THE ROLE OF INFORMATION AND FLEXIBILITY IN SMALL-FARM DECISION MAKING AND RISK MANAGEMENT: EVIDENCE FROM THE WEST AFRICAN SEMI-ARID TROPICS

by

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Table of Contents

Chapter One: Introduction

Chapter Two: Literature Review

Chapter Three: Farming Systems in the West African Semi-Arid Tropics

Chapter Four: A Methodological Approach for Examining the Value of Information

Table of Contents, continued.

Chapter Five: A Production Function Analysis and an Empirical Estimation of the Value of Information to Farmers in the WASAT

Table of Figures

Figures:

Tables:

Chapter One: Introduction

1.1 Motivations and Objectives

The challenges to agricultural research systems in Africa are immense, due to a wide range of ecological, technical, demographic and institutional factors. Per capita food production has been declining approximately 2% per year from 1970 - 1984, along with an acceleration of food imports and growth in population (World Bank 1984). A primary development goal in many parts of Africa is thus increased production of food crops and increased productivity of the small farmer. The West African semi-arid tropic region (WASAT) is an area comprised mostly of subsistence-oriented farmers that face most of the constraints to production found in all of Africa.

The general objective of this thesis is to improve agricultural policies in the Sahel through an improved understanding of the factors influencing farmers' production decisions. More specifically, the issue to be addressed is how farmers deal with such a harsh and risky environment, and what this information tells us in terms of the development of new technologies, the feasibility and adaptability of existing technologies, and the design of food and farm policies to improve the welfare of farming families in the WASAT. The motivation for this research lies in the severity of the problems faced by agricultural producers in this part of the world, the relative lack of success achieved up until this point by agricultural researchers with similar motivations, and the sparcity of empirical work focused on the implications of risk in small farm decision making.

Much attention has recently been given to a farming systems research approach (for example, see Moock 1986). This approach relies on the collection and analysis of farm-level production data in order to achieve a better understanding of farmers' objectives and constraints. This information is critical in the successful introduction and assimilation of new techniques and technologies that will improve the welfare of farming families. Matlon and Spencer (1984) concluded that the current set of new production technologies in the WASAT responds inadequately to the evolving needs, in the long term, of land base conservation in Africa, and in the short term, of production objectives. They attribute the failure of technologies that have been introduced in the past several decades to "an inadequate understanding of small farmer goals and resources used in formulating research objectives." A better factual base for scientists taking a farming systems approach to development should help policy makers, as well as plant breeders and agronomists by enabling them to formulate their objectives more clearly.

1.2 Production Risk

Farmers across the WASAT have to deal with a precarious environment in order to secure survival and reproduction in the face of risk and particularly environmental perturbations. This involves two major confrontations - that between man and nature, and secondly in transactions between people. In the first case, adaptive responses to risk in part take the form of agronomic strategies which have evolved as time-honored adaptations (and as necessary adjustments) to a risky environment. Farmer sensitivity and reaction to risk have been hypothesized to affect cropping patterns, agricultural investment and the adoption of new technologies (see Norman et al. 1981). In the second instance, social structure and institutions also allow people to share and manage risk (Vierich 1986). Intrahousehold resource allocation and distribution are important aspects with respect to the management of risk, as are interhousehold linkages within these societies. The issue of who has access to which resources is another important consideration when considering both inter and intra household management of risk.

Despite the hypothesized importance of risk there have been few empirical studies estimating the quantitative magnitude of risk, nor of the effectiveness and cost of risk management devices in the WASAT. How well farming households cope with their precarious environment with respect to agronomic practices is an empirical question that can be addressed given sufficient data. How well social structure and institutions serve to reduce risk is a further issue that is extremely important but more difficult to measure than risk management strategies in the form of agronomic practices.

Agronomic 'tactics' (that is, the methods actually available to a farming household to implement risk management strategies) that are utilized by farmers in dealing with a risky environment include cropping patterns suited to various types of soil and toposequence, inter-cropping, and crop diversification (spacial and varietal). These traditional strategies that ameliorate risk at the plot level have been very briefly discussed in the literature, with a call for more empirical work (e.g. Norman et al.). What has not been given much attention is the idea that flexibility in production plans and the ability to adjust to changing conditions (as new information becomes available) is another important method of dealing with uncertainty for small farmers whose primary uncertainties are weather-induced. An example of this is the practice of re-seeding part or all of a crop if the initial rains start early but don't continue. One of the effects risk has on a farmers' choice among production alternatives (i.e. strategies or techniques) is the consideration of maintaining enough flexibility to cope with the environment, a major source of the risk he faces. In other words, a farmer will attach a value or premium to the flexibility of a particular technique as well as to its expected yield. Little work has been done concerning the empirical implications of this concept for technological choice and production decisions of farmers in developing countries.

The reason this issue has not been addressed is due to the fact that most studies of farm household decision making under risk (e.g. see Anderson et al. 1977, Newbery and Stiglitz 1981) assume a farmer makes all his decisions at one point in time, at the start of the cropping season, and that all decisions are irreversible. This reasoning does not account for the sequential nature of the growing process of a crop or the ability of a producer to adapt to uncertainties throughout the stages of the growing season (the decision to replant, or whether to weed a second or third time, for example). The choice of models has relied on the use of traditional static microeconomic tools rather than dynamic models that are more in line with a dynamic production and decision making process.

The specific hypothesis to be examined is that flexibility in production plans and the ability to adjust to changing conditions is an important method of dealing with uncertainty for small farmers whose primary risks are weather-induced. The conceptual framework behind the work presented here will be the specification of a production model consistent with the sequential structure of the crop production process and the managers' solution of input choice problems.

1.3 Theoretical Framework

The method of analysis to study the importance of flexibility in production decisions will be to use a multistage modeling approach to reflect the dynamic nature of the production process. The estimation of a multistage yield function (incorporating, for example, the critical input stages of planting, replanting, first and second weeding) will provide information concerning the influence on yield of technology and the environment. Since rainfall provides the major source of uncertainty in the production process, it will be included as an explanatory independent variable. This will give us estimates of the coefficients indicating the relative importance of each input in the production process at each stage and their relative importance in explaining yields. Putting this into an expected profit maximization framework will provide information on the relative economic importance and role of flexibility of production plans as well as expected yield and yield variability.

We expect the results to support the hypothesis that the ability to revise future plans as new information becomes available is an important way subsistence farmers deal with risk. It is then possible to explore the implications for technological choice and production decisions, and the formulation of strategies and policies to ameliorate some of the risks these producers face and to increase the productive potential of small farming households.

1.4 Overview

The dissertation will proceed in the following manner. The objective of Chapter one was to provide the motivations and objectives of this dissertation. Chapter two presents a literature review, which is divided into three parts. In the first part I discuss the literature pertaining to the WASAT and the approaches that have been taken to studying farming systems with a brief look at particular studies into farmers goals and objectives. How risk and uncertainty affect the small farm household decision making process and the adoption of new technology are of particular interest, and the reasons for nonadoption of mature innovations are discussed. The second part of the literature review focuses on the influence of risk behavior on farmers' economic decisions within the more general economic and agricultural economic theoretical literature. My intention is to provide a brief overview of how the concepts of risk, uncertainty and information have been developed and used, historically within the economics literature and more specifically regarding agricultural economics research. Some of the major conclusions pertaining to agricultural decision making under risk in the context of small farmers in developing countries, and some empirical results will be the main focus of this brief review.

The final focus of the literature review will be on recent papers that have addressed the issue of dynamic agricultural production analyses that use models incorporating the sequential nature of the growth process and the decision making process. This allows the incorporation of flexibility and learning into the analysis, something that has not been achieved by the traditional microeconomic static tools that agricultural economists have relied on.

Chapter three provides a description of farming systems in the WASAT and the data to be used in the analysis. The dataset contains cross-sectional and time series observations. It comes from a five year farm survey undertaken by ICRISAT in six villages within three agro-climatic zones in Burkina Faso. The data set is unique for its longevity, geographical distribution, and extreme detail in production inputs and activities. It also includes structural household composition variables, as well as rainfall data.

Risk management strategies available to the household in terms of cropping strategies are also discussed in chapter three along with the tactics or means available to deal with risk. Risk itself is also more clearly defined, as the literature demonstrates the term risk can be confusing.

Chapter four and five describe the method of analysis to be followed and the theory behind it. The first step of the analysis is the estimation of the technical relationship of yield as a function of certain inputs to determine the relative magnitude of the coefficients and thus their importance in explaining yields. An extension of the quadratic production function is chosen as representative of the underlying technology. The next step involves a normative analysis, representing farmers objectives through the choice of a preference function, allowing an examination of the economic importance of such issues as flexibility and information. The risk-neutral case of expected profit maximization is derived and estimated for all three agro-climatic zones. The results of the fitted functions for each region and crop are examined, first in a general framework, then with the more specific goal of examining the principal phenomena under investigation, namely the value of information or flexibility.

Chapter six will discuss the results of the analysis and the implications for the design of farm and food policies as well as the development of new technologies. Any new policy aimed at enhancing risk management by small farm households (or increasing productivity) should augment or make more effective their choices in managing risk. The implicit tradeoffs in the current risk management system between lower risk, higher expected yield, and greater flexibility can be construed to reveal farmers' preference for, and valuation of, income insurance. Until new methods of insurance are found or become feasible, new technologies must allow the farming household to maintain the flexibility they require to deal with their harsh environment.

Chapter Two: Literature Review

2.1 Introduction: Farming Systems Research in the WASAT

Recent development literature focusing on the issue of the stagnation of the agricultural sector in Sub-Saharan Africa roughly falls into two categories - agricultural policy advocates and the technology-development advocates (Sanders et al. 1985).

The best examples of the agricultural policy proponents are found in various World Bank publications (World Bank 1981 and 1983). These reports stress the importance of reducing distortions on input and output prices as well as exchange rates, so that countries can better exploit their international comparative advantage within agriculture, especially with respect to export crops. This literature discusses the need to eliminate institutional barriers and increase investment in critical infrastructure in order for markets to operate more efficiently, giving farmers greater incentives to increase output. They argue that yield-increasing technologies will become rapidly more feasible in a more favorable economic environment.

Matlon and Spencer (1984) and FSU-SAFGRAD[1] (1984) voice viewpoints representative of the technology advocates. They stress the importance of a farmer-based "bottom-up" approach to analyzing the problems and constraints faced by the small WASAT farmers within a "farming systems

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[1] Farming Systems Research Unit of Purdue University - in conjunction with the Semi-Arid Food Grain Research and Development Project.

research" approach. After an extensive review of the past research done on village production systems in the WASAT, Norman et al. (1981) conclude that this approach provides the potential for overcoming the lack of success in improving the welfare of farming families. The commitment of international agencies such as ICRISAT and SAFGRAD to improve the welfare of farming families corresponds to a political commitment that exists in the Sahel countries to attain food self-sufficiency (see Sanders et al. p.35).

The technology development advocates focus on the farm-level constraints faced by the predominantly small farmers due to the extreme environment in which they must cope. Fragile soils and erratic rainfall are the main characteristics of this climate.

Matlon and Spencer (1984) point out the failure of crop improvement programs that have existed in the WASAT for several decades and suggest several reasons for this failure. One is the past emphasis on cash crops by the colonial powers (and lack of research into food crops). Another is the attempt by international crop research institutes to introduce high-yielding seed/fertilizer packages, an approach that was successful during the "Green Revolution" in parts of Asia. This "technology transfer" method of development (that is, the direct transfer of plant materials from other countries into the WASAT) has been largely unsuccessful due to different physical conditions in the WASAT which determine the technical potential of a given cultivar. For example, it is estimated that less than 2% of cultivated area devoted to sorghum and millet in West Africa is sown to varieties developed through modern crop breeding efforts (Matlon 1983). Matlon and Spencer (1985) explain the unsuccessful transfer in terms of both differences in soil characteristics and reliability of rainfall in the semi-arid regions of India as compared to Africa.

Priority within such crop improvement programs relying on transfers of plant materials has traditionally been given to yield potential, that is, to the development of high yielding varieties (HYV) under high-input management. Indeed this is just the approach that achieved substantial gains in Asia during the 1960's. The HYV package approach[2] was successful due to a high use of chemical fertilizers and adequate soil moisture to achieve production potential. However, WASAT soils tend to have an extremely low water holding capacity (making water control or water conservation techniques a critical need), along with generally lower overall fertility than that found in the Asian soils of the SAT. Less assured rainfall is also the case in the WASAT, making the adoption potential of a HYV package very low.

Spencer (1985) suggests that better internal policies and more favorable external economic climates are certainly important in improving the farmers situation, but that insufficient weight has been given to the part played by environmental constraints and the lack of appropriate technological solutions. The technology must be available for expanding the land area or increasing yields, whether or not the "prices are right", in order to bring about a sustainable growth in

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[2] An "HYV package" approach refers to the introduction of improved cultivars in conjunction with chemical fertilizers and new management techniques such as ridging, deep plowing, etc.

aggregate output. Others have echoed this sentiment that insufficient knowledge of the social and economic environment of the farmer has hampered both new technological development and appropriate farm policy (Eicher and Baker 1982, and Dewilde et al. 1967).

In a study of focusing on the adoption of new farm technologies by subsistence farmers in Northern Nigeria, Balcet (1982) argues that "extension should offer technical options for incorporation into the mixed cropping system rather than complete packages that are incompatible with it and involve risks; adaptive research should be oriented toward evolving technologies that provide such options..." (p.iii).

Lack of sufficient farm-level production data (as opposed to research-station data) has been cited as a severe constraint in several studies concerned with constraints to productivity and the adoption of new technologies in the WASAT (see Norman et al. 1981 p.60, also Jaeger 1985, p.84). This has meant little rigorous analysis of individual crop enterprise analysis has been undertaken for sorghum and millet, the staple food crop for millions of Africans. Norman et al. raise the issue of relevance for the village level studies that have been undertaken, citing that most of these studies have no more than a one year time span. This poses a problem in that one can never be sure the results are at all representative, for they may have been estimated in a year in which the weather, for example, was extremely good or poor.

There has recently been some work done on the micro-economics of production systems, particularly with regard to mixed cropping systems, in Northern Nigeria (e.g. Abalu 1976, Norman 1974, Balcet 1982). Throughout the WASAT, a central feature of traditional cropping systems has been the practice of mixed or inter-cropping two or more crops in the same field. Using farm-level data, Norman concludes that mixed cropping is a rational strategy both in terms of profit maximization and risk minimization.[3] He found that this held both under indigenous technological conditions as well as when the available improved technology for sole crops was considered. He emphasizes a need for more research into mixed cropping under improved technological conditions, since most research and extension efforts tend to focus on sole-cropping systems.

Similarly, also using farm survey data from Northern Nigeria, Balcet points out that the importance of production uncertainty at the level of the farm combined with the risk attitudes of farmers (which he attempted to elicitate from interviews), points to the general inadequacy of a "package" approach to introducing new technologies.[4] That is, there is a need for recommendations coming from the research stations that focus on divisible elements that can preserve the flexibility of the traditional system rather than on rigid packages

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[3] Norman compared 1) the profitability or net return of crop mixtures versus sole crops, and 2) the distribution of gross returns from crop mixtures and sole crops, and worked out the distribution of the difference, from which he calculated the probability of the gross return being higher for crop mixtures.

[4] Balcet took a programming approach to modelling individual farm household behavior to indicate what farmers "should" adopt, with field interviews then designed to compare the normative view with the farmers'own perception of benefits and costs of adoption.

that act to reduce it. Matlon (1987, p.77) argues that the complementarity of seeds, fertilizer, animal traction, etc., make a package approach desirable, but agrees that each component of such packages should be profitable when used alone, and preferably, should use resources available at the farm level.

