react differently to risk and also that the farmers will react differently according to their tenure situation. Owner-operator was the major tenure arrangement among the interviewed farmers. (See Table 3.9.)

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[5]The interview procedures are described in Chapter IV.

Table 3.8.--Distribution of sample farms, by size.

Size (ha)	Number of Farms
0- 30	67
31-200	25
> 200	22
Total	114

Table 3.9.--Tenure situation of sample farms, by size.

Size (ha)	Number of Farms			Total
	Owner	Share Cropper	Tenant Farmer (Colonist)	
0-5.5	..	..	24	24
6- 30	20	23	..	43
31-200	25	..	..	25
> 200	22	..	..	22
Total	67	23	24	114

Table 3.10 shows the average of some socioeconomic variables for the sample farmers. On the average, the owners were richer, more educated, and older than share croppers or tenant farmers.

Table 3.10.--Some socioeconomic characteristics of three types of farmers in Unai, Minas Gerais, Brazil, 1978.

Variable	Small Owners	Medium Owners	Large Owners	Owners (Average)	Share Croppers	Tenant Farmers
Sample size	20.00	25.00	22.00	67.00	23.00	24.00
Av. age of family head (years)	52.65	48.32	47.73	49.69	36.57	39.04
Av. size of household (no.)	5.40	6.48	6.00	5.96	4.65	6.08
Av. education of family head (years)	3.00	5.24	7.23	5.22	2.52	3.13
Net income (Cr$ 1,000)	57.48	408.16	1,000.04	394.05	33.33	16.70

Summary

In conclusion, the major difficulty for intensive agricultural use of the Cerrado is its low soil fertility, phosphorus being the most limiting nutrient. The results of the experiment showed significant responses to phosphorus fertilization. It is evident, then, that low fertility can be alleviated. The excellent financing conditions offered by the government support fertilization programs.

It is important, therefore, to determine the efficient rates of fertilizer application, taking into consideration its residual effects and the weather uncertainty. Of equal importance is the evaluation of the total effect of alternative government programs and policies on the efficient levels of fertilizer application when one is considering different classes of farmers defined according to their degree of aversion to risk. A description of the model to be used to help achieve these objectives and study these alternatives is given in Chapter IV.

CHAPTER IV

THE DECISION MODEL

Introduction

In agriculture, uncertainty permeates almost all types of decisions, including production, marketing, and financial decisions. This research will emphasize uncertain production decisions, in which availability of inputs and services, price of outputs, and, more frequently, the quantity of outputs produced are stochastic because they all depend on noncontrollable climatic events and other factors. (See Jensen and Halter, 1961, pp. 105-27, for more details about the presence of uncertainty in all three types of decisions.)

Risk, Uncertainty, and Probability

Several authors have used the terms risk and uncertainty in different ways. Knight (1921) provided the classic distinction between risk and uncertainty, defining risk as occurring in a situation in which the probabilities associated with different outcomes are measurable and uncertainty as a situation in which these probabilities are not measurable. Johnson (1976a, 1976b) defined risk as existing when present knowledge is adequate for making a decision, i.e., the cost of additional knowledge is exactly equal to its value (decision mode), and uncertainty as existing when specifications for a decision have not been met; the cost of acquiring

more knowledge is less than its value, so the decision is postponed and more information is acquired (learning mode). Rothschild and Stiglitz (1970, 1971) defined risk as that which increases when changes in the distribution of a random variable occur that preserve the mean and move probability from the center to the tails of the distribution. In some cases, this definition of risk is equivalent to distributions with constant means but increasing variance. Roumasset (1977) presented several other definitions that appear in modern decision theory: "Uncertainty is a state of mind in which the individual perceives alternative outcomes to a particular action. Risk, on the other hand, has to do with the degree of uncertainty in a given situation" (p. 1). One definition of risk widely employed is that risk is the probability that returns to a given decision will fall below some disaster level.

In this research, risk and uncertainty are used interchangeably to describe actions with more than one potential outcome; i.e., their precise outcome is not known at the time when the decision must be taken, but the likelihood of each outcome can be described by a probability-density function. The probability measures the chance of the occurrence of a particular outcome that, in this research, is identified as a random variable. There are at least three concepts of probability (Dillon, 1971, pp. 18-21): frequency (or objective), logical (or necessary), and personal (or subjective or judgmental).

In the objective type, probabilities are assigned to random variables from empirical analysis of frequency ratios. In the

logical type, probabilities come from classical theory or from a logical structure of the situation. The subjective probability of an event measures the conviction or the degree of belief that an individual has in the chance of occurrence of that event. These subjective probabilities normally differ from person to person for the same outcome; they may also vary over time for the same person because incorporation of intuitive knowledge is allowed. Subjective probabilities may coincide with objective probabilities. In the opinion of Dillon, the only valid probability approach for decision making is the subjective one because "the decision maker bears responsibility for his decisions and should use his own strengths of conviction" (p. 20).

Among the models of decision making under uncertainty developed and used recently, the one that seems to be the most promising is the expected utility model based on the Bernoullian approach developed more than 200 years ago. Its usefulness in the decision-making process lies in the fact that it allows for the incorporation of personal probabilities--the subjective nature of decisions is recognized explicitly in this approach. (See King, 1979, for a detailed discussion about the determination of subjective probabilities.)

Expected Utility Hypothesis or Bernoullian Decision Theory

Bernoulli recognized the law of diminishing marginal utility, which implies that one extra dollar is likely worth less to a rich man than to a poor man. This principle is the basis for the expected utility hypothesis, first deduced from a set of axioms by Ramsey in

1926 and later by von Neumann and Morgenstern in 1944. (See Dillon, 1971, for a review of Bernoullian decision theory in agriculture.) One of the several ways in which these axions are named is discussed below.

1. Ordering and Transivity. If a person confronts two risky prospective actions, F_1 and F_2, with more than one potential outcome or with a probability distribution of outcomes, he will prefer one of the two risky prospects or will be equally indifferent to each of them. If there are three risky prospects with F_1 preferred to F_2, which is preferred to F_3, then the person will prefer F_1 to F_3.

2. Continuity. If a person prefers the probability distribution F_1 to F_2 to F_3, then a subjective probability P exists such that he is equally indifferent to F_2 and a lottery with a probability distribution of outcomes: F_1 with probability P and F_3 with probability 1-P.

3. Independence. If the probability of occurrence F_1 is equal to the probability of F_2, and if F_1 is preferred to F_2, then a lottery with F_1 and F_3 as outcomes will be preferred to a lottery with F_2 and F_3 as outcomes.

If one has a decision maker whose preferences are in accordance with the above axioms, it is possible to deduce his utility function, i.e., a function that associates utility indices with the set of possible outcomes related to any risky prospect. According to Dillon (1971, p. 8), this function, called $U(F_i)$ has the following properties:

1. If F_1 is preferred to F_2, then $U(F_1) > U(F_2)$, and vice-versa.

2. The utility of a risky prospect is equal to the expected utility of its possible outcomes.

3. The scale on which the utility is measured is arbitrary; that is, uniqueness of the function is only defined by a positive linear transformation.

Thus, as one can see, utility function is only a device for attributing numbers or indices to possible outcomes of an uncertain prospect in order to help the decision maker select among the set of prospects. The rationale behind the Bernoulli approach is that, if the decision maker makes his choice according to the expected utility hypothesis (EUH), he will be acting according to his expressed preferences. In other words, in order to apply the EUH, the decision maker has to attach numbers, called utilities, which reflect his preferences, to all outcomes. Then the utilities, weighted by the probability of the occurrence of the corresponding outcome, are summed for each risky prospect. The result is the index of expected utility. The investor, in this case the expected utility maximizer, chooses the investment with the greatest expected utility.

Derivation of Utility Functions

The most direct way of using the expected utility hypothesis is to estimate the decision maker's utility function. The procedure more often used for eliciting preferences involves choice between outcomes of uncertain prospects and some certain outcome. (A good

description of methods available for deriving utility functions can be found in Anderson, Dillon & Hardaker, 1977.) A technique easier to apply and therefore more commonly used is the ELCE (Equally Likely risky prospect and its Certainty Equivalent). In order not to distort the utility assessment, the probabilities, as opposed to some other methods, do not vary, and are fixed at a neutral value of .5. This method is based on finding the certainty equivalent or the degree to which the decision maker becomes indifferent; that is, the degree of preference is the same both for the amount exchanged with certainty (certainty equivalent) or for the risky prospect. One starts assigning arbitrary utility values to the worst and best possible outcomes offered to the decision maker. After the certainty equivalent is found, its utility value can be easily calculated by the relation:

$$U(CE) = 1/2\ U(a) + 1/2\ U(b) \tag{4.1}$$

where a and b are the worst and the best outcome, respectively. No doubt that $U(a) < U(b)$.

The process continues in which successive points relative to new certainty equivalent points are found by new gambles formed with the worst and the best outcomes and the former certainty equivalent.

Once enough elicited points are found, a curve can be estimated. A variety of different functional forms, such as polynomial, logarithmic, or exponential, have been used. It is usual to categorize decision makers in terms of properties of their utility function. It is expected that all investors display positive marginal

utility for additional wealth $U'(x) > 0$; that is, their preferences are represented by an expected utility function $U(x)$, which is increasing and twice differentiable.

The problem here is that any positive linear transformation of $U(x)$ represents the same preferences. One solution to this problem is to use the absolute risk aversion coefficient $r(x)$ that is defined by

$$r(x) = -U''(x)/U'(x). \tag{4.2}$$

Pratt (1964) showed that $r(x)$ uniquely represents an investor's preferences. This absolute risk coefficient can, therefore, be used adequately to select the function form of the utility function.

The most commonly used polynomial is the quadratic function,

$$U(x) = a + bx + cx^2, \tag{4.3}$$

which implies increasing risk aversion. Several authors, however, notably Arrow (1964), believed that absolute risk aversion should decrease as the level of income, or wealth, increases. Empirical works have demonstrated that this does not always occur. The logarithmic utility function

$$U(x) = a + b \ln (x + c) \tag{4.4}$$

implies decreasing absolute risk aversion. The negative exponential utility function

$$U(x) = a - b e^{-cx} \tag{4.5}$$

implies constant absolute risk aversion.

Table 4.1.--Alternative utility functions and the coefficient of risk aversion.

Type of Risk Aversion	Functional Form	Restriction	Coefficient of Risk Aversion	Risk-Aversion Range
Increasing	$U(x)=a+bx+cx^2$	$a,b>0$ $c<0$	$\frac{-2c}{b+2cx}$	$\frac{b}{2c} \geq x \geq 0$
Constant	$U(x)=a-be^{cx}$	..	c	all x
Decreasing	$U(x)=a+b \ln(x+c)$	..	$\frac{1}{x+c}$	$x \geq -c$

Source: Lin and Chang (1978, p. 31). See article for fuller discussion of several utility functional forms.

Stochastic Efficiency

The model specified above requires knowledge of the farmers' utility regarding income and their subjective probability distribution functions. Eliciting farmers' subjective probabilities and encoding their preferences in utility functions is a difficult task, especially when one has to work with a large sample.

Discussing the difficulties related to eliciting data to construct utility functions, Roumasset (1976) commented:

> Since analysts and consultants face resource limitations in conceptualizing, programming, and solving problems, it may be, for example, that it is not rational from the analyst's point of view to follow an expensive procedure for estimating utility functions for each farmer in order to generate recommendations for farm inputs (p. 27).

Not only the difficulties and costs related to obtaining utility function are taken into consideration but also the methods used.

Moscardi and de Janvry (1977), for example, stated that, in these methods:

> The subject is asked to make decisions in reaction to a large number of randomly arranged hypothetical bets and insurance schemes. This approach has serious difficulties resulting from the fact that the subjects have different degrees of utility or disutility for gambling (the very method used to reveal their preferences) and that the concepts of probability are by no means intuitively obvious (p. 710).

One can see that, for several reasons, adequate elicited preferences are difficult to obtain. Given the above difficulties, the ideal would be an approach that allows for the consideration of risk and also does not require the direct estimation of the farmer's utility function.

The solution for the above problem is the criterion called stochastic dominance, presented in two independent works by Hadar and Russell (1969) and Hanock and Levy (1969). These authors developed an approach in which a large number of risky prospects could be reduced without knowledge of a decision maker's preference. The only thing needed is the probability distribution of outcomes for each investment strategy. The great advantage of this criterion is that it is consistent with the expected utility hypothesis; that is, the advantage lies in its general and simple presuppositions about the algebraic form of farmer's utility functions. These presuppositions are:

1. Any farmer prefers more profit than less.
2. Every farmer is risk averse.

Each of these presuppositions corresponds to one degree of stochastic dominance, that is, first-degree (FSD) and second-degree

(SSD) stochastic dominance, respectively. FSD is not controversial. SSD, which assumes that decision makers are averse to risk, is accepted by several authors but is not confirmed by all empirical studies in this area.

Definitions of FSD and SSD[1]

The choice between alternatives is described by a random variable x. U(x), defined for all x in the interval [a,b], is the utility function that represents the decision maker's preferences for x. It must be kept in mind that in uncertainty, utility maximization implies maximization of expected utility.

Consider now the case of a pair of continuous CDFs, F_1 and G_1, defined within the range [a,b] and respectively associated with two acts or risky prospects F and G. F_1 is related to its PDF f(x) by

$$F_1(R) = \int_a^R f(x)\, dx \qquad (4.6)$$

In the same way

$$G_1(R) = \int_a^R g(x)\, dx\ . \qquad (4.7)$$

These represent an accumulated area under f(x) and g(x), respectively. In the same way, one can accumulate areas under the CDF and then define

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[1]Based on Anderson (1974, pp. 132-40). See this reference for more detailed explanation about the stochastic dominance criteria and proofs of the theorems.

$$F_2(R) = \int_a^R F_1(x)\, dx \qquad (4.8)$$

and

$$G_2(R) = \int_a^R G_1(x)\, dx \qquad (4.9)$$

The assumptions related to the preferences are encoded in the utility function, and they involve their first two derivatives. In the case of FSD, the presupposition is that any farmer prefers more profit than less, implying U(x) monotonically increasing between a and b, or $U'(x) > 0$. Then F is said to dominate G in the sense of first-degree stochastic dominance if $F_1(R) \leq G_1(R)$ for all possible R in the range [a,b] with at least one strong inequality (i.e., the < holds for at least one value of R).