Most of the literature agrees that risk aversion is an important factor in the way farm households make decisions in the WASAT. However, little rigorous research has been done on the goals of farmers in the SAT of West Africa, with a corresponding lack of definitive research work on farmers' attitudes to risk and uncertainty (Norman et al., p.47). Since these attitudes towards risk and uncertainty will influence both the goals that farmers will follow and the types of improved technologies that they are likely to adopt, Matlon (1983, p.15) concludes that "the role of risk perception, risk aversion and risk avoidance strategies as a determinant of production and innovation is in particular need of additional research."

In looking at farmer attitudes and responses to risk, Balcet applied a concept of hierarchical decision-making (Gladwin 1976) to the questioning procedure in the field. The procedure involved a multi-step tree-like sequence of questions where first, the inputs or practices that were likely to compete or stand in the way of innovations were identified; second, the perceived productivity of the innovations was assessed as well as their place in the farmer's hierarchy of objectives; and third, a risk analysis to confirm or reject prior conclusions based on an assessment of the perceived impact on production variability was undertaken. This type of an approach to risk is similar to the goals of the approach taken in this study, as will become clearer shortly.

A recent risk study in West Africa was undertaken by FSU-SAFGRAD with researchers at Purdue University (see Lang, Roth and Preckel 1984). It focused on risk perceptions and risk management by farmers in several regions in Burkina Faso. Their objective was to identify the characteristics of production technologies attractive to these farmers. They were primarily interested in the impact of risk considerations on cropping patterns. Their measure of risk was obtained by determining yield variability over a ten year time span. Due to a lack of time series data, yield variability was estimated using subjective recall data, that is, the farmers were asked to recall yields for the past ten years.

They concluded that production risks (e.g. extreme variability in rainfall) do indeed affect farmers' cropping patterns, in that risk aversion prevents farmers from planting higher yielding crops. They also found evidence of differing underlying objectives and goals for different farming households, depending on their circumstances or wealth position. Some showed a 'safety-first' approach in that they chose to plant crops with lower yields, but the crop that produces the most food in a bad year. They found others exhibited more flexibility and appeared to be profit maximizers.

2.2 Background of Risk and Uncertainty Within the Economics Literature

A brief review of how the concepts of risk, uncertainty and information have been developed, how they have been used in economic models of behavior, and some of the principal conclusions of this literature drawn by agricultural economists will be presented. Emphasis will be on the implications of risk and uncertainty on agricultural production decisions, the adoption of new technologies, and economic development in the developing world.

Economic literature on uncertainty and information can be divided into two main categories, market uncertainty and technological uncertainty (Hirshleifer and Riley 1979). Main issues within the market uncertainty literature are market disequilibrium and price dynamics. Analysis of market uncertainty is leading to better understanding of market "imperfections", and would be of interest to the agricultural policy advocates, but I will not be concerned with this branch of literature here.

A review of technological uncertainty can be further divided into the concepts of the economics of uncertainty and the economics of information. Hirshleifer and Riley refer to the economics of uncertainty as passive responses to our limitations of knowledge whereas the economics of information can be thought of as an active response. An active response to a situation occurs where individuals are assumed to actually overcome some uncertainties by engaging in informational activities, as opposed to just adapting to uncertainties.

Perhaps a more useful distinction between the two is found in the framework within which each type of problem is analyzed. The economics of uncertainty has traditionally been analyzed in a static framework. For example, a profit maximizing model becomes an expected profit maximizing model with the introduction of a stochastic variable, e.g. the price of output. Responses to varying degrees of risk (e.g. price variability) are then studied. A "passive" response to knowledge is assumed in that there is no allowance for adjustments to the uncertainty, or any learning taking place.

Information, on the other hand, is somewhat meaningless when analyzed in a static framework. When put in a dynamic framework, one can distinguish active learning versus passive learning. A decision maker can actively seek or buy information and revise his decisions as he learns (i.e. he revises his subjective estimates as to the 'state of nature'), assuming that not all decisions are made at one point in time. Sequential decision making also allows learning by waiting, i.e. by putting off a decision until more information has been acquired simply by waiting (e.g. observing rainfall before planting). The ability of a decision maker to make sequential decisions allows him to incorporate new information and the study of the value of information is best analyzed in a dynamic framework.

I will first address the economics of uncertainty literature which is typically approached in a static framework. The purpose of this section is to provide the theoretical underpinnings, namely the theory of expected utility maximization, of approaches that are being taken in the study of responses to risk by agricultural producers.

2.3 Economics of Uncertainty

A distinction between the terms risk and uncertainty generally attributed to Knight (1921) is that risk refers to a situation where alternative outcomes exist with known probabilities and uncertainty to the case where the probabilities are not known. Savage (1954) disputed this segregation on the basis that every individual is able to form some subjective probability distribution over possible outcomes even though the objective distribution may not be known. The degree of belief or strength of conviction an individual has about a proposition is his subjective probability for it.

In decision-making under uncertainty, one can choose among certain "acts", while Nature may be said to 'choose' among "states". The individual can then formulate a (subjective) probability function expressing his beliefs as the Natures 'choice' of states. The possible outcomes under all possible acts and states can be derived (a 'consequence' function), and a preference-scaling or utility function can be defined over the consequences. Once an "expected utility rule" (see following paragraph) is defined, an individual is able to order those available acts in terms of preferences so as to determine which is most highly preferred.

The mathematical form of expected utility theory originated with Bernoulli in 1738, although it was von Neumann and Morgenstern (1944) that proved that expected utility maximization was derivable from five basic axioms and thus was a rational decision criterion. These axioms, or postulates of rational choice, have been put forth in the literature in a number of ways (see, for example Luce and Raiffa 1957).

The expected utility hypothesis (EUH) is a theory that allows us to index action choices under uncertainty. It is based upon the decision maker's personal strengths of belief (or subjective probabilities) about the occurrence of uncertain events and his personal valuation or utility of potential outcomes. The expected utility of an uncertain event is the sum of the utilities of each possible outcome weighted by its probability. The EUH asserts that the action choice with the highest expected utility is preferred by the decision maker. Thus it provides a logically appealing way of finding a preferred action. The validity of the theory depends on the acceptance of these axioms and of the concept of utility maximization as a description of human behavior.

Expected utility theory has dominated the analysis of decision making under risk. It has been generally accepted as a normative model of rational choice and widely applied as a descriptive model of economic behavior. In the uncertainty literature, utility is usually defined in terms of wealth (W) and the utility function is assumed to be monotonically increasing, i.e. to have $dU/dW > 0$, reflecting a positive marginal utility for wealth. At a given level of wealth the utility function is said to indicate risk aversion, risk indifference or risk preference so that d^2U/dW^2 is less than, equal to, or greater than zero, respectively.

An important concept in EU theory is that of risk aversion. If a gamble is less preferred than its certain expected monetary value, the preference is said to be risk-averse. The risk premium is defined as the amount a risk-averse person is willing to pay for a sure thing. Arrow (1971) and Pratt (1964) proposed as a local measure of risk-aversion for $U(x)$[4] the negative ratio of the second to first derivative, i.e. $-U''(x)/U'(x)$[5]. This provided for interpersonal comparisons of risk aversion and contributed to empirical analysis of risk attitudes. It is generally agreed, for example, that most people exhibit some degree of risk aversion. It is also argued for intuitive reasons that a risk averse persons' utility function for wealth should exhibit decreasing absolute risk aversion as his wealth increases, i.e. $-(d^2U/dW^2)/(dU/dW)$ declines as W increases (Sandmo 1971). If decreasing absolute risk aversion holds it follows that a persons' risk premium declines as wealth increases (see Menezes and Hanson 1970). In other words, as people get wealthier they are less willing to pay to avoid risk. The choice of algebraic form of the utility function thus depends on whether these or other attributes are pertinent, i.e. the

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[4] Where x can be defined as wealth, profits, returns, etc.

[5] Called the measure of absolute risk aversion, it will not vary with a linear transformation of the function, and will be a constant for both linear and exponential utility functions. This implies that risk preferences derived from exponential or linear utility functions are not affected by changes in the individuals wealth position.

choice of U should provide an acceptable representation of approximations of the decision makers actual utility function.

There are several problems with the expected utility theory as a practical approach to normative decision making under uncertainty. Briefly, some of the important drawbacks are: (1) uncertainty necessarily involves time, and uncertain choices and their consequences are sure to face the decision maker in overlapping sequence over his lifetime. A one-period time horizon utility function in wealth (e.g. Schlaifer 1969) or in monetary gains or losses (e.g. Anderson, Dillon and Hardaker 1977) may not be consistent with consumption over several time periods; (2) to use wealth or profit as the only argument in the utility function may be over-simplifying in that for some decisions makers, other attributes may influence choice; (3) the elicitation of an individual's utility is usually done by asking a series of hypothetical questions, which leads to problems in that different procedures can lead to different results, and there is no guarantee that the answers received correspond to what the decision-maker would do in a real-life situation; (4) eliciting personal probabilities is even more difficult than determining attitudes towards risk (for several approaches to doing so, see Anderson et al. 1977). How personal probabilities are formed and revised can be important for the adoption question, in that the capacity to learn a new probability distribution accurately is crucial for successful early adoption (Binswanger 1979a).

In applying the EUH as a descriptive model of economic behavior, it is assumed that all reasonable people would wish to obey the axioms of the theory and that most people actually do, most of the time. However, there is some experimental evidence that demonstrates systematic violations of the axioms of expected utility theory (e.g. Kahneman and Tversky 1979). Kahneman and Tversky argue that there are several classes of choice problems in which this phenomenun occurs and thus EUH as it is commonly interpreted and applied is not an adequate descriptive model of choice under risk. They found, for example, that people overweight outcomes that are considered certain relative to outcomes that are merely probable.

The economics literature on uncertainty has been largely concerned with defining risk and the implications on the comparative statics of the firm (e.g. optimal output) of differing restrictions on U (e.g. decreasing absolute or relative risk aversion). For example, Sandmo (1971) shows that under price uncertainty, optimal output for a risk averse firm (i.e. $U'(\pi) > 0$, $U''(\pi) < 0$) is less than the competitive solution under certainty.

There has been much empirical work done, and of interest here is the work by agricultural economists concerning economic development and attitudes and responses to risk of producers in the developing world. There has also been considerable debate among agricultural economists as to methodological approaches to decision making under uncertainty, and this will be explored in the following section as well.

2.4 Risk Analysis by Agricultural Economists

Agricultural economists were among the first economists to realize the importance of risk considerations to the producer and in understanding the functioning of the economy, and to attempt to formulate models for analyzing its consequences. Heady (1952) devoted several chapters of his classic text to risk. Much of the recent conceptual research into the influence of risk has focused on measuring the effect of risk averse behavior within the framework of the expected utility hypothesis (for an extensive bibliography of this literature, see Machina 1983).

For example, Anderson, Dillon and Hardaker (1977) survey research done up until 1977 of approaches to decision analysis under risk "based on the decision makers' personal strength of belief about the occurrence of uncertain events and his personal evaluation of potential consequences" (p. ix). Newbery and Stiglitz (1981) also base their analysis of the theory of commodity price stabilization on the assumption that individuals maximize their expected utility.

2.41 Expected Utility Analysis

The traditional method of expected utility analysis is to apply the assumption of risk aversion and interject a random variable (e.g. price) into the usual objective function. One concern of agricultural economists in trying to understand the role of risk and uncertainty has been how risk and uncertainty affect the efficiency of production and investment decisions by individuals (and firms and governments). In the context of agricultural production decisions, for individuals who are risk averse (and are assumed to maximize expected profits), it is hypothesized that they will tend to underinvest in inputs for production opportunities with risky outcomes (Binswanger 1979b)[6]. Thus one would expect to see lower output and higher prices for risky enterprises than would be the case for lower levels of risk.

With respect to the developing world, a related issue is the question of whether modern inputs being introduced into agriculture increase riskiness faced by producers, and if so, does that risk inhibit adoption of new technologies? Roumasset (1979) argues that if farmers are risk averse, the desired characteristics of a new technology are not only a high expected return (e.g. a high average yield for given input levels) but also a low variability to that return. For example, it has been suggested that a higher average yield may not be adopted by a risk averse farmer if it was also providing much more variable yields. An even broader issue being addressed is how the presence of risk and farmer's response to it influence economic development (e.g. Day 1979).

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[6] In this early study, Binswanger concluded that risk aversion prevents producers from investing as much in their land and production process as would be the case if they were less averse to risk.

2.42 Safety-First Models

With respect to analyzing decision making under uncertainty in the developing world, alternatives to the expected utility approach have been suggested. Roumasset (1976) has voiced strong criticism of the use of "full optimality" models in this context. He concludes that attitudes towards risk must be derived from a farmer's wealth position, the credit terms available to him, his investment possibilities, and also account for the institutional and social environment in which he lives. He and other critics of the expected utility models advocate basing the decision model on some feasible decision process, typically a rule-of-thumb (see Anderson 1979, for a review of other methods based on security motives). "Safety first" and "cautious optimizing" models are alternatives described by Roumasset as bounded rationality models more suited to the actual decisions as made by small farmers (due to the existence of a "disaster level"). Safety first advocates believe that at low levels of production, survival strategies dominate farmer behavior. These survival strategies are incorporated into decision rules (or rules-of-thumb), which can be lexicographic in nature. The implication is that analysis of marginal trade-offs between approaches is not possible as it is with the expected utility paradigm.

In terms of a definition of risk, in the expected utility aproach, a "risk premium" is defined as what risk averters will pay to avoid (Rothschild and Stiglitz 1970). It has been argued that this is unsatisfactory due to the implication that, in general, risk cannot be defined independently of risk preferences[7] (Roumasset 1979).

The safety first advocates, on the other hand, define risk by the probability that the variable in question (e.g. returns) will fall below some critical level (e.g. a 'disaster' level of income). This, however, can lead to a somewhat arbitrary decision as to exactly what a 'disaster' level is.

Although problems with each type of model are typically discussed, the two types of models (i.e. those based on a utility function versus those based on simpler safety criteria) have common aspects and methodological problems as well.

There have been instances when predictions of these two classes of models are similar (although identification of most researchers with either of the approaches usually prevents such comparisons). Both approaches require some knowledge about the attitudes towards risk of the decision makers whose decision is modeled. The utility based approaches require the elicitation or estimation of the utility function, with all the potential misgivings one might have about which procedure to use in order to do this. The safety-based approaches require the elicitation of disaster levels of income (or other constraints). Binswanger (1979a) points out that the determination of the latter can be chosen arbitrarily or based on some past observed income requirements, but is not likely to be any less difficult than

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[7] However, Rothschild and Stiglitz show that the riskiness of two distributions can be comparted if they have the same mean.

elicitation of utility functions. Both approaches are based on personal or subjective probabilities of outcomes of different choices. Thus the revision of personal probabilities becomes an important issue. For example, for the adoption question, the manner in which subjective probabilities are formed makes a great deal of difference in how, when, and why people adopt new techniques of production. The interaction of risk and learning is therefore an important but neglected aspect of much of the literature (see Day 1979).

2.5 Empirical Measures of Risk

Roumasset's empirical test of a lexicographic safety-first based model resulted in conclusions in contrast to the conventional wisdom that risk aversion may cause farmers to use less inputs than are needed to maximize expected profits (the case of risk-neutrality), and he found a risk-neutral model to give the best explanation of decision-making behavior. The data he used, however, was experimental data. The "yield gap" between experimental station and farm level plots has been shown by Matlon to be of such a magnitude as to make risk studies on experimental station fields suspect (see ICRISAT annual reports). That is, there was likely far less of a mean-variance trade-off present as one would expect at the farm level.

Binswanger and Sillers (1982) summarized other empirical studies measuring producers attitudes towards risk in the developing world.

They found evidence that "farmers in developing countries are almost universally risk averse, and that risk aversion, that is, farmer's attitudes towards risk, may not vary greatly between different cultural or agroclimatic environments, nor be very sensitive to variations in wealth" (p.18). However, empirical evidence supporting a fairly uniform degree of risk aversion (e.g. Binswanger's experimental study in rural India - see Binswanger 1980) does not help explain the substantial differences in observed behavior of small farmers, in particular, in the large differences in the use of purchased inputs among farm sizes. Thus Binswanger and Sillers conclude that the "indirect" effects of risk on producers are more important than the "direct" effects of risk (i.e. degree of risk aversion). These indirect effects of risk are related to credit accessibility and constraints faced by small farmers due to the risks of farming itself and to problems of imperfect information about borrowers and to the absence of good insurance markets.

2.6 Economics of Information

Up until this point, we have been concerned with the economics of uncertainty. In order to take a closer look at the interaction between risk and learning, I will move on to a look at what has been done with relevance to this thesis in the economics of information.

Informational activities can be described as non-terminal, in that a final decision is deferred while either waiting or actively seeking new information which will reduce uncertainty. Individuals are now assumed to undertake informational actions which allow them to overcome uncertainty to some extent. For example, if two possible states of the world are "Rain" versus "Shine", then a possible informational action is to look at the barometer. The consequence will allow an improved likelihood of behaving properly - not with certainty, though, since the barometer reading is not a perfect indicator of whether it will be sunny or not.

Thus the new element in the process of decision making is that the individual can acquire information, leading to a revision of probability beliefs, and in general, to a possible revised choice of action. This reformulation of probability distributions has generally been made in the context of Bayesian learning.[8] One of the implications of this revision of expectations is that the lesser the individuals confidence in his initial beliefs (which is indicated by the spread of the probability distribution - the tighter the prior probability distribution, the more confident), the higher the value may be attached to acquiring information (Hershleifer and Riley 1979, p.1395).

The value of informational gains can be measured by the expected utility gains from shifting to better choices. However, this would be an ex-post valuation, and the decision to seek information must be made beforehand (Chavas and Pope 1984). Marschak and Miyasawa (1968)

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[8] Models assuming Bayesian learning incorporate a mechanism for adjusting personal probabilities as new information becomes available.

explain that what one can obtain or purchase in terms of information is not an actual message (since you don't know beforehand what exact 'message' you will receive), but an informational service that generates a probability distribution of messages. What is important is that a costless information service can never lower the agent's expected utility. That is, the value of costless information can be shown to be always non-negative (see Lavalle 1978, Gould 1974, Hess 1982).

Information can also be gained by simply waiting. For example, in our case, the farmer learns over time by observing the actual rainfall during the growing season. Thus if he can remain flexible in making decisions, he can revise future plans as new information becomes available. This suggests that models of decision-making that are "open-loop" (learning is not explicitly taken into consideration), or static in nature, are not appropriate tools of analysis where new information has a significant influence on economic decisions (see Chavas and Pope 1984). The dynamic nature of the decision-making process (corresponding to the growth stages of the plant, for example) and the allowance for some temporal resolution of uncertainty cannot be captured in a static framework.

2.7 Information, Flexibility and Agricultural Production Response Models

The analysis of agricultural production has traditionally relied on the well-developed static tools of microeconomic theory (Heady and

Dillon 1961). However, these production processes occur over time and typically decisions are made at successive stages of growth when particular functions are performed (Chavas and Johnson 1982). For crop production, both the level and timing of inputs can be critical, especially for small farmers in harsh environments. Burt and Allison (1963) proposed formulating farm management decisions as multistage decision processes. Recently, dynamic modelling of agricultural production response has been undertaken in order to capture the importance of timing and flexibility in the decision making process (Chavas, Kliebenstein and Crenshaw 1985, Fawcett 1973, Antle 1983, Chavas and Johnson 1982). This approach also allows the incorporation of the role of new information that is acquired over time, and how it influences the way in which production decisions are made (Chavas and Pope 1984). For example, a farmer who is able to revise future plans as new information becomes available (at no cost) will never be worse off and tend to be better off.

Several authors have called for more empirical work to be undertaken on the interaction between risk and learning (e.g. Binswanger, Day in Roumasset et al. (eds) 1979) and the dynamic implications of risk and uncertainty. Day calls for the development of models which are based on the dynamics of plant growth and which considers the time distribution of inputs in interaction with critical periods in a plants development. He stresses that policy formulation should be based on an understanding of actual economic behavior and that the concept of "flexibility of response" is a directly experienced, empirically based concept whose attributes can be observed.

With the incorporation of risk in typical production models (whether an expected utility maximization approach or a safety-first based approach is taken), model results will depend on risk preferences (e.g. the agents' risk aversion coefficient). This implies much or agricultural decison analysis under risk is made based on personal or subjective probabilities of outcomes. Since these risk preferences can vary significantly both over time and between individuals, the results from these models may not be terribly informative or have much prescriptive power.

It is for this reason that Chavas (1987) suggests an alternative approach that "attempts to minimize the role of preferences in economic behavior and to maximize the role of technology and institutional environment" - factors that can be measured more easily than can risk preferences. What this implies is that risk behavior can come about due to the particular physical and economic environment of the decision maker.

If the ability of a technology to allow production plans to adjust to variations in the environment during the growing season is important to farmers, the traditional models focusing on the influence of risk averse behavior on farmers' economic decisions have also failed to recognize an important concept. This flexibility to respond to environmental uncertainty remains important even under risk neutrality assumptions (e.g. see Machina 1983).

This does not imply that risk aversion is unimportant. Instead, what I have tried to emphasize within this literature review is that (1) empirical research has suggested that the majority of individuals are not far off from being risk neutral; and (2) it is extremely difficult to properly ascertain and interpret levels of risk aversion without sufficient socio-demographic information and a better understanding of how individual (and farm household) attitudes towards risk are formed and how they affect decision making.

It is for these reasons that an approach that enables the researcher to separate out issues of risk aversion and the incorporation of new information into the decision process can be useful. This approach is described in chapter four.

Chapter 3. Farming Systems in the West African Semi-Arid Tropics

3.1 Introduction to the Data

The six villages chosen for the ICRISAT studies in Burkina Faso are located in three types of savanna. These three types of savanna roughly correspond to three different agro-climatic zones that can be distinguished by the amount of rainfall and its distribution throughout the year. They also represent the most common climatic zones in Africa, with the Guinean and Sudanian savannas together estimated to cover more than three-quarters of a million square miles. There are 150 households represented in the sample with 25 households selected from each village.[1] Detailed input/output data was gathered on a weekly basis for all major cropping activities for the period 1981 to 1983. Figure 3.1 shows the location of the six study villages within their respective rainfall zones.

The Djibo region represents the low rainfall and sandy soil of the northern Sahel savanna zone. It is characterized by a long term average of 500-700 mm. annual rainfall and a rainy season of 3 to 5 months. Pressure on arable land is high with large areas suitable only for grazing animals. The principal food crop here is millet, with fonio, cowpea, white sorghum and maize planted to small areas. Groundnut is the only cash crop that can be produced since cotton and

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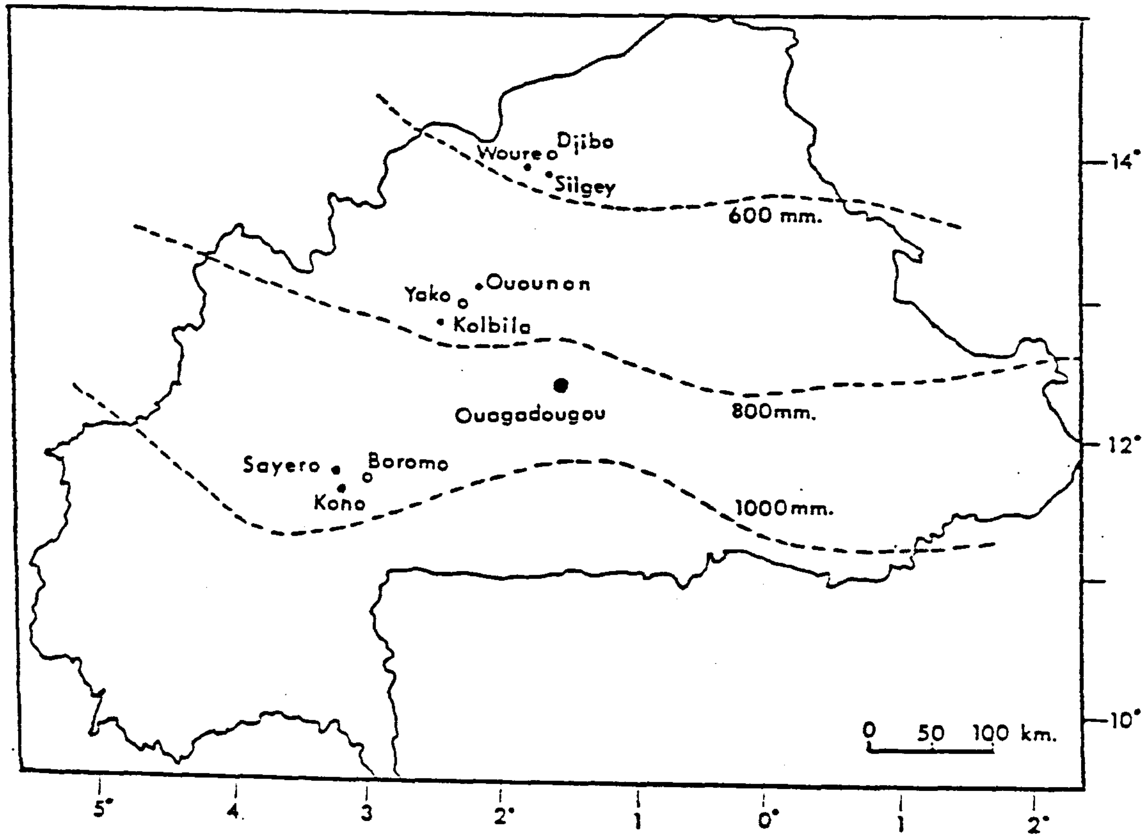
[1] For a discussion of sampling methodology, see Guide to Data Collection and Encoding Procedures, ICRISAT, West African Economics Program 1986.

Figure 3.1. Burkina Faso

Locations of ICRISAT study villages

and agro-climatic zones

- ○ Capital City
- ● Regional Administrative Center
- • Village



red sorghum require better soils and higher moisture levels. The dominant ethnic groups are the Rimaibe and Fulani. The Fulani are generally herdsmen to whom the cattle are entrusted, although a few of them have plots of land which they farm. Almost all work in the Djibo region is done by hand-tool, with some isolated progress being made with animal traction based on oxen power. The two villages selected for the sample in the Djibo (northern) region are Woure and Silgey.

The Yako region is representative of the Central Mossi Plateau, on which approximately 60% of Burkina Faso's 7.2 million (1983) live. Classified as the North Sudanian zone, it has a long term average rainfall of 700-900 mm. distributed over 4 to 5 months. Soils tend to be very shallow with low organic matter content. Due to a wider range of soils and higher levels of rainfall, sorghum plays a more dominant role in cropping systems, with white and red sorghum and millet constituting the major crops in terms of cultivated area. Maize is also grown, and groundnut and yams serve as cash crops. Donkey drawn scarifiers and weeders are used, but in general animal traction equipment is employed very little in this area. Increasing population pressure in this region has been associated with the gradual deterioration of the bush fallow system, along with a general deterioration of soils due to crusting, decreasing organic matter content and overgrazing. The Sudanian (central) villages are Ouounon and Kolbila.

The Boromo region is located in the Northern Guinean zone (also called the Southern Sudanian zone) with generally more than 900 mm. and

5 to 6 months of rain. Agricultural potential is the greatest here due to more favorable soils (generally deeper with higher organic material content) and rainfall conditions. Population pressure has not been high in this region, having been restricted by diseases such as river blindness (a serious problem in the river valleys of the Southwest). Major food crops are white and red sorghum, millet and maize, with some rice grown in the inundated lowlands (bas-fonds). Cotton is an important cash crop here. In a large part due to the institutional support of cotton production (i.e. the marketing agency, SOFITEX), oxen drawn traction has been increasing in use over the past 10 years, but is still used primarily on the cotton fields. Inorganic fertilizer use is higher in this region for both cash and food crops. The southern or Guinean sample villages are Koho and Sayero.

3.2 Cereal Land Allocation

The principal cereal crops in all of Burkina Faso are millet and sorghum, occupying an estimated 80% of the crop area. The relative importance of millet, sorghum and maize shifts as one moves from the northern regions to the southern. As seen in table 3.1, millet occupies more than 90% of the area[2] in the north, 22-42% in the central region, and 15-28% of the area in the southern region. Sorghum is generally seeded to less than 5% of the northern area, to upwards of

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[2] Area refers to the total area in our sample that was devoted to the principal crops, that is, it does not include the womens fields.

Table 3.1. **Area Devoted to Major Crops**

1. Djibo Region (Northern Sahel zone)

Hectares & (% of total area)

	WOURE			**SILGEY**		
	1981	1982	1983	1981	1982	1983
Millet	138.6(93)	127.9(92)	135.0(88)	158.4(94)	138.25(94)	145.6(95)
W.Sorghum	6.3(4)	7.3(5)	11.4(7)	7.0(4)	4.20(3)	3.8(2)
R.Sorghum	0	0	0	0	0	0
Imp.Sorghum	0	0	1.6	0	0	.05
Maize	1.8(1)	1.5(1)	2.1(1)	1.8(1)	1.20(1)	1.45(1)
Cotton	.26	0	0	0	0	0
Rice	.005	0	0	.15	.20	.3
Fonio	2.04(1)	3.4(2)	3.03(2)	1.7(1)	2.50(2)	1.9(1)
Groundnuts	.27	.31	.2	.67	.27	.18
Total Area	149.29	140.27	153.33	169.71	146.57	153.08

2. Yako Region (Sudanian Zone - Mossi Plateau)

	OUONON			**KOLBILA**		
	1981	1982	1983	1981	1982	1983
Millet	22.5(22)	24.6(22)	34.1(29)	39.2(41)	35.9(34)	35.7(42)
W.Sorghum	68.2(68)	75.4(68)	75.8(64)	47.6(49)	60.3(57)	38.3(46)
R.Sorghum	2.7(3)	4.8(4)	2.6(2)	5.9(6)	8.0(8)	8.4(10)
Imp.Sorghum	0	0	.2	.1	0	.4
Maize	1.9(2)	2.1(2)	2.5(2)	1.8(2)	1.0(1)	.8(1)
Cotton	0	0	0	1.9	.9	.5
Rice	0	.03	0	.4	.65	.01
Groundnut	5.3(5)	3.6(3)	3.1(3)	-	-	-
Total Area	100.6	110.5	118.4	96.9	106.7	84.1

3. Boromo Region (Guinean Zone)

	KOHO			**SAYERO**		
	1981*	1982	1983	1981	1982	1983
Millet		39.2(25)	53.9(28)	21.4(15)	27.6(19)	37.1(25)
W.Sorghum		56.2(36)	54.2(29)	44.3(31)	41.1(28)	40.9(28)
R.Sorghum		10.4(7)	16.9(9)	21.6(15)	13.3(9)	10.5(7)
Imp. Sorghum		0	0	0	0	.4
Maize		7.8(5)	16.7(9)	5.7(4)	8.3(6)	7.8(5)
Cotton		40.1(26)	47.3(25)	48.6(34)	55.2(38)	49.5(33)
Rice		2.99(2)	4.8(2)	.13	.8	1.5(1)
Total Area		156.7	193.8	141.73	146.30	147.70

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* The data for Koho in 1981 was not available for analysis.