Figure 4.1 illustrates the FSD. F_1 dominates G_{11} since F_1 is always to the right and below G_{11}. Nothing can be said, in terms of dominance, about the pairs of distributions F_1 and G_{12}, and G_{11} and G_{12} because G_{12} crosses both G_{11} and F_1.

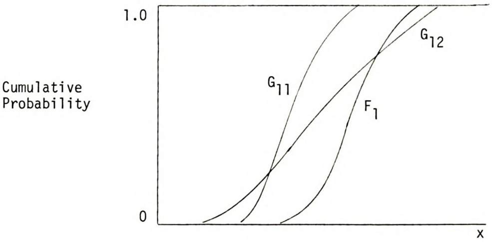

Figure 4.1.--An illustration of FSD.

In the case of SSD, the presupposition is that every farmer is risk averse. This means that the utility function should be concave; i.e., successive amounts of x have diminishing value to a farmer. This assumption will imply $U'(x) > 0$ and $U''(x) < 0$. The distribution F is said to dominate G in the sense of second-degree stochastic dominance if $F_2(R) \leq G_2(R)$ for all possible R with at least one strong inequality.

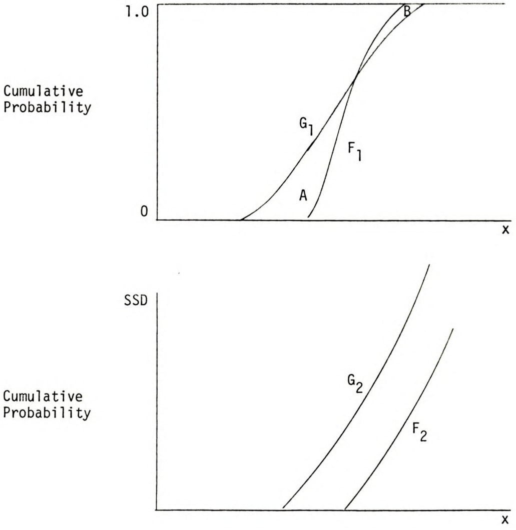

Figure 4.2.--An illustration of SSD.

Figure 4.2 illustrates the SSD. Distribution F dominates distribution G by second-degree stochastic dominance because the area under F_1 is always less than or equal to the area under G_1, or the area labelled A is not less than the area labelled B.

It is interesting to note how the risk-aversion coefficient r(x) is related to FSD and SSD: Under the FSD, the only restriction on the farmer's utility function is that $U' > 0$. This implies no restrictions on the coefficient of absolute risk aversion since $U'' \lesseqgtr 0$ and $- \infty < r(x) > \infty$. Under the SSD, assuming risk aversion of the farmer $U'' < 0$ did not restrict r(x); now it has to be positive $0 < r(x) < \infty$.

Thus the concept of FSD solves the problem of the special case in which all the farmers are in the set $U(-\infty, +\infty)$; the concept of SSD solves the problem for the agents in the set $U(0, +\infty)$. Using this analysis, one can find which alternatives are efficient, and, therefore, the nonefficient ones can be eliminated. Utilizing the cumulative distribution functions (CDF) of the several alternatives, one will know the distribution probability of the profit associated with each alternative. Considering the same level of probability, the alternatives that have higher profits will be chosen. This will be done for every degree of stochastic dominance. The alternatives that are not eliminated by the FSD will be tested by the SSD. Those not eliminated by the SSD will be considered efficient.

This process allows us to filter out the inefficient practices or technologies that would neither be preferred nor adopted by

the farmers averse to risk. The possibility is great, however, that even eliminating the inefficient technologies, one still has several alternatives left to choose from. Further reductions in the choice set can be made using an approach developed by Meyer (1977a). He proved that if one can set upper and lower bounds on the measure of absolute risk aversion, the choice set could be restricted to any desired size:

$$r_l(x) \leq r(x) \leq r_u(x) \tag{4.10}$$

The advantage of this approach is evident. The analyst is allowed to select the best investment alternative, if not for a particular farmer, at least for a group of farmers who are categorized in the same class by their degree of risk aversion.

Meyer's Criterion or Stochastic Dominance With Respect to a Function

Stochastic dominance with respect to a function is a recently developed stochastic dominance theorem that defines a more general and flexible form of stochastic dominance and relates it to a unanimous preference by well-defined groups of decision makers. The group of decision makers considered in this approach is defined by the set $U(r_1(x), r_2(x))$ in which all decision makers have increasing utility functions satisfying

$$r_1(x) \leq \frac{-U''(x)}{U'(x)} \leq r_2(x) \quad \forall x \tag{4.11}$$

Thus this set is defined by lower and upper bounds of risk aversion coefficients. As mentioned above, the absolute risk-aversion

coefficient uniquely represents the decision maker's preference. As one can see, first- and second-degree stochastic dominance are special cases of stochastic dominance with respect to a function. As seen before, for the first case one has $r_1(x) = -\infty$ and $r_2(x) = +\infty$; that is, FSD implies no restrictions on the decision maker's preference other than the assumption that U(x) is increasing and twice differentiable. In the case of the SSD, the flexibility of stochastic dominance with respect to a function allows for the definition of the group of all risk-averse decision makers by setting $r_1(x) = 0$ and $r_2(x) = +\infty$.

The rationale behind Meyer's criterion is that he found necessary and sufficient conditions on cumulative distribution functions F(x) and G(x) for F(x) to be preferred or indifferent to G(x) by all decision makers belonging to the class defined by $U(r_1(x), r_2(x))$. If this occurs, one says that F(x) dominates G(x). Any pair of cumulative distribution functions can be compared in this way. Meyer solved the problem by finding the utility function U(x) which satisfies

$$r_1(x) \leq \frac{-U''(x)}{U'(x)} \leq r_2(x) \quad \forall x \in [0,1] \tag{4.12}$$

and minimizes

$$\int_0^1 [G(x) - F(x)]\, U'(x)\, dx. \tag{4.13}$$

What is needed now is a check to see if the minimum is nonnegative or not. The expression in equation (4.13) is equal to the difference between the expected utility from F(x) and the expected utility

from G(x). If the minimum is greater than zero, the set of decision makers over which the expression is minimized will prefer F(x) to G(x); if the minimum is equal to zero, they will be indifferent between F(x) and G(x). If the minimum is negative, the set of decision makers will not be unanimous in choosing F(x) over G(x). In order to check to see if G(x) dominates F(x), one should replace equation (4.13) by

$$\int_0^1 [F(x) - G(x)]\, U'(x)\, dx \qquad (4.14)$$

Based on optimal control theory, Meyer defined the following theorem:

An optimal control $-U_0''(x)/U_0'(x)$ which maximizes $-\int_0^1 [G(x) - F(x)]\, U'(x)\, dx$ subject to $r_1(x) \le [-U''(x)/U'(x)] \le r_2(x)$ and $U'(0) = 1$ is given by

$$\frac{-U_0''(x)}{U_0'(x)} = \begin{cases} r_1(x) & \text{if } \int_x^1 [G(y) - F(y)]\, U_0'(y)\, dy < 0 \\ r_2(x) & \text{if } \int_x^1 [G(y) - F(y)]\, U_0'(y)\, dy \ge 0. \end{cases} \qquad (4.15)$$

According to this theorem, in order to calculate the solution at any point x, one chooses the control variable to be either its maximum or minimum according to the sign of the objective function from x forward. Then the solution at point x is easily determined. In his article, Meyer illustrated how the solution can be obtained for any distributions F(x) and G(x), such that G(x) - F(x) changes sign a finite number of times.

Stochastic dominance with respect to a function is a powerful tool, not only because it can reduce the efficient set of alternatives,

but also because it eliminates the criticisms against first- and second-degree stochastic dominance. Now, not only decision makers with different degrees of risk aversion can be considered,[2] but also the class of risk-loving decision makers--a group given practically no attention in risky decisions studies--can be analyzed. There are no restrictions about the risk-aversion function; $r_1(x)$ and $r_2(x)$ can be any two functions since $r_1(x)$ is always less than or equal to $r_2(x)$. Stochastic dominance with respect to a function also eliminates two requirements needed before. First, it removes the necessary condition for FSD and SSD that the lower bound of a dominant distribution not be less than that of an unpreferred distribution. In fact, the emphasis placed on the lower value of risky prospects is excessive. Consider distribution F(x) with values of x always greater than respective values of distribution G(x) for the same level of probability, with the exception of the smallest value of F(x) being less than the smallest value of G(x). Using either FSD or SSD, F(x) cannot be chosen, but it can be under the stochastic dominance with respect to a function for some classes of decision makers. Another point to be mentioned is that the mean of the dominant distribution does not have to be at least as large as the mean of the dominated distribution--a necessary condition for FSD and SSD. It is possible now to choose among distributions even when the mean of the dominant distribution is smaller than the mean of unpreferred cumulative distribution. This fact is very important because it allows one to

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[2]It is convenient to remind that, under SSD, all decision makers are considered risk averters.

trade a certain amount of mean away in order to obtain a reduction in risk.

Although stochastic dominance with respect to a function is an ideal way to select risk-efficient alternatives, in practice it will be an incomplete way if one does not have reasonable measure of the lower and upper bounds of risk aversion. The next two sections deal with this empirical question.

Earlier Empirical Studies of Risk-Aversion Measures

Few empirical studies measure risk aversion. Most studies deal with estimation of utility functions and the derivation of Pratt's absolute risk-aversion coefficient, commented on earlier in this chapter, which is defined as the negative of the ratio of the second derivative to the first derivative of the utility function. In addition to the difficulties and costs related to eliciting decision makers' preferences through the derivation of utility functions, mention should be made again of the fact that stochastic-dominance procedures began to be used in decision theory because of the possibility of avoiding specific assumptions about the algebraic form of decision makers' preference functions. Now, with the new developments of stochastic-dominance theory, more precisely, stochastic dominance with respect to a function, discussed earlier in this chapter, the necessity of determining lower and upper bounds in a decision maker's absolute risk aversion does not include using utility functions to find these measures. If adequate utility functions can be estimated, there is no necessity for efficiency criteria to select

feasible action choices because the valued utility function approach can be used to make predictions, reducing the efficient set to a single element. Then, under these conditions the use of utility functions in the stochastic-dominance approach is redundant. The following two sections present more recent procedures for determining interval measurements of decision makers' preferences for use with the criteria for stochastic dominance with respect to a function.

The Interval Approach to the Measurement of Decision-Maker Preferences

King and Robison (1979) recently published an article in which a new technique--having considerable promise--for making interval measurements of decision-maker preferences was presented. The basis of this procedure is that under certain conditions "a choice between two distributions lying on a relatively narrow interval, divides risk aversion space over that interval into two regions: one consistent with the choice and one inconsistent with it" (p. 3). Thus, the properties of confronted distributions define the two regions. Previously, selected pairs of distributions are repeatedly offered to the decision maker whose choices determine the risk-aversion space that is in accordance with his preferences. Using distributions defined over several ranges of system outputs, it is possible to construct an interval measurement of a decision maker's absolute risk-aversion function over the relevant range of incomes by connecting lower and upper points of that measure with linear segments. With an idealized series of questions, it is possible to narrow the interval measurement until attainment of a desired level of accuracy.

To implement this procedure, King and Robison generated several hundred random numbers from a specified distribution and grouped them in sets of six observations each, in which each element has a one-sixth probability of occurrence. Next, after establishing reference levels for absolute risk aversion, the authors used Meyer's criterion to identify boundary intervals for each pair of distributions. Based on the decision maker's preferences about the distributions, the authors had enough elements to construct the interval measurement of absolute risk aversion, because "[the decision maker's] responses to these questions serve as the basis for our measurement of absolute risk aversion, since they divide risk aversion space into regions consistent and inconsistent with his choices" (p. 10).

The advantages of this technique are evident. First, the risk-aversion function is not restricted; it can have any shape, which does not happen with the risk-aversion function derived from estimated utility functions. Second, all the difficulties described earlier with the estimation of utility functions are avoided here. Finally, what the authors believed to be the greatest strength of their technique, it makes it possible for "the analyst to make trade-offs between the accuracy and the discriminatory power of his representation of decision maker preferences" (p. 24). This is not allowed when one uses utility functions because only one element will make part of the efficient set.

A Less Precise, More General Approach to Measurement of Decision-Maker Preferences

The interval approach discussed in the previous section is doubtless an important contribution to the measurement of decision makers' preferences through their level of risk aversion. It is possible to have lower and upper bound risk-aversion functions for the same individual for a large range of income. What is desired, however, is some way in which recommendations for well-defined classes of farmers can be made without knowledge of farmers' individual attitudes to risk.

In this section, a different approach is presented in which less precise measurements of risk aversion are used which allow for categorization of farmers into different classes according to socio-economic characteristics. Some accuracy is lost in terms of risk-aversion measurement. But what is gained by this approach is simplification for the agricultural extension service through the provision of efficient practices tailored to well-defined groups of farmers. The basis of this approach is the same as the interval approach developed by King and Robison (1979); i.e., it is possible to divide the risk-aversion space into areas in which decision makers are unanimous in their preferences. (See Figure 4.3.)

If one individual whose risk-aversion function $r_i(x)$ lies between the interval $(r_1(x), r_2(x))$ prefers distribution F to distribution G, then all the other individuals whose absolute risk-aversion function is less than or equal to $r_2(x)$ and greater than or equal to $r_1(x)$ will reveal the same preference.