50% of the principal crop area in the central region, and to around 40% of the southern zone. Very little maize is grown in the Djibo and Yako regions, with 5-10% of the Boromo region devoted to it. Cotton becomes an important cash crop in southern Burkina Faso, occupying 25-38% of the area.

Millet, white sorghum and maize constitute the major part of the urban Burkinabe diet[3], in the form of a porridge-like substance called Tō which is eaten with various types of sauces. Beer (dolo) is made out of red sorghum. Red sorghum is also prepared as food in the same forms as white sorghum and millet. Red sorghum was not planted in the northern region, and constituted approximately 4-10% of the area planted to major crops in the central and southern zones.

Cereal land allocation is largely determined by land quality differences and the expected pattern of rainfall. Rainfall in the WASAT is not only poor in absolute terms coupled with a short growing season, but it is also extremely variable. Uneven distribution occurs firstly over time. Apart from long-term trends for the whole region, variability between years is high. Within a single crop season, the much dreaded dry-spells of one to several weeks often mean the difference between surplus and hard times. Spatially, variability is of course between agro-climatic zones, but large differences between villages and even plots are common. The short and localized heavy rain-torrents best typify this phenomena.

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[3] Rice forms a much more substantial part of the diet in urban areas.

Given this extreme variability in rainfall, soil conditions become of paramount importance. Soil fertility levels tend to be very low, with the dominant soils of the semi-arid tropics suffering from important chemical and physical deficiencies and thus they are often termed 'fragile'. Perhaps the most important characteristic is the soils capacity to absorb and retain the rain that does fall. In fact, as we shall see, it is exactly this interaction between rainfall and soil which shapes the farmers' basic options for cultivation.

Soil quality differences are best described in terms of the concept of toposequence (Stoop and van Staveren 1985). Gently undulating landscapes characterize the WASAT and within this landscape a pattern of land types and soils which is closely linked to the topography can be distinguished. Low fertility, drought sensitive and shallow soils with a high sand content can be found on the uplands. More fertile, moist to wet soils (with a higher loam, or clay content) are found on the lower slopes and lowlands (see figure 3.2). Broadly speaking, this change in soil type from top to bottom is accompanied by a decrease in infiltration capacity, but an increase in retainment capacity. Thus the same level of rainfall falling on these different land types can cause both droughts and floods during the rainy season.

This change in soil types is, among other things, related to the phenomenon of 'splash-erosion' that forms crusts on all soils containing loam. This can affect upper slopes, but is especially predominant on middle and lower slopes. A typical problem of the upper slopes, then, is drought, since sand has a low ability to retain water.

Figure 3.2. Toposequence

Toposequence:	Uplands	Upper Slopes	Mid-Slopes	Lower Slopes	Bas-Fonds
Crops:	Millet	Millet & White Sorghum		Red & White Sorghum	Rice
Soiltype:	Sandy	Higher Sand Content	Higher Clay Content		Clay

In contrast, the lower slopes are in danger of flooding. Erosion, bringing soil particles from the upper and middle slopes to the lowest areas, aggravates this problem by causing the lower slopes to easily clog. At the same time, erosion causes a transfer of fertility from top to bottom.

Given these soil and rainfall conditions, maize is the most risky crop to grow. It cannot be grown on soils that are either too wet or too dry, and demands relatively fertile soils. However, it is a highly preferred crop because its August harvest effectively bridges the 'hunger period' from planting (May-June) to the harvest of millet and sorghum (October-November).

Millet and sorghum exhibit demands on the environment that are somewhat complementary: millet is drought resistant, whereas sorghum is less so. Sorghum better resists flooding, millet hates 'wet feet'. Millet can be grown on very poor soils, sorghum performs less well on poor soils. These characteristics give rise to typical environmental 'niches', which in turn are responsible for major patterns of cultivation.

Matching the general soil-conditions along the toposequence to the environmental requirements of the major crops, the following pattern arises. Millet is better suited to the upper and mid slopes, and sorghum to mid to lower slopes. Besides rice, sorghum can tolerate some flooding, thus rice and sorghum are planted in the lowlands if the household has access to them. If general soil fertility is too low, maize is typically grown on small plots close to the compound, where manure is abundant due to the practice of keeping animals such as goats and sheep close to the compound. Thus the higher demands of maize can somewhat be met, even in areas where soil is very poor.

3.3 Environmental Risk Management

How are these production patterns related to rainfall expectations? The percent of total area devoted to any given crop (or variety, as we shall see) varies substantially from year to year (see table 3.1). Farming systems in the WASAT have specifically adapted to rainfall uncertainty by maintaining a high degree of flexibility in cropping decisions.

At the level of the cultivation of a single plot, the household has a number of technical options to reduce yield variability. These tactics are aimed at reducing the overall variability of yields, and can be broadly grouped into passive and active risk management techniques. Passive techniques are actions taken independently of the realization of environmental conditions. Active techniques of risk management are production practices which preserve flexibility into the cropping year. As environmental conditions are realized, specific actions are taken to fine tune the production technique to realized environmental conditions.

3.4 Passive Techniques of Risk Management

One example of a passive technique which stabilizes yields but which requires no active intervention as environmental conditions are revealed is low plant density, which lessens competition between plants for limited water and soil nutrients. Increased planting density (or intercropping plants between hills as opposed to the traditional strategy of mixed seed planting in the same pocket) requires substantially more labor at the critical planting time and can mean less area seeded or conflict with timely weeding (Matlon 1985). ICRISAT found that farmers tended not to follow higher recommended levels of seeding density on their farmer-managed trials (see the ICRISAT Annual Report 1982). Low plant density can also be realized through the practice of thinning after seedling emergence, an active technique which also requires more labor at a critical time (although often thinning is carried out in conjunction with first weeding).

Unfortunately, our data set does not include information on plant density.

The exploitation of toposequential "niches" can also be described as a passive risk technique. The practice of matching the type of crop to a particular microenvironment has been described earlier. The practice of planting sorghum primarily on the lower slopes, for example, reduces the variance of yields that would occur if it were planted on upland soils. The extent to which the farmers in our sample actually follow this toposequential 'matching' can be seen in table 3.2. In general, the data support this description of cropping patterns. Millet is usually planted on the higher slopes and sorghum devoted to the lower slopes and inundated lowlands. However, farmers will alter these patterns under various rainfall regions as can be seen from the intrayear variation. For example, in 1982 a higher percentage of sorghum was planted on higher slopes in Kolbila, following a fairly good year for rainfall in 1981. In 1983, however, after a bad 1982 season, sorghum again shifted lower down on the toposequence.

To the extent that farmers deviate from these patterns in general (e.g. planting a lot of sorghum on higher slopes, as seen in Koho in 1982 and 1983), alternative non-risk-based explanations must be sought. Another shift that occurs is due to rotational considerations. It has also been suggested that increasing population pressure has led to intensification in sorghum production even at the risk of increased variability in yields (Matlon, personal communication). Population

Table 3.2. **Toposequential Adaptation**

Percent of Area seeded in Lower (L), Middle (M), and Upper Slopes (U).

	1981			1982			1983		
	L	M	U	L	M	U	L	M	U
1. Silgey									
Millet	11	57	32	03	89	08	02	93	05
White Sorghum	88	12	0	85	15	0	37	63	0
2. Woure									
Millet	20	27	53	11	38	51	04	42	54
White Sorghum	-	-	-	86	06	08	46	54	0
3. Kolbila									
Millet	31	37	31	10	62	28	07	64	28
White Sorghum	40	44	16	19	41	49	11	59	29
4. Ouounon									
Millet	05	67	27	03	81	15	01	57	42
White Sorghum	09	58	33	03	74	26	01	70	28
5. Sayero									
Millet	10	10	80	0	30	70	0	37	63
White Sorghum	10	14	76	08	47	45	.4	48	51
6. Koho									
Millet	-	-	-	04	28	67	02	09	89
White Sorghum	-	-	-	04	21	75	05	22	73

pressures are particularly high in the villages of Koho and Kolbila where the practice of planting sorghum on the higher slopes is followed to a much larger extent than is seen in the other villages, which seems to support this hypothesis. As well, not all farms have sufficient access to all soil types, which allows one household to pursue these strategies in isolation.

Thus toposequential management strategies can also fit under the category of active risk management strategies in that farmers will alter these patterns during the season as the rainfall pattern becomes known with more certainty (Watts 1983). For example, if the first rains arrive early but are followed by a period of drought, a farmer may first plant sorghum on the lowlands but replant millet later in the revised expectation of insufficient rainfall for sorghum to succeed. This phenomena of crop substitution will be discussed in more detail shortly.

3.5 Active Techniques of Risk Management or Adaptive Flexibility

Passive techniques are managed through complicated sequential patterns of decision-making dependent on the onset, character, and duration of the rains. Timing of activities is recognized as crucial to reducing yield variability. Maintaining the flexibility to 'fine-tune' cropping activities as the season progresses, along with the availability of sufficient labor during 'bottleneck' times, are key issues. Daily decisions are made as the season unfolds due to the uncertainties faced. This close supervision and management revolve around two critical moments: the start of the rains and the first weeding. This sequential process of risk management can be simplified by decomposing each cropping season into five stages which roughly correspond to discrete decision-making segments.

3.51 Stage One: Clearing / Soil Preparation / Dry Seeding

This has been called the 'pre-rainy' season in which the rains are very light and variable. The farmer has little idea of what state of nature will prevail except his subjective estimates based on past experience. Soil preparation is generally nonexistent - until sufficient rain falls to soften the soil, it is too hard and crusty to break the surface without oxen traction. The prevalent method of seeding involves digging a hole with a hand hoe, dropping the seed into it, and pushing the soil back over it. Farmers are beginning to seed in straight rows with the practice of line tracing or shallow scarification which can been done by hand or by pulling a simple instrument behind a donkey. Deep plowing using animal traction (donkeys or the more effective oxen) is being used in some areas for soil preparation, particularly for cotton and maize in the Boromo region. Table 3.3 shows the incidence of animal traction employment in soil preparation for three villages in the different agro-climatic zones of our sample. A very low percentage of the area in the north and central villages is prepared for seeding by deep plowing. In the southern village of Koho, 26% of the sorghum land and 65% of the maize area was deep plowed before seeding.

Table 3.3 **Soil Preparation: 1983**

Percent of Seeded Area Prepared using the Following Techniques:

		Animal Traction			Hand-Tool	
Village	Principal Crop	Line Tracing	Shallow Scarification	Deep Plowing	Line Tracing	Deep Plowing
Woure	Millet	0	12	14	0	0
	White Sorghum	0	0	4	0	0
	Imp. Sorghum	0	0	0	0	0
	Maize	0	11	0	0	84
	Fonio	0	15	0	0	85
Kolbila	Millet	10	4	12	7	5
	White Sorghum	23	5	9	0	2
	Red Sorghum	11	14	6	0	0
	Imp. Sorghum	0	20	0	0	32
	Maize	0	6	0	0	96
	Cotton	0	94	0	0	0
Koho	Millet	0	0	8	0	8
	White Sorghum	0	0	26	0	8
	Red Sorghum	0	0	8	0	7
	Maize	0	0	65	0	28
	Rice	0	0	10	0	81
	Cotton	0	0	32	0	9

3.52 Stage Two: Planting

Planting begins with the commencement of the "true" rainy season - as the rains progress the soil is softened to allow planting. The farmer still cannot predict rainfall but is starting to form new expectations based on the "pre-rainy" season (and experience[4]).

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[4] Superstitions can play a large part in the prediction of rainfall in this part of the world. Apparently, many farmers have a "limited goods" perception of the amount of rainfall in any season. This can lead to premature planting when a few heavy rains come very early in the season, if they believe this signals little rain at the

The use of the hoe as the basic tool for cultivation has an advantage over mechanized methods, and that is its flexibility. It allows the farmer to continuously adjust his cropping pattern as the season progresses to further his objectives. When the first substantial rains come, farmers put all priorities on planting quickly. Planting by hand is preferred to deep plowing with animal traction in most instances since plowing can delay seeding unless the rains come very early (see Lang et al. 1984). Planting by hand also leads to the construction of varied mixtures of crops, as we shall see.

The variability of the date of planting from year-to-year demonstrates the degree of flexibility the farmers must have in the act of planting. For example, the range in average dates of planting for selected varieties of millet (although varieties differ between villages) varied by 9 to 21 days (June 6-June 27) over the three year period in Woure, 5 to 24 days (May 31-June 23) in Kolbila, and 11 to 28 days (May 22-June 19) in Sayero (see table 3.4).

Within a year, the average date of planting different varieties of millet and sorghum varies little in the north (3-11 days), slightly more in the Yako region (2-17 days), with considerable intrayear variation in planting dates evident in the Boromo region.

Fewer varieties are planted in the northern villages. For example, one variety of millet generally was seeded to greater than 70% of the total millet area in Woure. There is little range in the length of growing cycles (planting to harvest) evident between varieties (e.g.

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end of the season.

Table 3.4. Average Planting Dates and Length of Growing Cycles of Selected Varieties

	1981			1982			1983		
1. WOURE									
Millet Variety	Av.[1] G.C.	Percent[2] Area	Av.[3] Date	Av. G.C.	Percent Area	Av. Date	Av. G.C.	Percent Area	Av. Date
111	118	67	6/26	121	74	6/11	126	79	6/21
112	117	15	6/23	114	03	6/22	-	0	-
113	114	05	6/25	123	22	6/6	115	18	6/27
White Sorghum Variety									
122	126	93	6/27	142	81	6/13	130	82	6/29
123	126	03	6/29	133	14	6/9	129	12	7/3
2. KOLBILA									
Millet Variety									
311	150	15	6/2	139	26	6/6	135	15	6/11
312	141	25	6/5	140	28	6/7	139	38	6/10
313	153	22	6/8	145	14	6/23	153	24	5/31
White Sorghum Variety									
323	147	66	6/1	145	66	6/6	144	71	6/6
325	147	04	5/28	154	08	5/30	154	14	6/2
3. SAYERO									
Millet Variety									
611	191	30	5/13	190	46	5/11	174	33	5/22
612	192	29	5/15	174	03	6/3	173	10	6/3
613	145	05	6/19	182	21	5/22	177	23	5/27
614	198	08	5/13	182	01	5/25	179	15	5/28
White Sorghum Variety									
621	165	15	5/28	167	15	5/21	158	23	6/8
622	163	19	6/4	161	05	6/10	180	18	5/18
624	184	32	5/16	170	30	5/25	175	25	5/24
629	170	06	5/30	165	03	5/28	183	06	5/18
700	-	0	-	163	06	5/11	160	09	6/7

[1] Average length of growing cycle in days.
[2] Percent of area of crop devoted to that variety.
[3] Average date of planting.

a maximum of nine days difference in the length of growing cycles of millet in Woure). That is, there appears to be no true 'short-cycle' and 'long-cycle' varieties of either millet or sorghum available in the Sahel region. Because of a much shorter rainy season coupled with the extremely low water retention capacity of the sandy soils, there are fewer opportunities for replanting and for relay cropping which occurs in the south.

3.53 Stage Three: Seedling Establishment / Reseeding

The rains are (or are not) established. Plants have germinated and the degree of seedling establishment can be observed. On this information farmers can begin to form definite expectations of their cropping patterns. Poor seedling establishment leads to replanting and perhaps crop substitution. One tactic available to attempt to reduce moisture requirements is the replacement of long-maturing varieties by shorter-cycle varieties to avoid drought stress at the end of the growing season. This may develop into stage four (weeding) for the substitution of short cycle crops such as cowpeas. Intercropping can also emerge as reseeding during stage three or four - that is, crop mixes can emerge temporally as the season unfolds.

The extent of replanting a crop to the same variety, to a different variety, and to a different crop can be seen in table 3.5. The percentage area reseeded to a crop can vary considerably from year to year. For example, in Kolbila (the central region) the percentage

Table 3.5. Percentage of Total Area Re-Seeded

Percentage of millet or sorghum area reseeded to same variety, and
(% of seeded area that was reseeded to a different variety)

	1981		1982		1983	
Village:	Millet	W.S.	Millet	W.S.	Millet	W.S.
Silgey	9.2 (0)	9.5 (0)	13 (.5)	0 (0)	16.5 (.5)	2 (0)
Woure	11 (2.5)	7 (5)	16 (2)	57 (.4)	29 (1)	15 (0)
Kolbila	57 (2)	60 (7)	38 (19)	34 (0)	9.5 (0)	13 (7)
Ouounon	18 (0)	43 (28)	37 (0)	28 (6)	12.5 (0)	19 (2)
Koho	-	-	.5 (0)	8.4 (0)	35 (6.4)	36 (2)
Sayero	18 (0)	82(0)	7 (0)	13 (0)	40 (0)	53 (0)

Table 3.6. Crop Substitution with Replanting

Percentage of Area Re-Seeded to a Different Crop > 10 days After Initial Planting

	1981		1982		1983	
Village:	Millet	W.S.	Millet	W.S.	Millet	W.S.
Silgey	16.6	7.3	9.1	0	14.6	0
Woure	56	11	25	20.5	50	15
Kolbila	1	4.7	1.8	6.4	7.2	6.2
Ouounon	0	4.5	17	25	0	2
Koho	-	-	3.5	13.2	9.5	.7
Sayero	4.1	17.6	-	-	14.1	2.6

of millet area replanted ranged from 57% in 1981, to 38% in 1982, to only 9% in 1983, when the first rains came later and were fairly consistent once they arrived. There is more replanting occurring in the central zone than in the north or south, probably due to a greater lack of time and options, in the sense that there is better rainfall and soil moisture retention in the south, thus it is less necessary to replant there than in the north.

Generally very little varietal substitution takes place, but again this seems to depend on rainfall circumstances. For example, in Ouounon, 28% of the sorghum area was reseeded to a different variety of sorghum in 1981, but only 6% of the area in 1982, and 2% of the area in 1983 followed this pattern. Marginal areas were replanted to a different variety of the same crop in the Sahel zone.

It is in the north, however, that we can observe substantial areas being replanted to different crops altogether (the most prevalent being cowpeas, but many crop mixes emerge in this manner). Evidence of this is given in table 3.6. It is in the northern villages in particular that a considerable amount of replanting (or intercropping more than ten days after the initial planting) of a different crop occurs. Here again we see evidence of an adjustment of cropping patterns as the season unfolds. Strong interyear variability in this practice can also be observed. This again suggests that viable alternatives in terms of different lengths of growing periods do not as yet exist for sorghum and millet in the north and even central zones (also see table 3.4).

3.54 Stage Four: Weeding / Thinning

Two tactics are available to farmers at this stage to deal with rainfall variability. The first is the intensification of weeding when drought occurs to reduce weed-crop competition. The second is increased thinning to deal with drought stress.

The majority of weeding is also done by hand, with the chance of replanting and/or thinning being done simultaneously quite high due to peak demands on labor at this time.[5] The first weeding is the most arduous and time-consuming of the tasks. Both a timely weeding and sufficient labor to do the job well are important factors in determining yields.

The use of animal traction for weeding appears to have potential for relieving some of the labor constraint at this critical stage (see Lang et al.). It is being used rarely for weeding, however, except in the Boromo region, and mainly for cash crops such as cotton. The use of animal traction technology will be elaborated upon in the following section.

3.55 Stage Five: Harvest

The post-rainy season signals a decrease in the volume of rain that ideally corresponds to the final stage of plant growth, the

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[5] Unlike weeding, thinning requires a minimum soil-moisture level to avoid damage to plant roots.

maturation and 'filling' of the grain with requires decreasing amounts of moisture. If planting (or replanting) is done late, or a late-season drought occurs, with rainfall ending before head filling is complete, very poor yields are the result. Again, soil water holding capacity is another critical factor, since in the better soils in the south and on lowland fields, the effect can be an extension of the growing season.

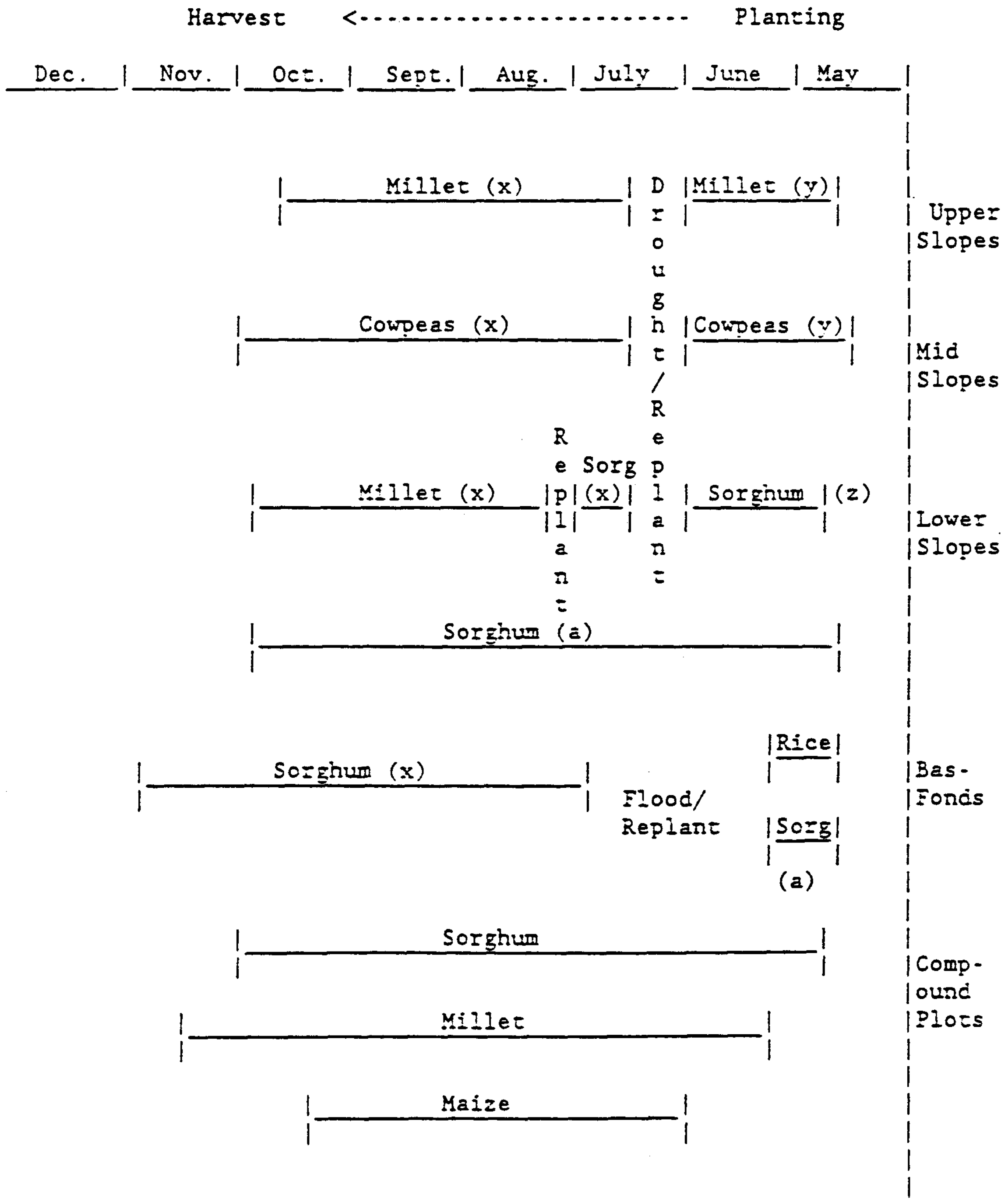
3.6 Summary of Active Risk Management Techniques

The degree of flexibility farmers actually possess in this sequential decision making process will of course depend on their access to resources, and will increase as environmental restrictions lessen as one moves south. It is important in analyzing decision making under risk that one does not impute a choice to something that is not technically feasible (for example, growing maize on very poor soils). In summary, we have discussed three broad means of coping with rainfall variability:

(1) the management of different toposequential land patterns,
(2) the sequential use of crops or crop varieties, and
(3) differing plant densities, through planting, thinning or weeding.

Figure 3.7 indicates how cropping patterns, crop varieties and toposequence are articulated in a sequential process of decision making in accordance with the demands of the rainfall regime. Figure 3.8 demonstrates the five generalized stages of cropping activities and the

Figure 3.7. Example of Toposequential Adaptation for the Central Zone



Note: Letters in parentheses symbolize different varieties.