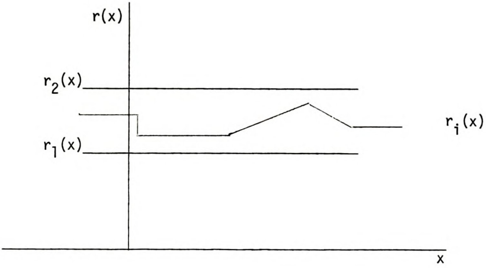

Figure 4.3.--Risk-aversion coefficient interval.

It is assumed here than farmers' utility functions are members of the exponential family. For risk-avoiding farmers,

$$U(x) = -e^{-rx}, \text{ where } r > 0, \tag{4.16}$$

for risk-taking farmers,

$$U(x) = e^{-rx}, \text{ where } r < 0, \tag{4.17}$$

and for risk neutrals,

$$U(x) = x, \quad \text{ where } r = 0. \tag{4.18}$$

Consequently, it is assumed that the farmers' absolute risk-aversion function can be considered as a constant for all the range of the system output. It is very convenient to work with this functional form of utility function because it is not a function of wealth. Several authors see this kind of function as an adequate approximation

of the preferences of many decision makers. (See, e.g., Howard, 1971; Savage, 1971; and Eliashberg & Winkler, 1972.)

To derive risk-aversion measures, a gamble is offered to farmers. The result of this risky-choice prospect makes a basis for the calculation of each farmer's certainty equivalent and consequently his risk-aversion coefficient.

Interview Procedures

In order to make recommendations to a large group of farmers, it is necessary to know the characteristics of a representative sample of individuals in order to extend the results to the whole community. For this research, 114 randomly chosen corn farmers located in the Cerrado region of Brazil were interviewed according to criteria described in Chapter III. The sample was stratified according to size of farm because it was believed that size of farms differed with respect to risk-aversion attitudes. Farmers were asked questions relating to their production systems and, more specifically, questions exploring the range of attitudes to risky corn yields. Farmers had to choose between hypothetical but realistic corn-production alternatives involving uncertainty versus sure outcomes.

The writer of this study participated in all the interviews, primarily in the question related to the choice between the risky and certain prospects. The seriousness of the question was explained to all the farmers, and their attention was called to the fact that there is no wrong or right answer. The questions were asked at a

speed that avoided boredom in the interview but, at the same time, that did not put the farmer in a dilemma. The farmers seemed to have no difficulty in understanding and answering the questions. The uncertain prospect contained two possible results with probabilities maintained at a constant level, i.e., at 25 percent for the worst outcome and at 75 percent for the best one. In order to avoid the use of probabilities and to be simpler for the farmer, a length of time to specify the frequencies was used, one out of four years for the worst outcome and three out of four years for the best outcome. The use of unequal probabilities is justified according to Scandizzo and Dillon (1976):

> Since in a simple two alternatives set, variance is completely confused with the range and skewness is completely confused with the relative value of the probabilities, it is clear that a risky prospect has to have both unequal outcomes and unequal probabilities to display the minimum characteristics of randomness required to produce a subject's reaction (pp. 11-12).

Further, the frame of time of four years "is the minimum amount of time required to make the prospect realistic to the subject" (p. 11).

The question as formulated for the interview was:

> Imagine that you are ready to plant your corn field and you are offered a choice between two alternatives called A and B. Would you prefer: (a) to use a "technology" which will give you every year a net cash return of Cr$ 6000.00/ha, or (B) to use a different "technology" which in three years out of four will give you a net cash return of Cr$ 7200.00/ha and in one year out of four will give you a net cash return of Cr$ 2400.00/ha?

If A was preferred to B, the cash return in A was decreased in steps of Cr$ 200.00 until either the farmer switched his preference to B or became equally indifferent to A and B. If the opposite occurred, the proceeding was analogous, the cash return in A being raised in

steps of Cr$ 200.00. The certainty equivalent was considered equal to the value of the cash return of alternative A when there was indifference. When a switch occurred, the certainty equivalent was considered as the value of the net cash return of alternative A minus Cr$ 100.00 if A was preferred to B and the same value plus Cr$ 100.00 if B was preferred to A. This means that indifference was considered to happen at the midpoint of the step change.

It should be mentioned here that the same question was given to all sample individuals, and, in order to be easily understandable, the question was phrased in terms of a unit of land (ha). However, each farmer was asked to extrapolate in terms of the land he intended to cultivate. Another advantage of this method is that recommendations can be made in terms of a unit of land.

Estimation of the Risk-Aversion Coefficient

The certainty equivalent is sufficient to classify the farmers as risk averse, risk neutral, or risk loving depending on whether that amount is less than, equal to, or greater than the expected value of the uncertain alternative.[3] The next step consists in calculating the risk-aversion coefficients. Two approaches can be used. The first one uses Pratt's relation:

$$\pi = 1/2\ V\ r(x) \qquad (4.19)$$

[3]The expected value of an uncertain prospect in this case is equal to: EV = (.75)(7200.00) + (.25)(2400.00) = Cr$ 6000.00

where π is the risk premium that is defined as the difference between the expected value of the gamble and the certainty equivalent; V(x) is the variance of the gamble;[4] and r(x) is the risk-aversion coefficient defined at the certainty equivalent point, given by the relation $r(x) = \frac{-U''(x)}{U'(x)}$.

This relation implies that the decision maker's risk premium is approximately r(x) times half the variance of the gamble; i.e., r(x) is twice the risk premium per unit of variance:

$$r(x) = 2\ \pi\ \frac{1}{V} \quad \text{, or in this case} \tag{4.20}$$

$$r(x) = 2\ \pi\ \frac{1}{4{,}320{,}000} \tag{4.21}$$

As the relation shows, the risk-aversion coefficient can be easily gotten.

There is, however, an alternative way to calculate risk-aversion coefficients, possibly more accurate, which employs the same assumption used earlier: Risk aversion is constant over the range of system outputs. It is assumed that the decision maker has a negative exponential utility function which implies constant absolute risk aversion. As was shown earlier in this chapter, at the indifference point, the utility of the certainty equivalent is equal to the expected utility of a risky prospect. Then,

$$U(CE) = (.75)\ U(7200.00) + (.25)\ U(2400.00) \tag{4.22}$$

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[4] $V = (.75)(6000.00 - 7200.00)^2 + (.25)(6000.00 - 2400.00)^2 =$ Cr$ 4,320,000.00.

Based on the above relation, the following equations can be formulated:

$$-e^{-r(x)\cdot(CE)} = (.75)(-e^{-r(x)\cdot(7200.00)}) + (.25)(-e^{-r(x)\cdot(2400.00)}) \quad (4.23)$$

for risk-averse farmers, and

$$e^{-r(x)(CE)} = (.75)(e^{-r(x)\cdot(7200.00)}) + (.25)(e^{-r(x)(2400.00)}) \quad (4.24)$$

for risk-loving farmers. In the case of risk-neutral farmers, r(x) is considered equal to zero. The constant absolute risk aversion is an average value. To find the value of r(x) that solves the above equations would require a search procedure (convergence method). The coefficient obtained from Pratt's procedure can be used as the initial value. The two procedures described are identical only if the distributions are normal, but a two-outcome gamble will hardly have a normal distribution.

It is interesting to note that the risk-aversion coefficient obtained from the described procedures is an average measure. Risk aversion, like utility, is defined as a point, and corresponding to a utility function is a risk-aversion function. The ideal should be to construct an interview procedure that would measure risk aversion at several wealth levels.

It is possible to change the range of outputs of the procedure used in the present study in order to have risk-aversion measures at

different income levels and not wealth levels. Different wealth levels would influence the risk-aversion attitudes and not the different income levels. It is hard to believe that changes in income in a short period of time would significantly change the wealth level. It is believed that risk aversion is not constant. It may decrease when the wealth level increases. However, the change in the wealth level does not happen from one day to another. It takes some time. And, if one is talking about one particular farmer, what is important is the present time, the present wealth level; that is, the recommendations should be made according to the risk-aversion coefficient measured at a point or at least as an average measure over the interval of the system outputs. However, if one is talking about a group of farmers, cross-section data can be used to relate risk-aversion measures and wealth or income levels. It is believed that other socioeconomic variables influence risk attitudes. These relations will be discussed in the next section.

A final point should be made here. If it is proved that certain variables, for example, size of farms, are important in classifying the farmers into different groups, a confidence interval, as constructed normally in statistics, could be used to obtain upper and lower bounds on $r(x)$. This interval should be the narrowest possible in order for the analyst to reduce as much as possible the set of efficient alternatives tailored for that specific group of farmers.

Figure 4.4 shows that, if such an interval defined by r_1 and r_2 can be constructed with a certain level of confidence, it is

not important what the different shapes are of the risk-aversion functions of different farmers, as shown by r_{i1} and r_{i2}. In other words, because r_1 and r_2 define a class of decision makers $U(r_1,r_2)$ that contains the farmers with the specified degree of confidence, the selected set of efficient alternatives would also have the same degree of confidence. We turn now to the important and final section of this chapter, the relation between the derived risk-aversion measures and the set of socioeconomic and structural variables that characterize the farmers.

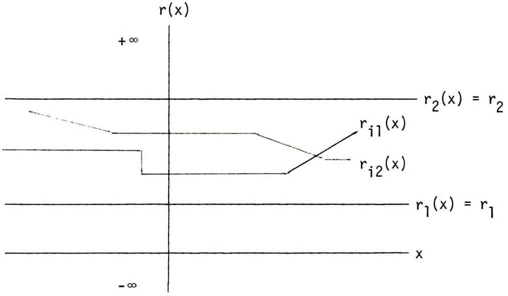

Figure 4.4.--Different shapes of the risk-aversion functions.

The Determinants of Farmers' Risk Attitudes

The utility and consequently the risk attitudes associated with the possible outcomes of a risky prospect are probably dependent

on more variables than the wealth level. In general, it is assumed that, other things being constant, younger farmers are less risk averse than older ones, that the more educated the farmer is, the greater is his willingness to assume risks, and the wealthier the farmer is, the greater his willingness to assume risks. The difficulty associated with including these variables in the decision model and the fact that they cannot be held constant calls for alternative techniques in order to lessen the impreciseness of this approach.

To date, the studies by Dillon and Scandizzo (1978), Moscardi and de Janvry (1977), Binswanger (cited in Douglas et al., 1979), and Halter and Mason (1978) seem to be the only ones that relate risk-aversion measures to decision makers' characteristics. The producer attributes more frequently used in these studies are farm size, legal form of ownership, age, family size, education, income, and gambling attitude, among others.

Table 4.2 summarizes the results obtained by Moscardi and de Janvry on a regression equation that related risk aversion and some socioeconomic variables of peasants in Puebla, Mexico. The results are in accordance with the authors' hypothesis that the farmers' socioeconomic and structural characteristics can be used to explain their risk-bearing capacity. The statistically highly significant results in the relation between risk aversion and off-farm income and land under control agree with Arrow's hypothesis that absolute risk aversion decreases with increasing wealth.

Table 4.2.--Regression estimates: risk aversion versus socioeconomic and structural characteristics.

Variables in Logs	Regression Coefficient	t-value
Intercept	2.079950	1.9248
Age	0.632502	1.0728
Schooling	-0.121252	-0.4496
Family size	-0.011686	-0.0424
Off-farm income	-0.091616	-2.0901
Land under control	-0.477450	-3.0141
Solidarity group membership	-0.365100	-2.3103

Source: Moscardi and de Janvry (1977), p. 716.

The work by Dillon and Scandizzo (1978), partially discussed in Chapter II, indicated that income level and other socioeconomic variables seem to influence risk attitude of small farm owners and sharecroppers in Brazil. Table 4.3 provides some of the "best" statistical fits of their study. The dependent variable is the risk premium. The standard deviation variable is used as a measure of risk. In both cases, the required risk premium is positively related to the riskiness of the random prospect, the ethical beliefs against gambling, age, and, for small owners, the household size. As before, Arrow's hypothesis that risk decreases as income increases prevails here. It was also concluded that, in general, small owners tend to be more risk averse than sharecroppers.

Halter and Mason (1978), studying attitudes toward risk among Oregon farmers, found, through regression analysis, that age, education, and percentage of land ownership, either separately or

Table 4.3.--Regression estimates: two tenure groups with subsistence assured.

Independent Variable	Small Owners		Sharecroppers	
	Regression Coefficients	Standard Errors	Regression Coefficients	Standard Errors
Constant	-9687***	1808	- 2103**	727
Income	- .28***	.08	- .11	.08
Age	34.95*	17.86	3.32	9.98
Household size	124.40	70.99	-17.57	51.15
Gambling attitude	422.52	405.74	591.40*	266.85
Standard deviation	3.93***	.46	2.71***	.30
R^2	.61	..	.71	..

Source: Dillon and Scandizzo (1978), p. 433.

*Significant between .01 and .05 levels.

**Significant between .001 and .01 levels.

***Significant above .001 level.

jointly, are statistically significant variables related to risk attitude.

Eleven farm and decision-maker characteristics were used in a stepwise regression having Pratt's risk-aversion measure as the dependent variable. The results are presented in Table 4.4. The signal of the education is in agreement with the hypothesis of the authors and with other studies. The same is not true for the variables age and percent ownership when considered above. But, as Halter and Mason pointed out, the effects of other variables jointly or conditionally must be considered. "Education level, for example, interacts with both age and percent ownership and any evaluation of these two effects should consider level of education jointly" (p. 107). One interesting result that they found is that older, less-educated farmers are more risk loving and that older, well-educated farmers are risk averse. These results should be interpreted with caution, however, and cannot be generalized because of the small sample size.

Table 4.4.--Results of statistical tests.

Variable	Regression Coefficient	Student's "t" Values
Constant	11.547	1.64
Percent owner	0.192	4.70
Education	-6.793	-2.38
Age	-2.088	-2.24
Education squared	1.088	3.02
Percent owned x education	-0.060	-4.08
Education x age	0.587	2.07

Source: Halter and Mason (1978), p. 105.