Figure 3.8. **Generalized Planting Stages***

```
|--| Farm Preparation/Manure/Burning
|  |--|
|     |--| Soil Preparation
|        |--|
|        |  |--| Planting Millet
|        |     |--| Interplanting Cowpeas or Sorghum
|        |         |--| Weeding/Ridging
|        |            |--| Planting late Cowpeas
|        |               |--| Replanting Millet/Weeding/Thinning
|Stage   |   Stages        ||--| Weeding/Thinning
| One    |   Two/Three     |   |--| Collecting fallen Millet
|        |                 |      |--| Cutting stalks of Millet
|        |   Planting/     |         |--| Weeding
|        |   Replanting    |         |  |--| Removal of Millet/Cowpeas
|        |                 | Stage   |     |--| Cutting Sorghum
|        |                 | Four    |        |--| Removal of Sorghum
|        |                 |         |           |--| Late Cowpea
|        |                 |         |   Stage      |--| Harvest
|        |                 |         |   Five:         |--| Collect
|        |<------->        |         |   Harvest          |--| Crop
|        | Millet          |         |                    |  |--|Resid-
|        | <---->          |         |<---------->        |       ues
|        |  early          |         |   Millet           |
|        |   Cowpeas       |         |                    |
|        |  <------->      |         |    <------>        |
|        |    Sorghum      |         |     early          |
|        |         <------>|         |      Cowpeas       |
|        |          late   |         |                    |
|        |           Cowpeas         |     <--------->    |
|        |                 |         |       Sorghum      |
|        |                 |         |                    |
|        |                 |         |           <------->|
|        |    <------>     |         |             late   |
|        |    Ridging      |         |              Cowpeas
|        |                 |         |                    |
|        |         <------>|         |                    |
|        |         Thinning|         |                    |
|        |                 |         |                    |
|Clearing|         <----------------------->              |
|Soil    |                 Weeding   |                    |
|Preparation               |         |                    |
|Dry Seeding Planting/Replanting     |   Harvest          |
|------->|<--------------->|______ __|<------------------>|_ ______ ___
 |     |      |      |      |      |      |     |     |      |      |
  Apr.  May    June    July   Aug.   Sept. Oct.   Nov.   Dec.   Jan.
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* This representation fits the central zone of our sample; in the north, the stages would shift right; in the south they would shift left.

kinds of specific decisions made within each stage in response to the particular rainfall regime.[6]

3.7 Other Risk Management Strategies

The distribution of crop yields facing a household will depend on whether the household is exposed to a good year or bad crop year in general, and whether a households' specific plots produce above or below the average yields for the year. Corresponding to these two sources of variation, the total yield variance can be decomposed into intertemporal and cross sectional (or intraannual) components.

3.71 Diversification Against Cross Sectional Risk

Cross sectional risk can be defined as the intraannual variance across plots of the same crop and management technique. By definition this risk component can be diversified locally through the scattering of plots. Spatial scattering can reduce crop yield instability to the extent that production risks are not perfectly correlated across microenvironments. For example, given the nature of rainfall in this region, it could rain on one field while the field next to it receives no moisture.

Access to heterogeneous agroclimates, across which production risks are not perfectly correlated, endows farmers with greater flexibility to

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[6] This diagrammatic representation is borrowed from Watts.

cope with yield risk. However, this access can vary considerably from farm household to household and from village to village. For example, Vierich (1986) found evidence of a strong relationship between access to resources (e.g. good land) and social status within a village in our sample.

Scattering can be tactically pursued at both the individual household level and at the level of interhousehold linkages. Any single household is presumably limited in the number of separate plots it can economically cultivate. But if additional households are brought into a cross sectional risk-reducing pool, the number of pooled plots can grow large enough to significantly reduce cross sectional risk.[7]

The costs of plot scattering are of two types. The first is the real expense of moving inputs between scattered physical locations. The second is the loss of time involved. The practice of growing maize on small compound plots in part reflects the fact that intensive cultivation and manuring is feasible only on fields close to the household residence. Transportation costs may prohibit delivery of inputs to fields with potentially higher marginal input productivity.

Intercropping is a second tactic which potentially reduces cross-sectional risk.[8] Risk reduction in intercropping can arise from the

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[7] The interesting questions with respect to this are how large are the "pools", and who in effect then "administers" them? Ellsworth (1987) discusses risk-sharing within and between households in a study which examines the importance of transfers and non-market transactions in Burkina Faso.

[8] Besides risk reduction, intercropping may be superior for other reasons, for example, higher average returns per acre for crop mixtures as compared to sole stands - see Jodha 1981, Norman 1974.

ability of at least one crop in the system to compensate for the failure or low yield of another crop under stress conditions (see Walker and Jodha). The ability of a crop to take advantage of sunlight, soil nutrients or soil moisture released by crops that are adversely affected conditions this type of a response (and is not possible in sole stands since all plants are affected in the same way). Thus we would expect variability of overall yields to be lower for intercropped plots than for sole-cropped plots due to such yield compensation effects. That is, if we think of the activity Y consisting of two crops planted in the same field, Y^1 and Y^2, and the two crops have different nutrient requirements at differing times within the season, we would expect $V(Y^1+Y^2)=V(Y^1) + V(Y^2) +2Cov(Y^1,Y^2)$ to be low if the $Cov(Y^1, Y^2)$ is very small or negative. For example, the yield of early millet and the yield of late cowpeas planted in the same field may be expected not to be highly correlated, thus the overall variance in the yield of that plot may be lower than that of a sole-cropped plot of millet.

Intercropping will also tend to have the same risk-reducing effects as plot scattering, since pure stands tend to attract fewer types of pests or diseases, but usually in quantities that do considerable damage (Norman). Since different crops have different requirements, mixed cropping results in an increase in the utilisation of environmental factors, and the symbiotic relationship between legumes, the producers of nitrogen, and other crops is important. Since so many crop mixtures exist, the issue becomes complicated by the fact that, depending on the type of crop mix, different crops may bring about complementary, supplementary, or competitive relationships.[9]

Measuring the extent of risk reduction due to plot scattering is difficult from even detailed farm survey data. However, some of the risk reduction (and yield) effects of intercropping may be considered by looking at the distribution of yields on sole-cropped plots versus multi-cropped plots, to the extent that one can control for different soil types and management techniques (see Carter, Kristjanson and van den Brink, forthcoming).

3.72 Reduction of Intertemporal Risk

Diversification into other activities besides cropping can be thought of as a means of dealing with intertemporal risk. Diversification implies that even in a bad year, not all activities will fail. Schemes to counter intertemporal risk include the maintenance of carry-over stocks, investment in cattle and other livestock and the host of non-farm activities members of a household pursue. Investment in livestock is a means of accumulating wealth, and in this respect it can also be regarded as a self-insurance mechanism since selling off assets is an important means of coping in hard times. Linkages with other households also serves to reduce intertemporal risk to the extent that

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[9] Although the practice of intercropping as replanting certain crops at different times (e.g. planting cowpeas later than sorghum) reduces competition when their maximum demands on the environment occur at different times (Norman 1983).

imperfect correlation exists between households (i.e. a bad year for me doesn't necessarily mean a bad year for my relative). Migration by a member (or members) of a household also serves as a diversification scheme to counter risk, since often these members send part of their income home, or return for the cropping season (see Vierich for a discussion of the importance of non-farm income-earning activities and the incidence of temporary and permanent migration). Donor relief assistance is a more recent element that may also be coming included in strategies to deal with risk.

3.8 New Techniques

1) Soil Fertility Management

The use of manure to help maintain soil fertility in certain areas is a traditional practice followed throughout the WASAT. There is some evidence that the traditional method of maintaining soil quality through a long bush-fallow system is gradually yielding to a more intensive short grass-fallow and continuous cultivation system, especially with increasing population pressure in many areas. Prudencios' study describes farmers soil management strategies in terms of a series of management 'rings' radiating outwards from the households compound in the center. Cultivation is more permanent in the rings closest to the household and fertility is maintained through application of large quantities of organic matter (household waste and keeping animals around the compound), low levels of cowpea intercropping, and is sometimes complemented by anti-erosion dikes to reduce runoff loss. The practice of cultivating a field for several years with no added fertilizers and then leaving it fallow for periods upwards of ten years is followed in the fields in the outermost rings at distances of several kilometers from the compound.

As population pressure mounts and fields are fallowed for shorter periods, a new constraint arises in the form of manure transport costs, as the fields requiring manure are more distant from habitation points. The average distance of manured plots from the households' compound in our sample was generally significantly less than that of the average distance of all plots in each region, supporting the idea of management rings.

Table 3.9 summarizes manure and chemical fertilizer use in each of the villages. Manure was not applied to sorghum plots in the Sahel, while approximately 30% of the millet area in Silgey and 50% of the millet area in Woure was manured, on average, over the three year period. In the Sudanian zone, manure was applied in general to more sorghum area (around 60% on average) than millet (approximately 38%), with most of the maize area manured. Total manured area varied considerably in this region from year to year (e.g. see millet area fertilized in Ouounon), but this may reflect data problems rather than strategies on the part of the farmers. Another factor may be that in the areas most affected by the 1982 drought, farmers had less biomass to apply as manure in 1983.

Table 3.9. Manure and Chemical Fertilizer Use: Percent of Area with Applied Manure and/or Chemical Fertilizer

Sahel Region

	Silgey			Woure		
Crop	1981	1982	1983	1981	1982	1983
Millet	35	34	23	61	50	46
White Sorghum	0	0	0	0	0	0
Red Sorghum	0	0	0	0	0	0
Maize	54	57	45	48	31	8

Sudanian Region

	Ouounon			Kolbila		
Crop	1981	1982	1983	1981	1982	1983
Millet	67	34	6	47	34	43
White Sorghum	44	35	26	63	76	80
Red Sorghum	73	68	34	54	52	16
Maize	100	98	75	99	99	29

Guinean Region

	Koho		Sayero		
Crop	1982	1983	1981	1982	1983
Millet	29	44	0	0	0
White Sorghum	27	45	15	8	8
Red Sorghum	18	15	26	20	2
Maize	63	78	88	39	35
Rice	10	2	-	-	-
Cotton	99	97	100	-	-

In the Guinean zone, manure was not applied to millet in Sayero, and to only small areas of sorghum. Farmers in Koho used manure on all crops (perhaps due to much greater population pressure and cultivation intensity in Koho), the most heavily manured being sorghum and maize fields, as well as cotton which also received the highest chemical fertilizer doses.

Virtually no chemical fertilizers were applied to fields in the Sahel region. In the central region, small amounts of chemical fertilizers were applied to millet plots (6.5 kgs/ha. on average over the three-year period), slightly more to the sorghum plots (averaging 13.8 kgs/ha.) and to 15.9 kgs/ha. on average on total maize area.
In the southern region, little or no chemical fertilizers were applied to millet plots. 3.1 kgs/ha. were applied to white sorghum plots on average, with 21.1 kgs/ha. to maize plots, and well over 90% of the cotton area was fertilized. Sorghum is rotated with cotton in this region, and thus benefits from the residual nutrients and is not always fertilized directly.

Prudencios' results suggest that through the use of organic and inorganic fertilizers and the growing of leguminous crops in rotation or as intercrops, it is possible for farmers to maintain soil fertility as fallow periods are shortened. This conversion from an extensive to a more intensified cropping system, however, will require more than the mere application of fertilizers, and represents a radical change in farming systems. When soil preparation activities are limited or nonexistent, the application and incorporation of both manure and chemical fertilizers is limited. It is a highly labor intensive activity, and labor is a constraint at the time when it is most effectively applied. Before some substantial rains have fallen, the soil is very hard and the spreading of manure or chemical fertilizers upon this crusted surface can lead to the problem of 'burning' unless rain falls shortly thereafter (for example, burning of roots occurs when seedlings emerge into incompletely decomposed organic matter), and to the problem of run-off down the slopes when the rain does occur. Thus an extension of manuring or fertilization activities must be accompanied by better soil preparation techniques (e.g. plowing) as well as soil conservation practices such as ridging or the construction of contour bunds. The general lack of such soil conservation techniques has of course led to the extensive problem of soil degradation and loss of fertility throughout the WASAT.

Since fertilization also has residual effects lasting longer than one season in many instances, it is important that it not be considered merely a variable input such as labor. It is in fact a long-term investment, and is considered such by the farmers. This raises the issue of property rights. Once an investment is made on a piece of land (e.g. planting a tree), that investment becomes the property of the original 'owner' of the field. If I have been given a plot of land to cultivate, but it may revert back to the lineage head who granted it to me and in effect owns it, I will have little incentive to invest in that piece of land in the longer term. As population pressures increase, greater intensification and a shift towards private property rights appears to be happening in some areas (see Vierich 1987).

Chemical fertilizers are not always available locally, and are expensive relative to crop prices unless highly subsidized. Due to the nature of much of the soils and the variability of rainfall, the use of chemical fertilizers is also very risky. Matlon found the application of NPK[10] and urea to millet in the Djibo villages to be "extremely risky and not profitable on average, even when fertilizer is costed at subsidized rates and with millet prices at near record post-harvest levels" (ICRISAT Annual Report 1983). Financial returns were marginally positive for sorghum in the Yako region only with subsidized rates for NPK and urea, but risks of loss were still high. Fertilizer use was found to be profitable only in the higher rainfall region of Boromo, but risks of financial loss were still not negligible.

2) Animal Traction

In many parts of Africa, the introduction of animal traction has been successful where the result was a considerable increase in the area cultivated beyond that which could be farmed using traditional techniques. In areas of the lowest population pressure in the semi-arid tropics, marginally profitable animal powered systems permit some

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[10] This fertilizer was developed for cotton and consists of nitrogen, phosphorus and potassium in a ratio of 14:23:15. It is probably due to a well-developed input supply infrastructure for cotton that this fertilizer is the one most commonly used on food crops as well in Burkina Faso.

expansion of cultivated area. This occurs particularly in areas where a lot of cotton and cash crops are grown, such as in the Boromo region.[11] As yet, however, methods by which these systems can evolve to more intensive, ecologically sustainable systems are generally lacking (Spencer 1985). The only villages in our sample in which non-negligible amounts of sorghum or millet area were deep plowed using animal traction were in the southern region.

Yield effects from deep plowing have been found to be generally not very large, and to vary greatly with soil type and rainfall pattern (see Jaeger 1985). The optimal plowing technique in terms of soil structure is through the use of a blade several times larger that that which an oxen team can handle[12]. This is because a small plow tends to break down the top layer of soil into such small particles that erosion becomes an issue. The use of the plow can therefore be expected to be more effective on clayey soils than on sandy soils, and once plowing is introduced, it becomes necessary to think about investing in soil conservation techniques (such as contour bunds or tied ridges - both of which face the basic problem of severe labor constraints).

The positive yield effects from plowing (primarily due to better water infiltration) can be countered by negative effects due to the timing of operations and labor bottlenecks. There is a conflict between

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[11] For example, Jaeger found that with animal-drawn weeding implements, a household can increase the area cultivated by more than 30%.

[12] A big blade would more effectively break the soil into larger chunks, allowing infiltration, but not erosion.

the time needed for plowing after the onset of the rains and the need to plant on time in order to make use of early rains. This limits the area that can be plowed, and reduces the time in which animals can be used by other farmers. Similarly, due to the rapid drying and hardening of soils following the rains, farmers face a conflict between harvest and end-of-season plowing, which means that crop residues are almost never completely incorporated. Several studies (e.g. Jaeger 1985, Sanders et al. 1985) have suggested a 'learning curve' effect which means at least six to eight years are required to achieve full economic benefits to the use of animal traction. The proper care, training and feeding of oxen also requires considerable adjustments in traditional farming systems.

3.9 Summary of New Techniques

The pattern that emerges from even a brief discussion of new techniques currently available for farmers in the WASAT is clear. Marginal adjustments to the system may lead to short-run gains, but problems arise in the long-run. Plowing or adding fertilizer is not enough. Plowing, ridging and fertilization can lead to substantial yield gains (see FSU-SAFGRAD annual report 1985). But at what cost?
The introduction of technological 'packages' has become popular in the last several years due to complementarity of new varieties, fertilizer, animal traction, etc. Yet research into rates of technological adoption have concluded that people don't adopt "packages" - they try one thing at a time on a small plot, for example. It is therefore desirable that each

component of the "package" be desired (e.g. profitable) when used alone. The gains must also be large enough to offset the added risk taken on by the disruption of their traditional methods - methods which have incorporated effective risk management techniques. In other words, even marginal 'tinkering' disrupts the balance of a system that is already fine-tuned to deal with extreme environmental stress.

3.10 Conclusion

Chapter three has briefly described farming systems in Burkina Faso with an emphasis on risk management strategies. These strategies were broken down into passive and active techniques, and the extent to which these practices exist in the villages of our sample was described. The importance of the ability to make sequential decisions as the season progresses (based on the onset, character, and duration of the rains) was evident in the data. The range in planting dates and the extent of replanting and intercropping after the initial planting highlighted the prevalence of sequential cropping decisions.

The degree of flexibility these farming households have is the greatest in the southern region, where the number of options (e.g. type of crops, timing of activities, etc.) is greater. The environmental constraints in the northern region were reflected in the number of technological options available. For example, fewer traditional varieties of millet and sorghum are used in the north and central regions than in the south.

Since flexibility in production plans is one method a farming household will use to deal with extreme environmental risk, an interesting issue is access to resources. Unfortunately this is beyond the scope of this study. It is evident, however, that a household which has access to resources that allow the pursuance of all or most of the risk management strategies outlined above will be better off than a household with poor access to resources (e.g. sufficient labor, good soils, etc.) and thus fewer self-insurance devices.

Chapter 4. A Methodological Approach for Examining the Value of Information

4.1 Modeling Production Response

Most production studies are based on single equation estimates of econometric production functions. For example, the Cobb-Douglas production function has been often used in both theoretical and empirical studies (see Marshak and Andrews 1944, Zellner, Kmenta and Dreze 1966). Single equation estimates have been justified by the assumption that production inputs are chosen as part of a one-period decision problem (Antle 1983). For example, in the Marshak-Andrews model, the firm chooses labor and capital inputs to use on a predetermined acreage at the beginning of the production period to maximize profits, where output Q is sold at the end of the production period at price P (with input prices given). Zellner, Kmenta and Dreze extend this model to include random prices and thus the farmer chooses inputs to maximize expected profits in a one-period framework.

However, most production decisions in agriculture are made sequentially. Farmers do not usually decide exactly which inputs to apply at one given point in time, i.e. at the beginning of the cropping season. For example, one would not decide to apply a certain amount of pesticide to a field before the type or extent of pest damage can be ascertained.

Many farm management decisions may be formulated as multistage decision processes, rather than the typical one-period specifications. In fact, both short-run and long-run production decisions are typically based on a multiperiod, dynamic optimization problem because inputs are not all chosen or utilized simultaneously. It is for this reason that Antle (1983) proposes that farmers' optimal input choices be regarded as optimal controls in a stochastic control problem. He found that "as a general principle, parameter estimates with desirable properties can be obtained only by specifying and estimating empirical production models consistent with the sequential structure of the production process and managers' solutions of input choice problems". His analysis shows that sequential solutions generally result in input demand equations which differ from those of one-period solutions, such as those obtained in the traditional static production function specifications.

In a more recent article, Antle and Hatchett develop an econometric model to measure the productivity of intermediate inputs. They point out that both agronomists and economists have researched the timing of intermediate inputs - for example, research on yield response to water application (see Antle and Hatchett 1986 for references), using experimental station data to estimate the yield response (production function). They further suggest that it is difficult to infer from experimental data what actual farmer production practices are and how farmers respond to changes in economic conditions. This becomes an especially critical point when one is studying production practices in the developing world. As mentioned earlier (see chapter two), the "yield gap" from experiment station to farm level can be extremely high in these areas.

Chavas, Kliebenstein and Crenshaw (1985) also follow a dynamic optimization approach to modeling production decisions. They argue that dynamic production follows a differential (or difference) equation characterizing the growth process of the plant or animal. This approach allows for the use of nutritional information in the specification of biological growth (which is of great value in livestock production processes; see Fawcett 1973), and is useful for analyzing the effects of changes in input use over time.

The differential or difference equation approach to the modeling of dynamic choices also corresponds to the "state" equation specification in optimal control theory. Optimal control methods have been shown to have useful economic applications (see Kamien and Schwartz 1981, Rausser and Hochman 1978), and have been used by agricultural economists in the optimization of agricultural production processes (Chavas et al. 1985).

4.2 Dynamic Production Models

A multistage or dynamic process is characterized by the task of finding a sequence of decisions that maximizes an appropriately defined objective function (Burt and Allison 1963). The production process is divided into intervals or stages, with a decision being made at each stage in the sequence of stages comprising the decision process. At any particular stage, the "state" of the process (or state of nature) describes the condition of that process and is defined by the magnitudes of state variables and/or qualitative characteristics.

In order to specify yield functions that reflect the biological growth underlying the production process, we first identify specific discrete stages of the growth process. Although the growth process of cereal crops is a continuous one, and the agronomist would probably specify such stages in a more technical manner, we can still roughly categorize the most critical growth stages of the plant which will correspond to the management activity taking place at that time. For example, a planting stage, first weeding stage, etc., can be differentiated.

Defining a "state equation" to characterize the growth process, we have:

(4.1) $u_{n+1} = f_n (u_n, x_n, e_n, T) \quad n=o,1,\ldots N-1.$

where: u_n = the state of the plant at stage n (e.g. height, biomass), assumed to embody the effect of all inputs and random components in earlier stages.

x_n = a vector of "controllable" decision variables affecting plant growth (e.g. weeding labor hours, kilograms of fertilizer).

e_n = a vector of "uncontrollable" environmental factors reflecting the uncertainty resolved at stage n (e.g. rainfall), but is unknown at stage n-1.

T = a technology variable representing given or fixed characteristics of technology (e.g. soil fertility measure).

N = number of stages involved in the growth process.

If we take the initial state u_0 as given, we can see that:

$u_1 = f_0(u_0, x_0, e_0, T)$

$u_2 = f_1(u_1, x_1, e_1, T)$

and: $u_N = f_{N-1}(u_{N-1}, x_{N-1}, e_{N-1}, T)$

which is a set of difference equations that can be reduced to:

(4.2) $u_{n+1} = g_n(x_n, e_n,;x_{n-1}, e_{n-1},;\ldots;x_1, e_1,;x_0, e_0, T)$

Assuming that yield is a function of the the state of the plant in its final stage, i.e. (3) $y = h(u_N)$, we can express a yield function as:

(4.3) $y = h(x_{N-1}, e_{N-1};\ldots;x_1, e_1;x_0, e_0; T)$

which is a multistage production function. For example, if there are four major stages of the growth process of a particular crop, (4.3) says that crop yield in the final stage depends on inputs applied in the first three stages and the given level of technology (e.g. soil fertility). Thus information on the state of the plant (u_n) during growth is not needed, that is, only final output is required to solve for the coefficients.

When the multistage production function specification is put within the framework of a decision problem, whether the assumption is that farmers choose inputs to maximize expected profits, or put into a more general framework of expected utility maximization (allowing for risk aversion), the differences between the one period solution and the solution to the sequential problem can be investigated and the economic implications made clear. One implication that is demonstrated by Antle and Hatchett is that input choice in a dynamic model is not determined simply by equating expected value of marginal product with factor price. This is because the effect of current decisions on future stages must be included. While they are concerned with measuring intermediate input productivity, this study is not.

A more relevant economic implication of the sequential nature of the farmers decision process in our context concerns the value of information. That is, the essential difference between the static problem and the dynamic one is that the sequential solution to a decision problem enables the decision maker to utilize new information.

4.3 Sequential Decision Making and Information: An Alternative Approach to Risk

What does the specification of a multistage production function have to do with accounting for the effects of risk in the decision process? Simply put, the most effective way of dealing with risk or uncertainty is by gaining as much information relevant to the decision as possible, and being in a position to utilize it. The preservation of flexibility when faced with uncertainty is a neglected aspect of behavior under risk. Indeed, static models that attempt to evaluate behavior under risk cannot address the issue of sequential decisions and learning - that is, of maintaining a flexible position in order to incorporate new information in later decisions.

In fact, with the incorporation of risk in typical production models (whether an expected utility maximization approach or a safety-first based approach is taken - see chapter two), model results will depend on risk preferences (e.g. the agents' risk aversion coefficient). This implies that much of agricultural decision analysis under risk is made based on personal or subjective probabilities of outcomes. Since risk preferences (i.e. the degree of risk aversion) can vary significantly both over time and between individuals, the results from these models may not be terribly informative or have much prescriptive power.

It is for this reason that Chavas (1987) suggests an alternative approach that "attempts to minimize the role of preferences in economic behavior and to maximize the role of technology and institutional environment" - factors that can be measured much more easily than can risk preferences. This implies that risk behavior comes about due to the particular physical and economic environment of the decision maker.

To illustrate this type of approach, a simple two-stage maximization problem will be used, in which the decision maker maximizes expected utility. From this, an explicit expression for the conditional value of information will be derived. A functional form is then chosen in order to examine the properties of the value of information in the risk neutral case.

4.4 The Model

Consider a decision maker facing a planning horizon of 2 periods, t=(1,2) and a preference function $U(W, x_1, x_2, e)$ where:

(i) U is a continuously differentiable von Neumann Morgenstern utility function.

(ii) w is the initial wealth position of the decision maker.

(iii) x_t is a vector of decision variables at time t.

(iv) e is a random vector representing the state of the world (e.g. rainfall distribution). e is not known at time t=1 (i.e. the decision maker only has a subjective probability distribution based on past experience), but e becomes observable by the agent before the next period t=2 decisions are made.

(v) U satisfies the condition $dU/dw > 0$ (reflecting a positive marginal utility for wealth).

(vi) d^2U/dx^2 is a negative definite matrix.

For ease of exposition, we are considering a 2-period planning horizon. The decision maker is assumed to maximize expected utility and makes economic decisions according to the following two-stage optimization problem:

$$(4.4) \quad V(w) = \max_{x_1} E \max_{x_2} U(w, x_1, x_2, e)$$

where: V(w) = the indirect objective function of the decision maker.

E = expectation operator over random variable e.

Notice that this is an unconstrained problem, that is, there are no restrictions placed a priori on x_1 and x_2. More realistically we would probably see limits put on the amounts of resources available to be used in any given period.

From backward induction, we can solve for the optimal second period decisions, $x_2^*(w, x_1, e)$ which are conditional on x_1, and $x_1^*(w)$, the optimal first period decisions. In a constrained problem, x_1^* and x_2^* would also be subject to any constraints placed upon them, e.g. $x_1 > 0$.

$x_1^*(w)$ are decisions made before any observations on the random variable e. $x_2^*(w, x_1, e)$ are chosen after observing e during period one. They can therefore be thought of as the ex-post or "full knowledge" choices of input levels. We will show that: (1) closed-loop solutions are superior to open-loop solutions to decision making problems, and (2) the value of information is always non-negative. The valuation of information derived will be that of 'perfect' information, i.e. information that resolves all uncertainty.

A less rigorous assumption could be made without changing the essence of the results. That is, we could assume the observation in period 1 merely 'signals' a message about e and allows a revision of subjective probabilities assigned to the state of nature in period 2. In fact, usually new information can only give the decision maker a better idea of the variable of interest through information on another correlated variable. For example, in weather forecasting, the barometer can give you a better idea about whether it will rain in the near future. The issue with 'imperfect' information then becomes how individuals reformulate personal probabilities. One way of modeling this reformulation of subjective probabilities as new information becomes available is in a Bayesian framework (e.g. see Epstein).

Thus the choice of $x_2^*(w, x_1, e)$ is made ex-post by solving:

$$(4.5)\ E \max_{x_2} U(w, x_1, x_2, e)$$

Expression (4.5) indicates that the second period decisions are a function of e and are made conditional on previous decisions x_1. We can compare this formulation to the one usually made, that is, when both x_1 and x_2 are chosen at t=1 with no possibility of observing e. If the decisions x_2 were made at t=1, it corresponds to the following problem:

$$(4.6)\ \max_{x_2} E\, U(w, x_1, x_2, e)$$

The solution to problem 4.6 can be denoted $\bar{x}_2(w, x_1)$. It is the ex-ante choice of x_2, conditional on x_1, or it could also be thought of as the "no knowledge" choice of second stage inputs. This is the typical static formulation of the problem.

4.5 The Value of Information

The value of information is related to the comparative performance of decision making processes given different levels of information. Thus we want to evaluate the difference in the value of the indirect objective function, in the sequential problem (4.5), and the static problem, (4.6). There are two issues to be confronted in this derivation. First, we want an ex-ante evaluation of the value of information, and secondly we want to evaluate the difference in monetary terms. The ex-ante as opposed to ex-post evaluation of the value of information is important. For example, it is possible to think of cases where information can actually make the decision maker worse off - however this would be an ex-post evaluation. An ex-ante evaluation means that the value of information will always be non-negative, as will be shown shortly.

The literature on decision theory (e.g. Lavalle 1978) suggests that the difference between the ex-post and ex-ante choice of x_2 translated into monetary terms measures the conditional value of information about e (i.e. conditional on the choice of x_1). Thus we can define a certain monetary value $V(x_1, w)$ which satisfies:

$$(4.7)\ E \operatorname*{Max}_{x_2} U(w, x_1, x_2, e) = \operatorname*{Max}_{x_2} E\, U(w+V(x_1, w), x_1, x_2, e)$$

or:

$$(4.8)\ EU(w, x_1, x_2^*(w, x_1, e), e) = EU(w+V(x_1, w), x_1, \tilde{x}_2(w+V, x_1), e)$$

V is the amount of money the agent is willing to pay or would have to be paid at t=1 in order to be able to choose x_2 knowing e versus making a decision about x_2 without knowing e. It is a prior value in the sense that it is evaluated based on the information available at stage 1, and not at stage 2. Notice that it is not the value of information in the sense that the information is good or bad, but the perceived value of information to the decision maker before he receives the information or makes a choice. For example, if the decision to be made at time t=1 is an irreversible one, the value of information may be zero.

$V(x_1, w)$ can also be described as the conditional selling price of information about e (Chavas, 1986): it is conditional on the first period decisions x_1, and it is a selling price because it measures the monetary value of doing away with the information, using the informed situation as the reference point. V can also be thought of as a lump-sum payment of the smallest amount of money required by the agent such that he or she is willing to choose x_2 during the second period (t=2) without learning about e.

It can be shown that the value of costless information, V, is always non-negative. First, we can show in the expected utility maximization framework that the following relationship holds:

$$(4.9)\ \operatorname*{Max}_{x_1} E \operatorname*{Max}_{x_2} U(w, x_1, x_2, e) \geq \operatorname*{Max}_{x_1, x_2} E\, U(w, x_1, x_2, e)$$

We know $U(w, x_1, x_2^*, e) \geq U(w, x_1, x_2, e)$ for all x_2, since x_2^* is an optimal value. Therefore, $U(w, x_1, x_2^*, e) \geq U(w, x_1, \bar{x}_2, e)$ for all (x_1, e), since $\bar{x}_2 \leq x_2^*$. Taking expectations of both sides:

$$(4.10)\ E\, U(w, x_1, x_2^*, e) \geq E\, U(w, x_1, \bar{x}_2, e), \text{ for all } x_1$$

or:

$$E \operatorname*{Max}_{x_2} U(w, x_1, x_2, e) \geq \operatorname*{Max}_{x_2} E\, U(w, x_1, x_2, e), \text{ for all } x_1$$

Since this holds for all x_1, maximizing both sides over x_1 gives us:

$$(4.11)\ \operatorname*{Max}_{x_1} E \operatorname*{Max}_{x_2} U(w, x_1, x_2, e) \geq \operatorname*{Max}_{x_1} \operatorname*{Max}_{x_2} E\, U(w, x_1, x_2, e)$$

The right hand side of (4.11) corresponds to an open-loop solution, where the inputs x_1 and x_2 are chosen at the beginning of the time horizon, based on the information available at that time. The left-hand side corresponds to a feed-back solution where learning is explicitly taken into consideration. (4.11) implies that, on average, better information tends to improve the decision-making process and make the agent better off ex-ante. This of course is very intuitive, in that it implies the best decisions are the well-informed ones. Another implication is that the value of costless information is non-negative, i.e. $V(w, x_1) \geq 0$.

So we can rewrite the left-hand side of (4.11) as the following:

$$(4.12)\quad \underset{x_1, x_2}{\text{Max}}\, EU(w + V(w, x_1), x_1, x_2, e) = \underset{x_1}{\text{Max}}\, E\, \underset{x_2}{\text{Max}}\, U(w, x_1, x_2, e)$$

which is a reformulation of the dynamic programming problem (4.4), but it is no longer a dynamic problem in the sense that it is now an ex-ante evaluation of the expected utility maximization problem - that is, both x_1 and x_2 are chosen at time t=1.

The optimal solutions to (4.12) can be denoted by $\bar{x}_1(w)$ and $\bar{x}_2(w)$. $\bar{x}_1(w) = x_1^*(w)$ since the ex-ante decisions of the first period are the same as in problem 4.4. However, $\bar{x}_2(w)$ is not the same as $x_2^*(w, x_1^*(w), e)$, the solution to the sequential problem. $\bar{x}_2(w)$ is now an ex-ante decision since it is made based on the information available at time t=1, before the decision maker learns about e. It is also a compensated choice function since it can be influenced by the wealth compensation $V(\bar{x}_1, w)$. Chavas (1987) describes $\bar{x}_2(w)$ as the "decision that would be made if the agent had to decide x_2 at time t=1 (i.e. before knowing e) while he is compensated for not being able to take advantage of the information that becomes available between t=1 and t=2." (p.7)

4.6 Measuring V, the Value of Information

In appendix A an explicit formulation for V is derived in a general framework. It is quite complex and little can be said about the properties of the value of information - the influence of some parametric change on V is not obvious in the general case. The properties of the value of information and its implications will therefore be discussed in the context of a particular production function specification. The functional form chosen is an extended quadratic form (extended in the sense that it includes third-order terms).

Consider the following specification for the production function:

$$(4.13)\quad Y(x_1,x_2,e) = a(x_1,e) + 1/2\ x_2'A(x_1)x_2 + x_2'b(x_1,e)$$

where: $Y(x_1,x_2,e)$ is an uncertain production function.
x_1 are input decisions made in the first period.
x_2 are input decisions made in the second period.
e denotes temporal production uncertainty.
$A(x_1)$ is a negative definite matrix corresponding to the strict concavity of the production function in x_2.
$a(x_1,e)$ and $b(x_1,e)$ are some functional forms, not necessarily quadratic.

This model is different from the traditional specification of a quadratic production function in two ways. In the first place, third order terms are included, as has already been discussed. Secondly, the manner in which the stochastic variable, e, influences the dependent variable, Y, is not typical.[1] As can be seen, e enters in the function in the interaction term with the x_1 and x_2 variables, and thus the impact of the stochastic variable on Y is not direct, as is seen in most stochastic production function specifications. The implication of this is that the choice of technique, x_1, influences how the stochastic variable influences yields, as well as the choice of x_2. In our particular case, for example, whether plowing was performed or not influences the impact of rainfall on yields and on the replanting or weeding decision.

Assuming risk neutrality and that input and output prices are known and non-stochastic, the decision maker maximizes expected profits:

$$(4.14) \qquad \underset{x_1}{\text{Max}}\; E\;\{\; \underset{x_2}{\text{Max}}\; p^*y(x_1,x_2,e) - r_1'x_1 - r_2'x_2\}$$

The conditional value of information, $V(x_1)$ is derived from the following:

$$(4.15)\; V(x_1)=E\; \underset{x_2}{\text{Max}}\{p^*y(x_1,x_2,e) - r_2'x_2\} - \underset{x_2}{\text{Max}}\;\{E\; p^*y(x_1,x_2,e) - r_2'x_2\}$$

and equation (4.12) takes the form:

$$(4.16) \qquad \underset{x_1,x_2}{\text{Max}}\{\; V(x_1) + E\;[p^*y(x_1,x_2,e)] - r_1'x_1 - r_2'x_2\}$$