The Relation Between Risk Aversion and Farmers' Characteristics in the Present Study

We turn now to discuss the model used in this present study. It should be remembered here that one of the objectives of this study was to recommend fertilizer-application rates tailored to well-defined classes of farmers. To work with the stochastic dominance with respect to a function criterion presented earlier, a procedure is needed that uses the relationship between risk attitudes and other variables to classify the farmers. Regression analysis and discriminant and classificatory analysis are the tools to describe these relationships.

The variables selected are age, education, family size, tenure arrangement, income, size of farm, and contact with sources of information. It is believed that, more than the education level alone, the contact with sources of information influences attitudes toward risk. The introduction of this new variable is based mainly on two reasons. First, it is possible for a less-educated farmer to have more access to sources of information than to a more-educated farmer, allowing the farmer to have a clearer understanding of new technologies. In terms of temporal cause-effect outlook, this means there is a greater probability of increasing ownership and consequently the wealth level and therefore a higher capacity of the individual to take risks in agricultural production. Second, it is common among poor farmers to find individuals who, even though they have attended three or four years of school, do not read or write because they have not had the opportunity after leaving school to practice

what they learned. In this case, the education level represented by the years of school is meaningless.

One information index[5] was constructed to represent the contact-with-sources-of-information variable. The index is composed of 11 different information sources. It was assumed that the relative value of these sources could be obtained from persons in extension, fertilizer sales, and rural banking services. These values would serve then to weight the different information sources. To each farmer, one value of the information index was presumed based on a presence or absence of each one of the 11 sources. Table 4.5 contains the coefficients for the information index. For example, if a farmer had contact with the private extension service during the last year, 156 points would be added to his information index. The possible total is equal to 1,000 points.

The regression model has as the dependent variable the absolute risk-aversion measure given by Pratt's relation because, as discussed before, the coefficient allows interpersonal comparisons. The independent variables are income, age, family size, wealth level,[6] and education or information level. The level of income can be thought of as influencing farmers' attitudes to risk. However, the opposite relationship could also be considered, i.e., the farmer's attitude

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[5]The construction of this index was based on the study by Nelson (1971). See Appendix A for the method of calculating the index.

[6]Because of the difficulties associated with getting this value, the size of farm or farms owned by the individual is used as a substitute for the wealth level.

toward risk as affecting his level of income, because it can be assumed that lesser degrees of aversion to risk lead to a greater likelihood of becoming wealthier.

Table 4.5.--Coefficients for the information index.

Sources	Coefficient
1. Newspaper: read	103
2. Private extension: contact	156
3. Radio: own	109
4. Banks: contact	52
5. Demonstration plots and experiment stations: contact	87
6. Meetings and expositions: contact	77
7. Government extension: contact	176
8. Agricultural magazines: read	117
9. Technicians of cooperatives: contact	91
10. Television: own	16
11. Pamphlets and agricultural communications: read	16
Total	1,000

This, then, is a simultaneous-equation model that involves a two-stage least-square procedure. Several cross-sectional regressions are computed based on different sets of independent variables, various functional forms, and diverse subsets of the farmers' sample based mainly on different tenure arrangements. The regression analysis shows the intensity of the relationship between the risk revealed by the farmers and their socioeconomic characteristics but does not indicate anything about how to group the farmers in some relative homogeneous classes according to their degree of risk aversion. For this reason, the discriminant analysis, a multivariate procedure, is

used because it is a powerful statistical tool, and it seems appropriate for the purposes of this present study. The number of groups based in the absolute risk-aversion coefficients will be set prior to the analysis. The discriminant procedure gives the percentage of the observations correctly classified into each group. If the results are considered satisfactory, this analysis provides an additional link between the two separate parts of the Bernoullian decision theory of risk used in this research. The first part refers to the utility component of the study that can be provided by the farmers themselves according to the techniques described in this chapter. The second part, the probability component, is the use of objective probabilities from fertilizer experimental results reported earlier.

The discussion of methodology is now complete. The criterion identified by Meyer has been defined. This criterion provides a useful basis for normative recommendations. These results are presented in the next chapter.

CHAPTER V

PRESENTATION AND ANALYSIS OF RESULTS

This chapter reports risk-aversion measures, the estimation of the risk-aversion function, the classification of farmers according to their revealed attitudes toward risk and their socioeconomic characteristics, and, finally, the efficient fertilizer application rates for each of the defined classes.

Risk Attitude Coefficient Estimates

As described in Chapter IV, certainty equivalent[1] measures are sufficient to classify the farmers as risk averse, risk neutral, or risk loving, depending on whether that amount is less than, equal to, or greater than the expected value of the uncertain alternative. The distribution of the analyzed sample farmers by their classification according to the risk attitude, based on the described criteria, is summarized in Table 5.1. These results show that not all farmers can be considered risk averters, as some studies have assumed. However, this table shows that risk aversion is most common among small farmers, with the greatest concentration among small owners.

[1]It should be remembered that a certainty equivalent is the amount exchanged with certainty that makes the decision maker indifferent between this exchange and some particular risky prospect. In the case of a linear utility function, this value is the expected value of the prospect; in this particular case, it is Cr$ 6,000.

Table 5.1.--Percentage distribution of farmers classified by tenure type and revealed risk attitudes.

Risk Attitude	Tenure Group					
	Owners			All Owners	Tenant Farmers	Share Croppers
	Small	Medium	Large			
Aversion	90	68	41	66	71	65
Neutrality	5	20	23	16	4	13
Preference	5	12	36	18	25	22

In terms of small farmers, it is interesting to note that these findings are similar to those obtained by Scandizzo and Dillon (1976) for a population of subsistence peasants in northeast Brazil. They found that, on the average, small owners seem to be more conservative than share croppers, which suggests, as these authors wrote, "that sharecroppers feel more secure at considerably lower levels of income than small owners. Perhaps this is because they are more used to larger fluctuations of returns and/or because, at the same time, they can share their risks with the landlords" (p. 13). All groups show a significant percentage of their element displaying risk preferences.[2] This emphasizes the importance of the model used in the present study, which allows for differences of risk preferences between farmers.

[2]It should be remembered that, in all cases, risk was measured at a point.

Measurements of Risk Aversion

As important as the classification of farmers according to risk preferrers, risk neutrals, or risk averters is the magnitude of their risk attitudes. For this it is necessary to obtain a measure that reveals the precise attitude toward risk and the resulting risk premium. Using the methods described in Chapter IV, the responses to questions presented to farmers provide a value of r, the risk-aversion coefficient.

To help relate r to risk premiums and certainty equivalents, Table 5.2 presents some results of the gamble offered to the farmers, i.e., a gamble that yields either Cr$ 7,200 with probability equal to three-fourths or Cr$ 2,400 with probability equal to one-fourth. For example, a farmer indifferent between a sure return of Cr$ 5,500 and the risky prospect would have a risk aversion measure equal to .203. The figures in this table were obtained assuming that the

Table 5.2.--Relationship between risk-aversion coefficients, certainty equivalent, and risk premium.

$r(10^3)$	Certainty Equivalent (Cr$)	Risk Premium (Cr$)
-0.947	6,900	-900
-0.305	6,500	-500
0.000	6,000	0
0.203	5,500	500
0.347	5,100	600

decision maker has a negative exponential utility function, which implies constant absolute risk aversion, and that the utility of the risky prospect is equal to the utility of its certainty equivalent. A range of possible outcomes using this approach and the Pratt's relation, both described earlier, is shown in Figure 5.1. As can be seen, both methods present similar results only around the risk-neutral region. For reasons presented earlier, the measures obtained from the first approach are used in this study.

The cumulative distribution functions of r can be estimated using Schlaifer's (1959) fractile rule. The estimated frequency distributions obtained from the cumulative distributions, for each different group of farmers, are shown in Figure 5.2.

The results show a distribution of risk aversion highly skewed toward the risk averters (and centered around .228) for small owners, and more skewed toward the risk preferrers (and centered around -.019) for the large owners. In the cases of medium owners (centered around .070) and share croppers (centered around .075), the distributions seem to have a normal shape. The greater variation (amplitude) of the risk-aversion measures is present in the case of the tenant farmers. This particular group shows elements (individuals) extremely risk averse ($r = 1.98 \times 10^{-3}$) and elements clearly risk loving ($r = -2.88 \times 10^{-3}$). Perhaps because of the characteristics of this particular group, all kinds of behavior can be expected. They are very poor farmers, belonging to a community that receives government help on a group basis. They come from several regions of the country; some of them never have farmed before. They receive

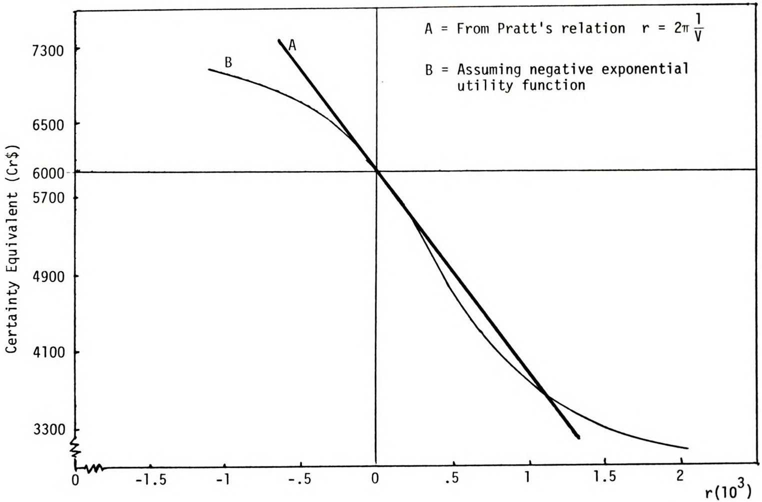

Figure 5.1.--Values of the risk-aversion coefficient using two different approaches.

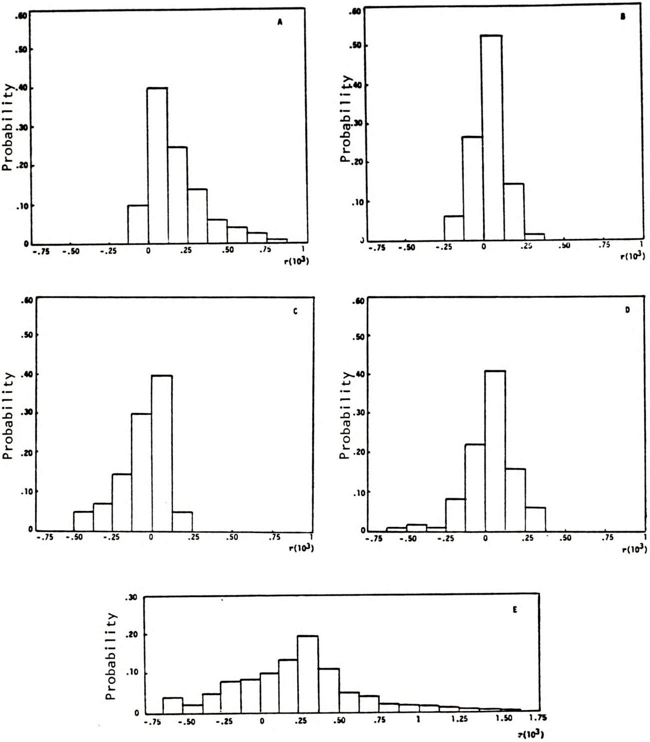

Figure 5.2.--Probability distribution of risk attitude coefficient estimates for (A) small owners, (B) medium owners, (C) large owners, (D) share croppers, (E) tenant farmers.

a small portion of land and repay with labor for the community and/or for the government. Usually every year they "receive" a different portion of land to farm. They do not try to "invest" in the land they are farming, first because of their poor financial condition and second because they have to "return" the land after the season's crop, and probably will cultivate the next crop on a different piece of land.

Both the share croppers and the tenant farmers were included in the analysis thus far, just to show how different tenure arrangements can reveal different attitudes toward risk. It is assumed that, for the other objectives of this study, emphasis should be given to the owner-farmer group. It seems logical to think that the "pioneer" explorers of the Cerrado should be owners because of the necessity of capital investment and consequently financing to start the intensive cultivation of that region. In time, surely, all different tenure groups will appear, but for the purposes of the present study, it seems adequate to work only with the owners group.

Figure 5.3 gives a better idea about the distributions of r for three different categories of owners. The three distributions have different median values and locations, which support the hypothesis that, in general, large farmers are less risk averse. The medium-size farmers are shown to have a more neutral position. Although there appear to be differences in risk attitudes among the different-sized farmers, it is not possible to have a distinct interval of r for each different class. It is not possible, for example, to classify

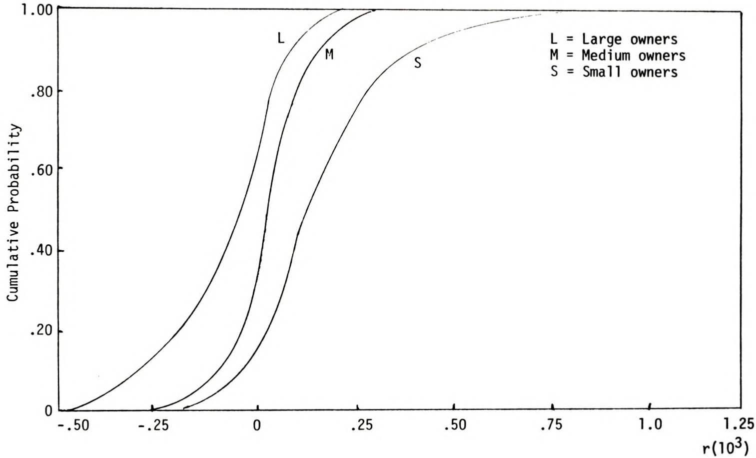

Figure 5.3.--Cumulative probability distributions of risk attitude coefficient estimates for small, medium, and large owners.

the small, medium, and large farmers as risk averters, risk neutrals, and risk preferrers, respectively. This point will be discussed later.

Determinants of Attitudes Toward Risk: Regression Estimates

As seen above, the size-of-farm variable alone, although it seems to have some influence on risk attitudes, is not sufficient to classify the farmers. Other producer attributes, perhaps, are influencing farmers' behavior toward risk. Other variables such as age, education level, family size, income, and contact with sources of information, possibly accounting for some of the variation in risk attitude, are used in a regression analysis. Several cross-sectional regressions were computed, based on different sets of independent variables, various functional forms, and diverse subsets of the farmer sample. In all cases, the dependent variable is the absolute risk-aversion coefficient given by Pratt's relation because, as seen earlier, this measure allows interpersonal comparisons.

Attempts to find any significant relationship between the estimates of r and the variables considered were, in general, successful. In most of the cases, the signs of the parameters were in accord with what was expected.

Table 5.3 presents least squares estimates for the three owner-tenure groups and for all farmers pooled together, for one among several of the models tried. As explained in Chapter IV, it was thought that a two-stage least squares procedure would be adequate for this analysis because of a possible simultaneity between

Table 5.3.--Two-stage regression estimates: risk aversion versus socioeconomic and structural characteristics.

Endogenous Variable = Income

Variable	Small	Medium	Large	All
$r(10^3)$	-1.52×10^5 (-.69)[a]	-4.06×10^5 (-.72)	-3.23×10^6 (-1.23)	-1.18×10^6 (-1.83)
Size of farm (ha)	-1.10×10^2 (-.05)	2.53×10^3 (3.25)	1.32×10^2 (1.24)	2.55×10^2 (5.74)
Age (years)	-7.73×10^2 (-.42)	-2.13×10^2 (-.07)	3.16×10^3 (.31)	4.59×10^3 (.81)
Scholarity (years)	-1.56×10^4 (-.60)	2.85×10^3 (.32)	6.91×10^4 (1.20)	4.87×10^4 (2.04)
Constant	1.82×10^5 (1.32)	1.47×10^5 (.74)	7.29×10^4 (.12)	-2.90×10^4 (-.10)

Endogenous Variable = r

Variable	Small	Medium	Large	All
Income (Cr$ 1,000)	-2.15×10^{-5} (-.74)	-3.26×10^{-7} (-1.69)	-8.80×10^{-8} (-1.33)	-9.03×10^{-8} (-1.57)
Family size (no.)	8.80×10^{-2} (-.59)	-1.84×10^{-2} (-1.60)	6.41×10^{-3} (.57)	-8.47×10^{-3} (-.86)
Age (years)	-3.75×10^{-2} (-.54)	5.60×10^{-3} (1.55)	-4.42×10^{-5} (-.02)	5.10×10^{-3} (1.82)
Information index	-5.06×10^{-5} (-.03)	1.92×10^{-5} (.08)	-2.61×10^{-4} (-.91)	-4.89×10^{-4} (-2.37)
Constant	2.99 (.72)	4.14×10^{-2} (.20)	2.09×10^{-1} (1.06)	2.15×10^{-1} (1.19)

[a]Figures in parentheses are the computed "t" values.

r and income. In the risk-aversion equation, the only statistically significant parameter is the one for the variable that accounts for the contact with sources of information (henceforth called information index), confirming the hypothesis that the more educated (informed) the farmer is, the greater is his willingness to assume risk.

As suggested by Halter and Mason (1978), several different functional forms were tried, taking into consideration the linear and quadratic terms of the variables as well as their linear interaction terms. The only significant results were found in the model for all owners analyzed together, using a stepwise procedure. These results are presented in Table 5.4, in which only the statistically significant estimates appear. Although statistically significant, the coefficient for the information index variable has a signal opposite that for the model presented in Table 5.3. These results seem to be in accordance with Arrow's hypothesis that absolute risk aversion decreases with increasing wealth. Also, the assumption that, other things being equal, younger farmers are less risk averse than older ones, is confirmed in this case.

The results reveal that some socioeconomic variables influence farmers' attitudes toward risk. The next step is then to classify the farmers in relatively homogeneous classes according to their degree of risk aversion. The discriminant analysis technique seems to be an adequate procedure for this purpose. The results obtained using this approach are presented in the following section.

Table 5.4.--The relation between r and farmer attributes (all owners together).

Variables Remaining in the Equation	Regression Coefficients	Students' t Values
Age	.1004	2.14
Income	$-.3028 \times 10^{-5}$	-2.62
Information	$.6226 \times 10^{-2}$	2.04
Information x income	$.3218 \times 10^{-8}$	2.47
Constant	-3.8172	-2.38
R^2	.79	

Classification of Farmers According to Their Degree of Risk Aversion

Chapter IV showed that, in order to have a perfect match with the stochastic dominance with respect to a function criterion, it is necessary to have well-defined groups of individuals, i.e., groups of farmers that can be classified according to their upper and lower bounds of measures of risk. We think discriminant analysis is an appropriate tool for this purpose, because it allows the researcher to maximize the discrimination among predefined groups of individuals by combining the variables in some way and it helps in placing new individuals in groups by establishing rules for that placement. The same variables used in the regression analysis are useful here. The problem is to find the linear combination of these variables that produces the maximum difference between the previously defined groups. The discriminant function does this. If this function produces significant results, it can be used to allocate new individuals of unknown group to one of the original groups. Then a new sample of

farmers can be categorized in different classes, with similar attitudes toward risk, on the basis of the linear discriminant function of their socioeconomic and structural variables.

The starting point, then, is to classify the farmers in distinct groups, according to the measure r. Figure 5.3 showed distinct distributions of risk attitudes for each tenure arrangement. To attribute a different class, based on confidence intervals, to each of the tenure groups would not be helpful because great portions of the intervals would overlap. Thus it was decided to combine the three groups' observations and to estimate the cumulative probability distribution of the risk-attitude coefficients. These results are reported in Figure 5.4. Figure 5.5 shows the frequency distributions obtained from the cumulative distribution function. Inspection of these figures shows that this distribution appears to be normal. In fact, a normal distribution, with mean equal to .0880 and variance equal to .0365, fits the observations very well. It was decided to divide the area under the probability distribution function into three equal parts; i.e., we truncated the tails of the distribution in the plus and minus 1.65 standard deviations from the mean. Now we have three subpopulations, which are believed to have similar attitudes toward risk and are defined by the measures of r presented in Table 5.5. The farmers whose risk-aversion measure lies in one of these intervals can be said to belong to a low-risk (I), intermediate risk (II), or high-risk (III) aversion group.

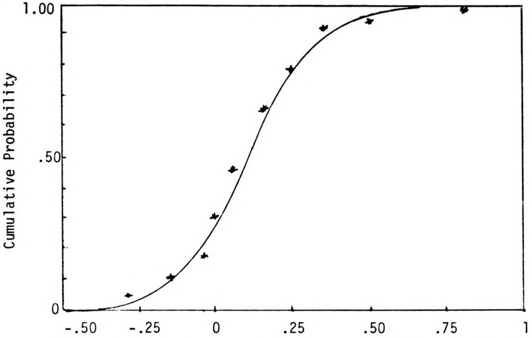

Figure 5.4.--Cumulative probability distributions of risk attitude coefficient estimates for all owners ∿ N(.0880, .0365).

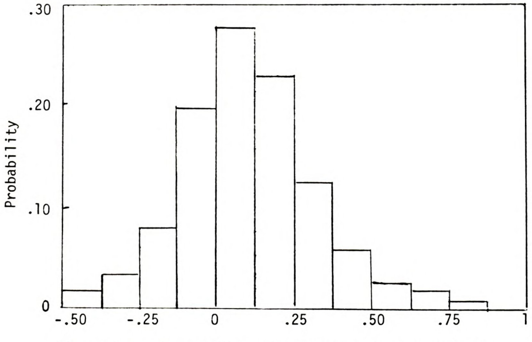

Figure 5.5.--Probability distribution of risk attitude coefficient estimates for all owners.

Table 5.5.--Limits of r for different groups of farmers.

Group	$r(10^3)$ Lower Bound	$r(10^3)$ Upper Bound
I	-.22732	.00583
II	.00584	.17017
III	.17018	.40332

Table 5.6 shows the average values of the socioeconomic variables and the number of farmers classified in these three different groups. These variables were used in the discriminant analysis. With the exceptions of the family size variable, there seems to be a strong association between risk attitudes and the other variables.

Now we must estimate the discriminant function that will classify the farmers in the same groups--I, II, and III. If the percentage of observations correctly classified into each group is considered satisfactory, this means that there is a relationship between r (or classes of individuals based on r) and the variables used in the analysis.

Classification of Farmers According to Risk Attitudes and Discriminant Analysis

The computer program DISCRIMINANT[3] was used to perform the discriminant analysis through a stepwise method selecting the "best" set of discriminating variables. In this case, all of the variables

[3]Subprogram DISCRIMINANT of SPSS--Statistical Package for the Social Sciences. See Nie et al. (1975).

Table 5.6.--Average values of socioeconomic variables for farmers categorized according to their attitude toward risk.

Group	Age (Years)	Scholarity (Years)	Information Index	Family Size	Size of Farm (Ha)	Income (Cr$ 1,000)
I (n=23)	43.91	7.70	722.61	5.39	1,130.22	993.66
II (n=29)	50.79	4.52	559.55	6.69	424.17	301.61
III (n=15)	55.20	2.80	400.13	5.60	49.33	116.91
I-II-III (n=67)	49.42	5.22	579.84	6.00	582.63	497.83

remained in the final function. The results of this analysis are presented in Table 5.7. It is possible, then, to compare the classification given by the discriminant analysis with the number of elements set for each group prior to the analysis. In total, 86.6 percent of the known cases were correctly classified, being that 82.6 percent remained in the low-risk-aversion group, 89.7 percent in the risk-neutral group, and 86.7 percent in the high-risk group. We consider these results satisfactory.[4] One important point to be observed here is that all misclassified farmers were misclassified into adjacent rather than extreme classes.

Table 5.7.--Prediction results, according to risk aversion and discriminant analysis.

Actual Group	Number of Cases	Predicted Group Membership		
		Group I	Group II	Group III
I	23	19 (82.6)[a]	4 (17.4)	0 (0.0)
II	29	3 (10.3)	26 (89.7)	0 (0.0)
III	15	0 (0.0)	2 (13.3)	13 (86.7)

[a]Figures in parentheses indicate the percentage of cases correctly classified.

The classification function coefficients are presented in Table 5.8. The placement of a new element is achieved through the use of this set of classifications, one for each group. These

[4]Classification made according to the predicted results given by the regression parameters of Table 5.4 presented the same total percentage of cases correctly classified.

coefficients are to be multiplied by the respective variable values, summed together, and added to a constant. The new individual would be classified into the group with the highest score.

Table 5.8.--Classification function coefficients.

Variables	Groups		
	I	II	III
Age (years)	1.3015	1.3404	1.4623
Scholarity (years)	.21061	.18259	.15690
Information index	.11217	$.99098 \times 10^{-1}$	$.82083 \times 10^{-1}$
Family size (no.)	-1.8961	-1.6800	-2.1900
Size of farm (ha)	$.41856 \times 10^{-2}$	$.25723 \times 10^{-2}$	$-.27495 \times 10^{-2}$
Income (Cr$ 1,000)	$-.14652 \times 10^{-5}$	$-.41314 \times 10^{-5}$	$-.31770 \times 10^{-5}$
Constant	-63.166	-55.392	-50.615

A final point should be made here. It is important to have classification functions as simple as possible, for prediction purposes. The computer program furnishes the entry criterion. The variables, by decreasing order of importance, are: information index, income, size of farm, family size, age, and scholarity. We then decided to try several different functional forms. The best results were achieved with the following set of independent variables: family size, size of farm, income, and information index. In this case, 80.6 percent of the cases were correctly classified.

The results obtained in this section allow us to continue this study; i.e., we now have information about the different categories of farmers. The lower and upper bounds of these respective

defined groups of decision makers can be used in the efficiency-selection criteria that predict the rates of fertilizer applications best suited to each of the analyzed groups.

The Identification of Preferred Choices

The final objective of this study is to examine the impact of different degrees of risk aversion on optimal fertilizer rates, i.e., to identify optimal levels of fertilizer application on corn production in the Cerrado region of Brazil, for different classes of decision makers categorized by their attitudes toward risk.

The results obtained thus far provide only part of the information required to apply the evaluative criterion of stochastic dominance with respect to a function in ordering any two possible action choices. The results refer to the utility component of the study, and were provided by the farmers themselves. One now needs information on the probability component of the study; this information will be provided through the use of objective probabilities from the fertilizer experimental results reported in Chapter IV.

Objective Probabilities

The starting point in obtaining the objective probabilities is to use the corn yield observed for each point (eight consecutive crops) of each of the ten treatments reported earlier. The first step is to transform each yield point into a respective return point by the linear expression

$$R_{ij} = P_c C_{ij} - P_v V_{ij} - F$$

where R denotes return; C denotes corn yield; V denotes variable factors of production related to amounts of fertilizer applied, phosphorous in this case, and other related variable inputs; F denotes fixed costs, all per unit area (ha); P_c and P_v are the respective unit prices of C and V; and the subscripts ij denote, respectively, the i^{th} treatment, the j^{th} crop, and/or the j^{th} level of fertilizer applied.

The next step is to estimate the return distributions. One recommended way is to use Schalaifer's (1959) rule that: "If a sample of n observations is drawn from some distribution and analyzed in order of size, the t^{th} observation is a reasonable estimate of the t/(n+1) fractile of the distribution" (p. 104). Then one can graph a smooth cumulative distribution function (CDF) through the fractile estimates. This rule is nonparametric and, according to Anderson (1973), it "is reasonable in the sense that the expected fraction of the population falling below the t^{th} order statistic is t/(n+1)" (p. 77).

In our case, there would be ten distributions of outcomes associated with each different action choice (treatment). As stated earlier, the application of stochastic dominance with respect to a function criterion involves pairwise comparisons of these distributions. In this particular case, 45 comparisons would be necessary. This selective criterion would point out the efficient treatment(s) or action choice(s) for each different class of farmers; i.e., it will provide an ordering of the strategies that is consistent with the postulates of expected utility for all distributions.

This procedure, as described so far, is useful when one intends to analyze only the observed data. A good example is given by the selection of new crop varieties from nursery trials. The different results obtained with the same variety will allow the researcher to estimate the respective probability distribution in the way described earlier, and then to apply the Meyer criterion.

To accomplish the objectives of this study, however, it is necessary to have an approach in which it would be possible to analyze levels of the decision variable (fertilizer application, in this case) in other than the original observations. This would allow us to explore more adequately the possible effects of the credit policies, for example. In this particular case, one could extend the analysis to 12-year plans--the length of time the farmers have to repay the loans. The analysis could be extended in another direction also; i.e., one would have the possibility of generating a large number of action choices other than the predetermined alternatives. It is hard to believe that the best alternative is among these few predetermined alternatives. Therefore, this approach would permit one to determine more efficiently the levels of the decision variable.

In this particular case, we think that a convenient approach would be to relate the variables in the same way we do in a conventional production-economics analysis, i.e., to make use of a production function for corn yields. With this function, it is possible to predict distributions for however many levels of decision variables

are desired and to apply the outlined procedure for locating the efficient set.

In the next section the estimated production function and the final results of this study are presented. A recent and promising technique developed by Robison and King (1978) and King (1979), in which the Meyer approach is incorporated as the evaluative criterion in a Monte Carlo procedure, is used.

Production Function

The fertilizer experiment described in Chapter III was conducted to evaluate different phosphorus fertilization strategies and the residual effectiveness of the fertilizer. The soils of the Cerrado region of Brazil are very low in available phosphorus in their natural state and require large initial applications and regular maintenance applications after the first crop. The economic conditions should dictate if this large amount of phosphorus needed to correct the deficiency in soils could be spread over the years. The results of the experiment demonstrate that there is a significant residual effect of phosphorus. This carry-over effect is important and it needs to be estimated. We make use of a statistical method developed by Stauber, Burt and Linse (1975) to estimate carry-over phosphorus and corn yield-response function, simultaneously.

According to those authors, the carry-over relationship can be specified by the first-order difference equation

$$R_t = \alpha_0(A_{t-1} + R_{t-1})^{\alpha_1} W_{t-1}^{\alpha_2} \quad t = 1,2,... \quad (5.1)$$

where R_t denotes the residual phosphorus in the soil in year t, in Kg/ha of phosphorus carried over from applications in previous years; A_{t-1} (the decision variable) denotes the phosphorus applied to corn in year t-1; W_{t-1} denotes seasonal precipitation in millimeters received during the growing season in year t-1; and α_0, α_1, and α_2 denote the unknown parameters.

In our case there is no residual in the first year; therefore, $R_1 = 0$. It is assumed that corn yields are influenced by plant-available phosphorus and amounts of rain received,

$$C_t = f(P_t, W_t) \tag{5.2}$$

where C_t denotes corn yield in kilos per hectare for year t and $P_t = A_t + R_t$ denotes plant-available phosphorus in year t. Available phosphorus this year would be, then, a function of phosphorus applied this year and applied phosphorus and weather conditions in previous years. Statistically, we would have

$$C_t = \beta_0 + \beta_1 P_t + \beta_2 W_t + \beta_3 P_t^2 + \beta_4 W_t^2 + \beta_5 P_t W_t + e_t \tag{5.3}$$

where the betas denote the unknown parameters of the production function and e_t denotes the random error term.

Since $P_t = A_t + R_t$, and making use of Equation 5.1, we can have the following relationship

$$C_t = g(A_1, A_2, \ldots A_t, W_1, W_2, \ldots W_t; \alpha_0, \alpha_1, \alpha_2, \beta_0, \beta_1, \ldots \beta_5). \tag{5.4}$$

Because of the nonlinearities in Equation 5.1, we made use of a nonlinear method (Complex Algorithm) to estimate the unknown parameters. The

Complex Algorithm[6] is an iterative method; i.e., starting values are picked and upgraded by the algorithm until a convergence criterion is satisfied. To get the "best" fit for the estimated equation, the complex algorithm was set to minimize the least squares objective function

$$S = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2$$

where $\hat{Y}_i$ = predicted or calculated value of the dependent variable for the i^{th} observation,

Y_i = experimental value of the dependent variable for the i^{th} observation, and

N = number of experimental points.

The best values of the model parameters are obtained when the objective function is minimized. A subroutine for linear regression was adapted to the complex algorithm, which provides standard deviations for the estimated parameters of Equation 5.3. The results are presented in Table 5.9. The signs of the estimates (a's and b's) are the expected ones. The origin is far from the sample values of independent variables, which gives little importance to the b_0 estimate.

The estimated production function can now be used to predict values for corn yields using any combination of values for the independent variables, i.e., any particular fertilizer strategy, of which there is a large number of combinations. We decided to have the decision variable A_t approximated by discrete intervals on

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[6]See Kuester and Mize (1973).

their continuous scales of measurements. The levels of A (kilos of phosphorus applied per hectare) were 0, 80, 160, ... , 2,000.

Table 5.9.--Regression results for yield and carry-over equations.

Coefficient	Variable	Estimate	Standard Error[a]	Student's "t" Values[a]
Carry-over equation:				
a_0	..	498.0000	..	..
a_1	P_{t-1}	1.0121	..	..
a_2	W_{t-1}	-1.0235	..	..
Yield equation:				
b_0	..	-3425.99070	3153.59340	-1.09
b_1	P_t	5.49900	1.73520	3.17
b_2	W_t	15.36611	9.90118	1.55
b_3	P_t^2	-.00506	.00063	-7.99
b_4	W_t^2	-.01155	.00778	-1.48
b_5	P_tW_t	.00957	.00253	3.79
R^2	..	.80		

[a]The standard errors and t values are only approximate because of the nonlinearities in the parameters.

The Empirical Decision Model

All the information required for the application of the evaluative criterion of stochastic dominance with respect to a function were provided in the previous sections of this chapter. The utility

and the probability components of the decision model can be combined to select the set of efficient choices for a class of decision makers. However, a very large number of choices can be generated, which produces a computational burden because the process of stochastic dominance involves pairwise comparisons.

A technique recently developed by Robison and King (1978) and King (1979) is the solution for this problem. This technique allows the analyst to identify and also evaluate a large number of possible strategies without modifying the nature of the problem considered. It is a powerful and highly flexible technique that is generally applicable in a wide range of decision problems.[7]

This technique incorporates the stochastic dominance with respect to a function criterion into a Monte Carlo programming as the evaluative criterion. The flow chart in Figure 5.6 illustrates how the procedure operates. A strategy is constructed at random, and a distribution of outcomes is generated for several different states of nature. A second strategy is constructed, also at random, and its distribution of outcomes is generated in a manner analogous to the previous one. The two strategies are then compared, using the Meyer criterion for the classes of farmers defined by the interval of values of the absolute risk-aversion coefficients, presented earlier. The algorithm stores the dominant function (its distribution of outcomes) and drops the dominated one, or stores both if neither strategy dominates the other. New strategies are generated

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[7]See King (1979) for a detailed explanation of this technique.

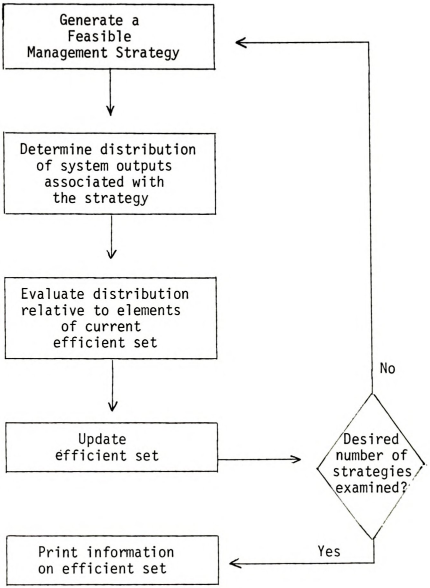

Figure 5.6.--Flow chart of a Monte Carlo programming.

Source: King (1979), chapter 5.

and compared with the current set of efficient strategies in a sequential fashion until a desired number of alternatives has been examined.

The Construction of the Strategies

To consider the financing conditions offered by the Brazilian government for the exploration of the Cerrado region, a 12-year planning horizon was considered in this study--a length of time estimated to be suitable for the analysis of the credit policies and also to analyze the residual effect of fertilizer application.

A management strategy here is defined as a set of 12 controllable system input levels that determines the amounts of fertilizer to be applied every year of the planning horizon. Then one has

μ_i = kilos of phosphorus applied in the i^{th} year

$i = 1, \ldots, 12$

The decision variable is approximated by discrete intervals of 80 kilos of phosphorus applied per hectare, the same as was used in the experiment. These controllable system input levels are constrained to the following lower and upper limits:

Minimum Level (Kg/ha)	Variable	Maximum Level (Kg/ha)
160	μ_1	2,000
0	μ_i, i=2,12	320

The only possible values for μ_i are 160, 240, ..., 2,000 for the first year and 0, 80, 160, 240, and 320 for the second to the twelfth years. In the Monte Carlo programming, the value of each controllable system input is treated as a random variable in the

construction of the strategy through the use of a generalized discrete uniform generator.

The Determination of the Distribution Outcomes

The next step of the Monte Carlo simulation technique is the determination of the distribution of outcomes associated with each constructed strategy. Twenty states of nature are considered here to represent the exogenous system input levels--the weather, in this case. Assuming the rainfall has a normal distribution with a mean of 672 mm and a standard deviation of 186.3419 mm, 20 states of environment are generated,[8] each one having 12 observations, one for each year of the planning horizon. Every constructed strategy is considered under each one of the states of nature, and its 20 outcomes will define a cumulative distribution function for the system output variable. As King (1979) pointed out, this procedure guarantees that each different strategy is considered to exactly the same range of possible events.

The system output variable is given by return in cruzeiros per hectare, as described earlier in this chapter. First, the physical relationships, i.e., the yield-response relationship and the phosphorus carry-over function estimated earlier, are used to produce the yield distributions. Then they are transformed into return distributions, taking into consideration the financing conditions offered by the Polocentro program, as described in Chapter III.

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[8]See Manetsch and Park (1977) for this generation method.

The costs are subdivided into four categories because of differences in the interest rate. We then have: investment costs, operating costs, fertilizer maintenance costs, and initial (correction) fertilizer costs.[9]

We will illustrate with only one of these categories. The others will be implemented in a similar manner. The initial investments needed to start to explore the Cerrado are relatively expensive, mainly because of the necessity of clearing the land and the large amounts of limestone, usually four metric tons/ha. As an "incentive," the financing conditions are very good for this kind of investment. The farmer has 12 years to repay, with no payment being necessary in the first six years, and interest rates varying from 10 to 14 percent. However, inflation in Brazil is very high, and payment by installments is not corrected. This means that, from 7 to 12 years from now, the real values of installments will be very low. We feel it is important to take this fact into consideration. For example, a farmer in the seventh year will have to pay back for every Cr$ 100 he borrows now, an amount equal to only Cr$ 7.53 in "today's money value," which is given by:

$$RINV(7) = \frac{(1 + RINV \times 6)\ XINV}{(1 + RINF)^7} = 7.53$$

[9]Initial investment costs were considered equal to Cr$ 8126/ha; operating costs equal to Cr$ 2022/ha; and fertilizer maintenance costs equal to Cr$ 2302/ha.

where

$$XINV = \frac{(1 + RINV)^6\ 100}{6} = 29.53$$

RINV = .10 = interest rate

RINF = .30 = inflation rate

Multiplying the corn yields by the price of corn and discounting all the variables and fixed costs in the manner described above will give us a net return in Cr$/ha for the year. The residual fertilizer in the twelfth year is multiplied by the price of the fertilizer and added to net return value. The present discounted value is calculated, summing the returns of every year using a discount rate of .03. The present value is converted to an average value by the annuity formula:

$$A = \frac{PV \cdot r}{[1 - (1+r)^{-n}]}$$

where

A = annuity

PV = discounted present value

r = interest rate

n = 12 years.

This value will form one point in the distribution function for the system output for a particular strategy and one state of nature. The other 19 points that will complete the cumulative distribution function for the same strategy will be calculated in the same way, but based on the remaining states-of-nature data.

The Efficiency Set

The generated strategies are evaluated according to the stochastic dominance with respect to a function criterion for the owners classified in Groups I, II, and III, as defined earlier in this chapter. For every group in different situations, 1,000 strategies were generated. There is no guarantee that the true optimum will be identified, but because of the large number of iterations performed, there is a large probability that the optimal or nearly optimal strategy will make part of the efficient set. It is not feasible to present the mass of numerical results. Only the results of some of the analyzed situations will be presented.

Results

The efficient sets of choices for classes I, II, and III of decision makers are presented in Tables 5.10, 5.11, and 5.12, respectively. These tables contain information about the control variable levels, the distribution of outcomes, and their expected and standard deviation values, for each strategy. In all cases, the following figures were used: price of corn equals Cr$ 1.83/Kg, price of phosphorus fertilizer equals Cr$ 9.98/Kg, investment interest rate equals 14%, operating expenses interest rate equals 15%, and rate of inflation equals 30%.

The efficient sets for classes I and II of decision makers each contain five strategies, and the one for class III contains six

Table 5.10.--Efficient set of choices for class I of decision makers.

	Efficient Plan				
	1	2	3	4	5
Year	Amounts of Phosphorus (Kg/ha)				
1	960	960	960	960	1040
2	80	160	0	80	0
3	160	80	160	160	160
4	160	320	240	240	240
5	320	240	80	320	240
6	80	160	320	80	80
7	240	240	80	160	240
8	320	160	160	320	160
9	80	80	0	0	160
10	160	240	240	240	160
11	240	320	160	160	240
12	80	160	240	240	0
State of Nature	Outcomes = Net Returns (Cr$/ha)				
1	922	-12	1232	638	792
2	1679	781	3335	1237	2197
3	5758	4962	6570	5703	5823
4	5851	5274	7018	5991	6362
5	7276	6832	7067	7143	7027
6	7319	7424	7535	7664	7545
7	7719	7943	7685	7677	7916
8	8144	8417	7698	8261	8008
9	8449	8486	7857	8385	8170
10	8455	8571	8016	8445	8327
11	8511	8641	8124	8449	8351
12	8533	8721	8226	8536	8450
13	8535	8744	8287	8549	8463
14	8639	8809	8420	8680	8530
15	8652	8823	8520	8763	8698
16	8808	8829	8587	8814	8748
17	8871	8909	8590	8875	8826
18	8906	8964	8605	8901	8886
19	8953	9044	8881	8911	8950
20	9068	9065	8916	9113	9032
Expected outcome	7453	7361	7458	7437	7455
Standard deviation	2248	2595	1861	2349	2164

Note: Price of corn = Cr$ 1.83/Kg; investment interest rate = 14%; operating interest rate = 15%; inflation rate = 30%.

Table 5.11.--Efficient set of choices for class II of decision makers.

	Efficient Plan				
	1	2	3	4	5
Year	Amounts of Phosphorus (Kg/ha)				
1	960	960	880	960	960
2	0	0	80	0	0
3	160	160	160	160	80
4	240	80	0	240	320
5	80	160	320	240	160
6	320	240	240	80	80
7	80	160	240	240	160
8	160	160	0	160	240
9	0	160	240	80	0
10	240	0	160	80	240
11	160	240	80	80	160
12	240	160	160	80	160
State of Nature	Outcomes = Net Returns (Cr$/ha)				
1	1232	1922	1743	1538	1278
2	3335	3988	3510	3340	3479
3	6570	6764	6314	6930	6876
4	7018	6988	6565	7305	7147
5	7067	7126	7128	7427	7296
6	7535	7318	7478	7470	7515
7	7685	7323	7574	7549	7636
8	7698	7757	7793	7615	7718
9	7857	7834	7959	7867	7767
10	8016	7874	7993	7896	8012
11	8124	7916	8043	7935	8030
12	8226	8016	8065	8003	8107
13	8287	8245	8291	8168	8147
14	8420	8299	8425	8321	8311
15	8520	8304	8499	8341	8400
16	8587	8393	8537	8399	8411
17	8590	8453	8594	8460	8537
18	8605	8579	8669	8697	8581
19	8881	8777	8794	8751	8875
20	8916	8846	8808	8884	8901
Expected outcome	7458	7436	7439	7445	7451
Standard deviation	1861	1632	1761	1766	1806

Note: Price of corn = Cr$ 1.83/Kg; investment interest rate = 14%; operating interest rate = 15%; inflation rate = 30%.

Table 5.12.--Efficient set of choices for class III of decision makers.

	Efficient Plan					
	1	2	3	4	5	6
Year	Amounts of Phosphorus (Kg/ha)					
1	800	960	880	960	960	1040
2	80	0	80	0	0	0
3	80	80	160	80	160	160
4	80	80	0	80	80	0
5	240	160	240	240	160	240
6	160	80	240	240	240	0
7	240	320	240	80	160	320
8	80	80	160	80	160	0
9	160	160	0	320	160	160
10	80	80	0	0	0	0
11	320	80	240	0	240	320
12	160	160	240	320	160	240
State of Nature	Outcomes = Net Returns (Cr$/ha)					
1	2009	2153	2091	2094	1922	2036
2	4461	5198	3850	4541	3988	4657
3	6534	6250	6637	6455	6764	6359
4	6970	6791	7243	6807	6988	7014
5	7192	6804	7267	6926	7126	7105
6	7223	7219	7332	6970	7318	7187
7	7408	7335	7604	7417	7323	7414
8	7411	7426	7744	7593	7757	7430
9	7583	7677	7745	7643	7834	7489
10	7674	7694	7748	7809	7874	7668
11	7926	7792	7916	7820	7916	7794
12	8019	7814	7934	7872	8016	7804
13	8115	7893	8242	7900	8245	7972
14	8123	7900	8255	8113	8299	7983
15	8125	8061	8303	8207	8304	8168
16	8216	8121	8314	8227	8393	8318
17	8309	8313	8388	8238	8453	8375
18	8493	8329	8458	8452	8579	8466
19	8532	8484	8636	8681	8777	8638
20	8640	8623	8646	8773	8846	8641
Expected outcome	7348	7294	7418	7327	7436	7326
Standard deviation	1524	1423	1591	1516	1632	1503

Note: Price of corn = Cr$ 1.83/Kg; investment interest rate = 14%; operating interest rate = 15%; inflation rate = 30%.

strategies. This means the efficient sets contain only .5 percent of the total number of strategies examined. This fact makes evident the power of the decision model used in this study.

It should be remembered here that class I represents decision makers with a low degree of risk aversion, class II is intermediate, and class III represents the owners with high aversion to risk. The results demonstrate that the degree of preferences indeed should influence the farmer's decisions. In general, the higher the degree of aversion to risk, the less spread is the distribution of outcomes of the strategies; i.e., the extreme values of the outcomes of the strategies relative to less-risk-averter groups embrace the extreme values of the outcomes concerning more-risk-averter groups. Consider the efficient plan two of class I. It has a relatively low expected return. One of the possible outcomes has a negative value. However, there are several possible outcomes with large return values, which allows this strategy to be included in the efficient set for representing owners with a low degree of aversion to risk. Also, in general, the total amount of fertilizer to be applied along the planning horizon is inversely proportional to the degree of risk aversion.

A good result here is that only one strategy is common to adjacent classes. The third strategy of class I is equal to the first strategy included in the efficient set of class II, and the second strategy of this last set is equal to the efficient plan five of class III.

It is interesting that, in all the selected strategies, the amount of phosphorus fertilizer recommended for the first year is very high relative to the amounts for the other control variables. These amounts vary from 800 to 1,040 Kg/ha. In all cases, the amounts suggested to be applied for the second and third years are relatively low, varying from 0 to 160 Kg/ha. If one considers only the second year, four of the five strategies contained in the efficient set of class II and five of the six strategies concerned with class II recommend no application of phosphorus at all; the other two recommend only 80 Kg/ha. Those results reflect two things. First, the special characteristics of the concessional interest rates on credit for the exploration of the Cerrado area of Brazil allow the heavy costs, relative to initial investments and large amounts of corrective fertilizer and limestone, to be spread over the length of a 12-year planning horizon. Second, there is a significant carry-over effect for phosphorus fertilizer from one year to another. In fact, if one considers the states of nature used in the Monte Carlo technique in this study, it is possible to estimate the residual effect for phosphorus fertilizer applications using the regression results for the carry-over equation presented in Table 5.9. The residual effects of an application of 1,000 Kg, taking into consideration the first set of randomly generated precipitation levels, are presented in Table 5.13.

One interesting result is the one presented by strategy six for the group of high-risk-averse owners, which specifies no

application of phosphorus in the even control variables with the exception of the last one. This means that, in fact, there is a significant phosphorus carry-over from one crop to another.

Table 5.13.--Estimated fertilizer carry-over and carry-over proportion under randomly generated precipitation levels.

Year	Applied Phosphorus (Kg/ha)	Phosphorus Carry-Over (Kg/ha)	Carry-Over Proportion (%)
1	1,000	..	..
2	..	573	.573
3	..	411	.717
4	..	223	.543
5	..	170	.762
6	..	133	.782
7	..	74	.556
8	..	42	.568
9	..	37	.881
10	..	16	.432
11	..	11	.688
12	..	7	.636

The composition of the efficient sets for the analyzed groups of farmers is not very sensitive to changes in some of the parameters. If price of corn is increased by 10 percent, for example, the new efficient set[10] for class I of decision makers comprises four

[10]This and some other results regarding alternative specifications of the parameters may be found in Appendix B.

strategies, three of them being the same as in the first situation when price of corn was assumed to be Cr$ 1.83/Kg. The new strategy is quite similar to the remaining ones. The efficient set for class II of decision makers now contains the same five strategies from the first case and a new one, also quite similar to the old ones. Class III remains unaltered. The use of 10% interest charge in the expenses with investments and a 13% operating costs interest rate does not alter the efficient set results for the three groups of owners. In all cases, because the inflation rate is higher than the nominal rate, the real interest charged was negative. Although the negative rate correctly reflects the reality, it was decided to run the model with positive real interest rates. The results (presented in Appendix B) modify only slightly the composition of efficient sets, while the pattern of decision variables seems to be unchanged. The only difference, of course, is in the financial returns to phosphorus fertilization in all new situations studied.

In summary, the empirical results show that the introduction of farmers' preferences in the form of risk-aversion measures would have important impacts on the decision-making choices. Highly risk-averse owners, for example, tend to make use of strategies that would produce less gain but would not incur losses. This indicates that one should recommend strategies efficiently tailored to each class of decision makers.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary of Objectives

The central concern of this study was with the development of a method that could combine fertilization-response data with preferences of decision makers and could consequently help research and extension workers select more effectively new practices and make more efficient the adoption of these practices by the producers. The area to which this study was applied is the central region of Brazil: the Cerrado. This region probably constitutes the largest contiguous mass of undeveloped agricultural land in the world.

The objectives of this study were (1) to estimate risk-aversion coefficients for corn producers in the Cerrado region of Brazil and to relate them to socioeconomic variables; and (2) to measure how farmers' attitudes toward risk influence their adoption of alternative corn-production techniques.

Summary of Findings and Conclusions

This section presents a summary of the results and the major conclusions of the study. It is recognized that some model specifications can be improved, producing, therefore, more refined results and consequently better conclusions.

When regression techniques were used, attempts to find a significant relationship between risk-aversion measures and some socioeconomic and structural variables, such as age, educational level, family size, size of farm, income, and contact with sources of information, were generally satisfactory. The use of a different approach, i.e., the discriminant analysis, also showed that there seems to be a strong relationship between risk attitudes and those same variables. This result was proved by the high percentage of farmers correctly classified in each predefined group. In total, 86.6 percent of the known cases were correctly classified, which was considered a satisfactory result for the purposes of the study.

These findings allowed for the continuation of the study; i.e., the information on the lower and upper bounds of risk-aversion measures was used in an efficiency-selection criterion that predicted rates of fertilizer applications best suited to each of the analyzed groups.

Regarding the construction of strategies for fertilizer applications, it was first necessary to relate physically the corn-response production and the phosphorus carry-over functions. This was necessary because of the absence of a carry-over phosphorus measure in the soil. The results showed that, indeed, there is a significant phosphorus residual effect from one year to another. Also, it was perceived that corn production responds very well to phosphorus application.

The use of these relationships in a Monte Carlo programming mode made possible the generation of a very large number of strategies. The utility and probability components of the decision model were

combined to select the set of efficient choices for each class of decision makers. This selection, made by the stochastic dominance with respect to a function criterion, took into consideration, at once, all of the aleatory elements that can interfere in the viability of the proposed strategies. In this sense, this criterion can be considered highly efficient from the risk-consideration point of view.

The financing conditions offered by the Brazilian government for the exploration of the Cerrado region were taken into consideration. The special characteristics of this financing, together with spreading costs, produced plans with large applications of fertilizer in the first year of the planning horizon. The model used allowed the consideration of corn response to total plant-available phosphorus, which is the sum of the carry-over phosphorus and the amounts applied currently as fertilizer. The decision model criterion applied to discounted net returns over a 12-year planning horizon considered automatically all of the production, financial, and economic aspects simultaneously. Model evaluation showed that price and concessional interest rate on credit changes had almost no effect on the results.

The results demonstrated that attitudes toward risk should influence the farmer's decisions. It is recommended that the risk-averse farmer make use of strategies producing, in general, lower expected returns, but less subject to losses. In general, the financial returns to phosphorus fertilization seem to be excellent. The only cost not considered in the analysis was the one related to the land factor. It should be remembered, however, as mentioned in Chapter III, that raw land in the Cerrado area is inexpensive.

Implications

It is useful, based on the results obtained in this study, to seek implications for research, extension, and agricultural policy.

This study and others showed that farmers' attitudes to risk vary; therefore, conventional agricultural research that considers only mean values is not applicable. This suggests more effort devoted to measuring and evaluating probability distribution functions. It also suggests that the results obtained in unfavorable environmental conditions should be reported, because technologies selected as efficient under favorable conditions may be considered different if all possible conditions are taken into consideration. Accounting for probability-distribution functions facing farmers would permit recommendations of actions more efficiently adjusted to farmers' attitudes to risk and also environmental conditions (more adequate recognition of farming risks).

The model developed in this study allows for the generation of strategies under several combinations of environmental conditions and farmers' attitudes to risk. This produces important results for educational programs in which farmers can learn about the different situations they face.

The extension service can provide more accurate prescription if recommendations are tailored to farmers' attitudes toward risk. This could allow them to recommend technologies that are individually "best" rather than an average strategy not entirely preferred by any category of farmers.

The model used in this study can be used to evaluate policy instruments designed to modify risk, such as crop-insurance schemes and minimal price supports. For example, alternative policies could be compared, based on the resulting efficient sets facing decision makers and the likely farmer response to the policy.

The agricultural exploration of the Cerrado area of Brazil--as the production of corn demonstrated in this study, and it is believed would occur for other crops--requires a high initial investment in fertilizers and limestone. Fortunately, the Brazilian government is solving this problem by offering good financing conditions associated with relatively low interest rates. This credit policy is adequate, as shown by the results of this study, and there seems to be no reason to change it. However, it is known that, despite these favorable interest rates, small farmers generally are not benefited because, in most cases, they do not have enough collateral to secure the loan. It is hoped that the new Brazilian government, through its Ministry of Agriculture, will find ways of facilitating access to credit for the smaller farmers.

Limitations and Suggestions for Further Research

The analytical framework used in this study is found feasible for the identification of preferred choices given the decision makers' preferences. There are, however, some aspects of this study that can be extended--for example, the relationship between risk attitude and socioeconomic and structural variables. In the discriminant analysis, the index that accounted for the information availability

to the decision maker proved to be a good discriminator. However, this index variable is not operational, because a lot of information is needed for its construction. Further research should concentrate on variables that are simpler to collect and construct and also on how to estimate values of these same variables that are representative of well-defined groups of farmers.

One other possible extension of this study would be to account for plant-available soil moisture. In Chapter III, it was noted that the Cerrado region, in general, receives ample but not well-distributed rainfall--a phenomenon called "veranico," or little summer, which lasts two or three weeks, during which time it does not rain. This poor distribution of rainfall, coupled with low moisture retention ability of the soil, causes plants to be more susceptible to insects and diseases. A measure more representative of useful moisture than mm's of rain received during the growing season would be, instead, to specify the weather variable as the number of stress days after planting and fertilization.

Another extension could treat the functional form of the production function. A difficult problem is to choose the algebraic form of the response function to fertilizer. Because of the impossibility of knowing the true form, other forms should be tried, to get an idea about the probable consequences of using different forms in the residual equation, and consequently on how the alternative specifications affect the set of efficient strategies.

Price uncertainty is likely as important a source of uncertainty as weather, which together affect the distribution of outcomes

associated with any strategy. Hence it should be considered. The model used allows for the inclusion of any number of stochastic variables. However, in many cases, random factors are not independent, and the assessment of correlation between random variables is difficult.

Finally, more research is needed on the empirical measurement of risk aversion and consequently the determination of its upper and lower bounds. Experiments should be conducted to identify individuals' (or well-defined groups') risk-aversion measures that are simpler and intuitive and also that could be provided by the farmers themselves without submitting them to a series of questions.

APPENDICES

APPENDIX A

CALCULATION OF INFORMATION INDEX

APPENDIX A

CALCULATION OF INFORMATION INDEX[1]

Source

The information index is made up of 11 different information sources, each weighted by their value as a source of agricultural information. The rationale for the index was based on the hypothesis that local persons in extension, banking, and fertilizer sales would have reliable knowledge of the relative value of various information sources as aids to management. Three extension agents, three bankers, and three fertilizer dealers in the region were interviewed in order to obtain their opinion on the relative importance of information sources.

Question

a. Newspapers
b. Technicians of private firms
c. Radio
d. Bankers
e. Demonstration plots and experimental stations
f. Meetings & expositions
g. Extension agents
h. Agricultural magazines
i. Technicians of cooperatives
j. Television
k. Pamphlets and agricultural communications

1. Among the above items, which do you consider to be the most important source of agricultural information for the farmer? ____
Least important? ____

Of the remaining 9, which is the most important? ____
Least important? ____

Of the remaining 7, which is the most important? ____
Least important? ____

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[1]With the exception of the results, this appendix is quoted from Nelson (1971), Appendices C and D.

Of the remaining 5, which is the most important? ____
Least important? ____

Of the remaining 3, which is the most important? ____
Least important? ____

2. The most important item is how many times more important than the least important? ____ times

Calculation of Weights

An average of the responses with respect to the difference between the most and least important factor was computed and linearly distributed according to the number of items. The average difference was 45; thus a factor ranked first receives a weight of 45.0, the second 40.5, etc.

Calculation of Coefficients

The coefficients for each of the factors were computed by summing the number of times a factor was ranked first times the weight given to first-place ranking plus the number of times the factor was ranked second times the weight given to a second place ranking, . . . , plus the number of times the factor was ranked last times the weight given to the least important factor, yielding 11 information subtotals. Then the summation of the subtotals of each factor was divided into the subtotal of each factor to obtain a ratio for each component of the index. The summation of the value of these ratios equals 1.0 (later multiplied by 1,000).

Calculation of Index Value for a Farmer

The index value for an individual farmer was calculated based on a presence or absence concept. For example, the weight of 103

would be included in his information index if he had read a newspaper regularly during the last year.

APPENDIX B

A SAMPLE OF ALTERNATIVE RESULTS OF THE MODEL

Table B1.--Efficient set of choices for class I of decision makers.

	Efficient Plan			
	1	2	3	4
Year	Amounts of Phosphorus (Kg/ha)			
1	960	960	960	960
2	80	160	160	80
3	160	80	80	160
4	160	320	320	240
5	320	240	240	320
6	80	160	160	80
7	240	240	240	160
8	320	160	80	320
9	80	80	160	0
10	160	240	80	240
11	240	320	320	160
12	80	160	240	240
State of Nature	Outcomes = Net Returns (Cr$/ha)			
1	1470	436	883	1151
2	2314	1338	1546	1829
3	6826	5923	6254	6734
4	6894	6306	6452	7086
5	8487	8009	8136	8343
6	8564	8691	9115	8944
7	9013	9267	9123	8970
8	9507	9751	9726	9637
9	9781	9848	9759	9750
10	9843	9964	9796	9784
11	9868	10065	9902	9795
12	9916	10096	9962	9933
13	9923	10171	10061	9936
14	10012	10203	10198	10082
15	10037	10246	10210	10136
16	10217	10255	10215	10227
17	10264	10340	10244	10273
18	10329	10371	10333	10307
19	10355	10473	10402	10318
20	10489	10508	10495	10538
Expected outcome	8705	8613	8641	8689
Standard deviation	2492	2876	2740	2604

Note: Price of corn = Cr$ 2.01/Kg; Investment interest rate = 14%; Operating interest rate = 15%; inflation rate = 30%.

Table B2.--Efficient set of choices for class II of decision makers.

	Efficient Plan					
	1	2	3	4	5	6
Year	Amounts of Phosphorus (Kg/ha)					
1	960	880	960	960	960	1040
2	0	80	0	0	0	0
3	160	160	160	160	80	160
4	240	0	80	240	320	240
5	80	320	160	240	160	240
6	320	240	240	80	80	80
7	80	240	160	240	160	240
8	160	0	160	160	240	160
9	0	240	160	80	0	160
10	240	160	0	80	240	160
11	160	80	240	80	160	240
12	240	160	160	80	160	0
State of Nature	Outcomes = Net Returns (Cr$/ha)					
1	1786	2368	2549	2130	1838	1317
2	4126	4321	4837	4127	4281	2881
3	7671	7386	7941	8129	8067	6889
4	8226	7696	8153	8508	8310	7452
5	8252	8347	8278	8618	8502	8210
6	8760	8752	8567	8740	8792	8813
7	8982	8861	8575	8824	8867	9215
8	8991	9068	9000	8851	8978	9348
9	9133	9228	9101	9146	9063	9521
10	9295	9273	9133	9198	9324	9660
11	9448	9334	9215	9239	9346	9709
12	9563	9386	9323	9314	9391	9821
13	9622	9634	9571	9466	9467	9835
14	9757	9778	9616	9660	9649	9865
15	9879	9859	9635	9666	9730	10089
16	9936	9875	9715	9750	9746	10147
17	9948	9945	9775	9800	9871	10199
18	9960	10048	9941	10050	9949	10273
19	10266	10172	10146	10117	10257	10345
20	10294	10179	10214	10268	10277	10443
Expected outcome	8695	8676	8664	8680	8685	8702
Standard deviation	2064	1952	1809	1957	2002	2399

Note: Price of corn = Cr$ 2.01/Kg; investment interest rate = 14%; operating interest rate = 15%; inflation rate = 30%.

Table B3.--Efficient set of choices for class III of decision makers.

	Efficient Plan					
	1	2	3	4	5	6
Year	Amounts of Phosphorus (Kg/ha)					
1	800	960	880	960	960	1040
2	80	0	80	0	0	0
3	80	80	160	80	160	160
4	80	80	0	80	80	0
5	240	160	240	240	160	240
6	160	80	240	240	240	0
7	240	320	240	80	160	320
8	80	80	160	80	160	0
9	160	160	0	320	160	160
10	80	80	0	0	0	0
11	320	80	240	0	240	320
12	160	160	240	320	160	240
State of Nature	Outcomes = Net Returns (Cr$/ha)					
1	2647	2799	2736	2738	2549	2662
2	5360	6160	4686	5441	4837	5569
3	7684	7364	7805	7597	7941	7489
4	8107	7977	8412	7944	8153	8225
5	8428	7989	8511	8131	8278	8329
6	8467	8437	8585	8180	8567	8368
7	8618	8541	8854	8590	8575	8640
8	8633	8637	8993	8827	9000	8658
9	8806	8921	8996	8878	9101	8715
10	8948	8938	9027	9064	9133	8877
11	9222	9029	9198	9088	9215	9036
12	9322	9061	9213	9158	9323	9081
13	9405	9138	9565	9185	9571	9247
14	9410	9167	9565	9417	9616	9276
15	9425	9356	9633	9505	9635	9475
16	9501	9402	9633	9529	9715	9646
17	9638	9636	9732	9545	9775	9684
18	9834	9639	9780	9793	9941	9799
19	9887	9812	9985	10031	10146	9979
20	9985	9958	10004	10126	10214	9988
Expected outcome	9566	8498	8648	8538	8664	8537
Standard deviation	1689	1575	1763	1678	1809	1666

Note: Price of corn = Cr$ 2.01/Kg; Investment interest rate = 14%; Operating interest rate = 15%; inflation rate = 30%.

Table B4.--Efficient set of choices for class I of decision makers.

	Efficient Plan					
	1	2	3	4	5	6
Year	Amounts of Phosphorus (Kg/ha)					
1	880	800	800	960	960	960
2	0	160	160	80	80	80
3	160	80	160	160	160	80
4	320	240	320	160	240	240
5	240	160	240	320	320	240
6	80	160	0	80	80	240
7	160	320	240	240	160	240
8	320	0	160	320	320	160
9	160	240	80	80	0	160
10	160	160	240	160	240	0
11	80	160	160	240	160	320
12	80	240	320	80	240	80
State of Nature	Outcomes = Net Returns (Cr$/ha)					
1	-1998	-1756	-2335	-2164	-2455	-1947
2	-364	255	-959	-1407	-1856	-1209
3	3303	2908	2651	2671	2609	2585
4	3405	3540	3884	2764	2896	2962
5	4340	4217	4324	4189	4049	4403
6	4494	4814	4643	4232	4569	4454
7	4686	4860	5040	4632	4582	4539
8	4886	4915	5066	5057	5167	5072
9	5004	4958	5142	5362	5290	5102
10	5175	4983	5187	5368	5351	5167
11	5192	5005	5212	5424	5355	5253
12	5218	5177	5232	5446	5442	5394
13	5252	5336	5298	5448	5454	5436
14	5254	5414	5421	5552	5585	5509
15	5410	5429	5490	5565	5668	5597
16	5507	5457	5537	5721	5719	5710
17	5639	5485	5603	5784	5781	5778
18	5773	5749	5676	5819	5806	5812
19	5852	5783	5781	5866	5816	5814
20	5965	5842	5876	5981	6019	5995
Expected outcome	4400	4418	4388	4366	4342	4371
Standard deviation	2001	1889	2149	2248	2349	2171

Note: Price of corn = Cr$ 1.83/Kg; investment interest rate = 14%; Operating interest rate = 15%; inflation rate = 0%.

Table B5.--Efficient set of choices for class II of decision makers.

	Efficient Plan			
	1	2	3	4
Year	Amounts of Phosphorus (Kg/ha)			
1	880	880	960	800
2	80	80	0	160
3	160	160	160	80
4	0	0	240	240
5	320	240	240	160
6	240	240	80	160
7	240	240	240	320
8	0	160	160	0
9	240	0	80	240
10	160	0	80	160
11	80	240	80	160
12	160	240	80	240
State of Nature	Outcomes = Net Returns (Cr$/ha)			
1	-1287	-929	-1499	-1756
2	479	829	302	255
3	3283	3616	3892	2908
4	3534	4222	4267	3540
5	4097	4246	4389	4217
6	4447	4310	4432	4814
7	4544	4583	4512	4860
8	4762	4723	4577	4915
9	4928	4724	4829	4958
10	4962	4727	4858	4983
11	5012	4895	4897	5005
12	5034	4913	4965	5177
13	5260	5221	5131	5336
14	5394	5234	5283	5414
15	5468	5282	5303	5429
16	5506	5293	5361	5457
17	5563	5367	5422	5484
18	5638	5437	5660	5749
19	5763	5615	5713	5783
20	5777	5625	5846	5842
Expected outcome	4408	4396	4407	4418
Standard deviation	1761	1591	1766	1889

Note: Price of corn = Cr$ 1.83/Kg; Investment interest rate = 14%; Operating interest rate = 15%; inflation rate = 0%.

Table B6.--Efficient set of choices for class III of decision makers.

	Efficient Plan		
	1	2	3
Year	Amounts of Phosphorus (Kg/ha)		
1	800	960	880
2	80	0	80
3	80	80	160
4	80	80	0
5	240	160	240
6	160	80	240
7	240	320	240
8	80	80	160
9	160	160	0
10	80	80	0
11	320	80	240
12	160	160	240
State of Nature	Outcomes = Net Returns (Cr$/ha)		
1	-988	-862	-929
2	1463	2182	829
3	3536	3234	3616
4	3972	3775	4222
5	4194	3788	4246
6	4225	4202	4310
7	4410	4318	4583
8	4413	4410	4723
9	4585	4661	4724
10	4676	4677	4727
11	4928	4776	4895
12	5021	4797	4913
13	5117	4877	5221
14	5125	4884	5234
15	5127	5044	5282
16	5218	5105	5293
17	5312	5297	5367
18	5495	5313	5437
19	5534	5468	5615
20	5642	5606	5625
Expected outcome	4350	4277	4396
Standard deviation	1529	1423	1591

Note: Price of corn = Cr$ 1.83/Kg; investment interest rate = 14%; operating interest rate = 15%; inflation rate = 0%.

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