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[1] See Just and Pope 1978, for a discussion of how the stochastic element of production has typically been incorporated in theoretical and empirical work and the limitations to these specifications.

Under competition, the first order necessary conditions for an optimum solution for x_1 are:

(4.17) $\partial V/\partial x_1 + E\ [p^* \partial y(.)/\partial x_1] - r_1 = 0$

where: $\partial V/\partial x_1$ is the marginal valuation of information.

Here we see an explicit expression showing the relationship between the choice of x_1 and the value of information, V, i.e. $\partial V/\partial x_1$. This implies that stage one decisions will be affected by the ability to take into account new information gained before the stage two decisions are made. Intuitively, we know that the stage two decisions will be affected by new information - the fact that the first stage decisions are also affected is not so intuitive a result.

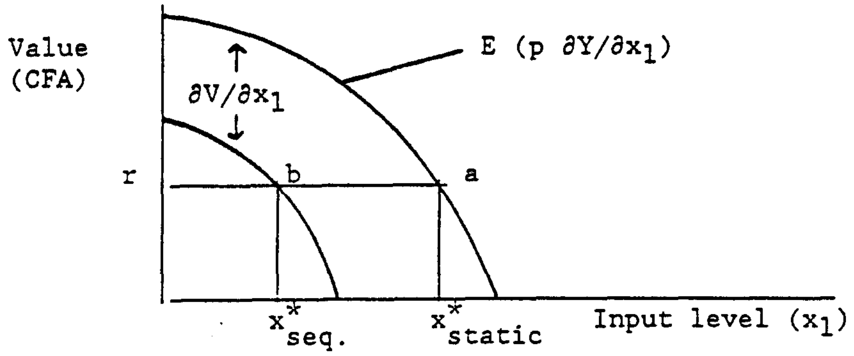
Informational effects will in fact shift the input demand curves. In the static model, at the optimum, the following condition will hold:

(4.18) $E\ (P\ \partial y/\partial x_1) = r_1$; this would be at point a in diagram 4.1.

In our dynamic framework, accounting for information, this becomes:

(4.19) $E\ (P\ \partial y/\partial x_1) + (\partial V/\partial x_1) = r_1$; which if $\partial V/\partial x_1 < 0$ can be represented by point b.

Diagram 4.1.



In the case where $\partial V/\partial x_1 < 0$, the implication is that flexibility considerations will act to actually shift back the input demand curve for x_1, resulting in a lower optimum level of the input x_1 (with $\partial V/\partial x_1 > 0$ the opposite is true). Thus the sign of the marginal valuation of information will thus determine the direction in the shift of the demand curve.

For the production function described in equation 4.13, $V(x_1)$ can be derived analytically and is equal to[2]:

$$(4.20) \qquad V(x_1) = -1/2 \ p \ \text{trace} \ \{ \ A(x_1)^{-1} * \text{Var} \ b(x1,e) \ \} \geq 0$$

Thus V is derived directly from the estimated coefficients of the production function, and will be positive since the trace $\{A(x_1)^{-1}$ * Var $b(x_1,e)\}$ will be negative if $A(x_1)$ is a negative definite matrix, and Var b is a positive semi-definite matrix.

The marginal valuation of information, $\partial V/\partial x_1$, can be negative, zero or positive depending on how $A(x_1)$ and the variance of $b(x_1,e)$ vary with x_1. However, the last term in the production function $(x_2'b\{x_1,e\})$ must include a three-way interaction term between x_1, x_2, and e or else the marginal value of information, $\partial V/\partial x_1$ will be equal to zero.[3]

Thus second order approximations of a production function are not sufficient in modeling the impact of temporal uncertainty on economic decisions. In order to avoid imposing strong restrictions on the way

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[2] see appendix B for a derivation of V for this functional form.

[3] For example, if $b(x_1,e)$ is a linear function $\alpha x_1 + \beta e$, then Var b = β^2 Var e, and $\approx$Var $b/\approx x_1 = 0$.

information influences production decisions, third order terms must be included.

An 'extended' quadratic function was therefore chosen for the empirical estimation of the production function, in order to allow the examination of the influence of information without a priori restricting the direction of the influence of information by the choice of a less flexible functional form. It is also due to the considerations above that the inclusion of third order terms (i.e. interaction terms between first stage decisions, second stage decisions, and the production uncertainty term, e) become of paramount interest in our empirical work, and will be referred to as the "information variables".

Typical production studies incorporating risk considerations are based on two considerations - expected return (e.g. average yield) and uncertainty of variability of those returns (e.g. variability of yields). In expression (4.12), however, we explicitly see a third consideration which should be analyzed apart from the introduction of risk aversion, and that is the value of information, V.

Looking at a risk neutral case allows the inclusion of temporal price and/or production uncertainty and to concentrate on the influence of temporal uncertainty on production decisions. The introduction of risk aversion can then be made into this framework, making it possible to study the effects of both risk aversion and information. However, this is beyond the scope of this study. In the absence of a priori information on risk preferences, it seems reasonable to focus here on how other factors (besides risk preferences) can influence economic behavior under risk.

Chavas (1987) derives an expected utility maximization problem including a risk term R, representing the agent's degree of risk aversion as well as a term D, representing the valuation of information (reflecting the ability of an agent to modify production plans as new information becomes available). With the incorporation of a risk premium (e.g. the Arrow Pratt absolute risk aversion coefficient[4]), the optimization of the objective function suggests that a producer would seek: (1) a high expected return, (2) a low risk premium if he is risk averse, and (3) a high value of D. He notes that D and R are clearly different with D tending to increase the value of the objective function while R would decrease it under risk aversion (under risk neutrality, R=0, but in general we have shown that $D \geq 0$).

The implications for our problem (the risk neutral case) are that (1) the flexibility to respond to new information remains important even under risk neutrality, and (2) if individuals truly are risk averse, the value of information term we obtain in the derivation of the risk neutral case may not be the true V. This is because the presence of risk aversion can affect V and $\partial V/\partial x_1$ since both R and V depend on x_1 and on the subjective probability distribution of e, thus making it difficult to isolate the effects of risk aversion, R, from the informational considerations, V. Unfortunately, it does not seem

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[4] $-U_{ww}[w+D+E(f)]/U_w[w+D+E(f)]$ where E(f) are expected returns, w is wealth, D is the value of information and $U_w=\partial U/\partial w$.

possible to state in general if V would be under or overestimated in this case. Again, further research is needed in this area.

The influence of the value of information, or the ability to maintain flexibility on the choice of x_1 and x_2 can be very different than the effects of risk aversion. The demand for flexibility is in fact basically unconnected with risk aversion. This is because many rather than few positions available for future choice implies nothing about the variability of final payoffs. For example, one person might value flexibility because, by appropriately adapting choices to the information received, it permits a more nearly certain payoff. But, another might value flexibility because it allows taking an informed higher risk (Jones and Ostroy 1984).

A person could be risk averse, the effect of risk aversion being incentives to use more of x_1, for example, whereas $\partial V/\partial x_1 < 0$ due to flexibility considerations. For example, a risk averse farmer may wish to plant a long-cycle high-yielding variety since in general it exhibits lower yield variability and in this sense is less risky. However, if this variety must be planted very early in the season to do well, informational considerations may mean a disincentive to plant it as opposed to a shorter-cycle variety, since a shorter cycle variety will allow more flexibility in the timing of planting.

The relationship between the degree of uncertainty or risk and the value of information is not clear. Intuition suggests that information becomes more valuable as risk increases. Gould (1974) and Hess (1982) show that an increase in risk in the Rothschild-Stiglitz meanpreserving spread sense (e.g. variance) does not lead to any general unambiguous relationship between risk and the value of information. Chavas and Pope (1984) point out that although risk and information require the existence of uncertainty, they are basically different economic concepts. Measuring the value of information involves an ex-ante evaluation of an ex-post situation, while the economics of risk has generally been limited to an ex-ante analysis (e.g. Pratt 1964, Arrow 1971).

One of the implications of this identification problem is that it is possible that people have been attributing certain behavior to risk preferences, whereas it may in fact be due to flexibility considerations. In order to answer this question empirically, good information is needed on (1) the nature of the objective function, (2) the technology, (3) a characterization of the uncertainty, and (4) people's preferences. Since risk preferences can be difficult to determine, this study has attempted to address the issue of risk behavior according to (1) and (2) and (3).

4.7 Conclusion

A great deal of the theoretical literature has been based on the nature of the objective function of the decision maker. For example, agricultural economists concerned with agricultural decision making under uncertainty in the developing world have vigorously debated the expected utility maximization paradigm versus 'safety first' and other motives as being more representative of underlying preferences.

Both approaches have their similarities as well as problems, but neither allow an explicit consideration of the role of new information (or the decision makers' desire to remain as flexible as possible to deal with uncertainty), when formulated as one-stage problems.

The role of costless information in economic activities has been shown in a general theoretical framework to be non-negative. The implications for our specific problem should be made clearer. Since the farming systems in the WASAT are largely based on manual cultivation, they have the strength of flexibility, which is reflected in the ability of the farmer to continually adjust his cropping pattern as the season unfolds. A crucial property of small farm decision making is the producers ability to be continuously adjusted and tuned to environmental variability, that is, the ability to respond as new information becomes available. Because certain decisions are affected by the opportunity to learn, the choices made available to decision makers in terms of technological options should account for this role of acquiring information. Static models do not allow the evaluation this property or its influence on an agent's decisions.

The methodology described in this chapter allows an investigation into this property. The value of information, V, is derived from an expected profit maximization problem (the risk neutral case), allowing the separation of the issues of risk and information. V is essentially the smallest lump-sum payment required by an agent such that he or she is willing to choose x_2 (the second stage inputs) during the second period without learning about e. In chapter five, an extended quadratic production function is estimated for WASAT farmers, and the properties of V are explored in this context.

Chapter Five: A Production Function Analysis and an Empirical Estimation of the Value of Information to Farmers in the WASAT

5.1 Choice of Functional Form

In a production function analysis, the choice of functional form is critical, in that it will determine the type of relationship between inputs and outputs. When estimating a dynamic econometric production model, both the issues of functional form and stochastic specification (i.e. the error term) must be considered carefully. As Antle and Hatchett (1986) point out, "the choice of functional form in production analysis involves weighing theoretical validity against practical considerations such as tractability and data availability" (p.941).

Traditional static production functions based on data gathered from farm production practices are abundant (although not from the developing world) in the agricultural economics literature. A number of functional forms have been used to estimate functions on plot, farm, regional and national levels. Popular functional form specifications include the Cobb-Douglas, quadratic and higher order polynomials, transcendental and the translog (e.g. see Heady and Dillon 1961, Zellner, Kmenta and Dreze 1966, and Christensen, Jorgenson and Lau 1973). The selection of any specific type of equation to express production phenomena automatically imposes certain restraints or assumptions with respect to the relationships involved and the optimum resource quantities which will be specified. For example, the linear model imposes constant marginal products and unbounded output; the Cobb-Douglas imposes constant input elasticities and unitary elasticities of substitution. In many cases, researchers do not wish to impose some of these restrictions on the technology, and a number of more flexible, second order functions such as the quadratic and translog have been used, as well as more complex non-linear models. Unfortunately, no set of "rules" exists that can dictate which functional form is a priori the correct one to choose. Ultimately, an algebraic form of the function which appears consistent with the phenomena under investigation must be chosen.

Marshak and Andrews (1944) questioned the adequacy of estimating the production function alone from empirical production data. They argued that in addition to output being determined by inputs, input demands are themselves dependent on output. Thus the production function and the input demands should properly be estimated as a simultaneous system. However, Zellner, Kmenta and Dreze (1966) argued that producers may view the production process as being a random one, and thus choose inputs to maximize expected profit. This implies that input demands are a function of expected output rather than actual output, so inputs and output are not determined simultaneously.

These models are based on the assumption that production inputs are chosen as part of a one-period decision problem. When production decisions are made sequentially, and the opportunity for learning exists, Antle (1983) has shown that sequential solutions may produce models which require either single equation or simultaneous equation estimation methods. Which method is required will depend on the assumptions about information used and data availability.

5.2 The Spillman Function

The initial functional form chosen to capture the underlying technological relationships between crop output and inputs was a non-linear exponential function similar to the Spillman function described by Heady and Dillon (1961). The Spillman function was appealing because it captured the idea of the sequential nature of the input decisions being made and the fact that at any stage of the growing process, increments to input levels (or lack thereof) could either increase potential output, or signal an end to the growing process.

In general, a function of the following form was fitted: $Y = M - AR^x$, where: Y=total output; x=total inputs; M=maximum total output which can be attained by use of the variable resource; A is total increase which can be reached by increasing x; $M - A$ is the level of output defined by fixed resources; R is a constant defining the ratio of successive increments to total product (Heady and Dillon, p. 77).

Unlike Heady and Dillon's static representation, this function was formulated as a stage-wise function where at each input stage (planting, rainfall period 1, replanting, etc.), intermediate output would result in increments to the total product, such that if at each stage 'optimum' levels of inputs (x) were added (e.g. rainfall), the product curve would reach the hypothetical maximum M. Lower levels of rainfall would result in lower output, and a total lack of rainfall at any of the stages, for example, would imply a zero output, thus representing the risky nature of the production process. While this functional form was felt to adquately characterize the data in terms of known logic of the growing process of the plants, in statistical terms there were many problems with the non-linear specification.[1]

The second functional form estimated was the extended quadratic form that was described in chapter four. This function allowed us to estimate V, the value of information (whereas with other functional forms such as the Spillman, it becomes more complex), the focus of this study.

5.3 The Extended Quadratic Production Function

A quadratic production function remains linear in parameters but relaxes many of the restrictions of the first-order functions, including constant elasticities and additive separability. This flexibility occurs at the cost of more parameters to estimate. The marginal products do not bear a fixed ratio to each other as in the case of the Spillman function, and the quadratic function allows both a declining and negative marginal productivity. Second-order flexible

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[1] Convergence problems appeared in the non-linear estimation of the function. Also, when convergence was obtained, it was found that the results depended heavily on the starting values given, thus suggesting that one could not be certain of whether the maximum reached was a global or merely a local optimum.

forms such as the quadratic and the translog are often viewed as local approximations to the (unknown) true model (see Heady and Dillon, p.204).[2]

The facilitation of a derivation of V was a primary motivation for choosing an 'extended' quadratic specification of the technological relationship between inputs and output, and which will be defined shortly. As discussed in chapter four, the inclusion of third-order terms is necessary in order not to impose strong restrictions on the way information influences production decisions. A more complex functional form or one without third-order terms would not have allowed an empirical investigation of informational issues. The fact that the choice of technique influences how the stochastic variable (rainfall) affects yields, was also captured with this specification. For these reasons, a quadratic function which is 'extended' to include third-order terms was estimated.

5.4 Specification of the Model

The following two-stage extended quadratic production function was estimated:

$$Y(x_1,x_2,e)= ax_1 + x_1'\alpha x_1 + \beta x_2 + x_2'Ax_2 + (be + cx_1e)x_2 \tag{5.1}$$

where: Y is yield per hectare of millet or sorghum.
x_1 are decisions made before rainfall is known.
x_2 are decisions made after rainfall is observed.
e = rainfall (total mm.) between x_1 and x_2.
a and c are ix1 matrices, where i=no. of included x_1 variables.
b is a jx1 matrix, where j=number of included x_2 variables.
A and α are diagonal, negative definite matrices.

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[2] The fitting of a polynomial type production function is nothing other than the evaluation of the first few powers in a Taylor series expansion of the unknown true production function.

The general form of this model was described in chapter four. In moving to the specific empirical model to be estimated, it became apparent that the inclusion of too many parameters would cause problems econometrically. It thus became necessary to set some of the parameters equal to zero. For example, the A matrix was assumed to be diagonal, which means that interaction terms between the x_1 and x_2^2 variables were not included. Other parameters were tested to see if they were significantly different than zero, as will be described shortly.

Due to limited information about the true functional form, several models were specified and will be presented, since it is not evident a priori which model is the 'true' model. These model specification problems may lead to possible biased estimates since we do not know which is the correct model. However, it was felt that the exploration of different models gave us valuable economic information despite possible misspecification biases causing econometric problems.

5.41 Explanatory Variables

Data from two villages in each agroclimatic zone were merged cross-sectionally, and three years of data for each zone were merged intertemporally. The included explanatory variables (x_1 and x_2) which were chosen as the most important factors affecting yields, are described in table 5.1 (see chapter three for a detailed description of the data used).

As described in chapter three, soil quality differs greatly and is strongly related to the position in the toposequence. Information on the type of soil (e.g. sandy, clayey), the position of the field in the toposequence (e.g. plateau, lowlands), and it's proximity to the compound (i.e. compound plots were assumed to be good soil), were used to define a proxy variable (soiltype) to account for the predominant soil quality of each plot. The traditional variety of millet or sorghum planted was identified as either short-cycle or long-cycle through the farmers own identification of the cycle length of particular varieties.[3]

The timing of planting is a critical factor that was included alone and in interaction with rainfall and replanting since they are so strongly interrelated. The timing of the first weeding can also influence yields and thus the number of days between planting and first weeding was included in some cases. Other variable factors included the number of labor hours spent on first weeding and second weeding, and the kilograms per hectare of added chemical fertilizer and/or manure. A dummy variable for plowing was added to differentiate plots that had been deep plowed using animal traction in the Southern zone. Average input use and average yields per crop for each region are given in Appendix D.

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[3] Often farmers identification did not match the actual length of the growing cycle (although the three years were very dry ones); as mentioned in chapter three, differences between short-cycle and long-cycle may not in fact be very large, especially in the North.

Table 5.1. **Explanatory Variables**

Name of Variable	Description of Variable	Expected Influence on Yields and Trade-offs Involved
Soiltype X_{11}	Dummy variable; good soil=1 bad soil=0	Yields on clay soils are expected to be higher than those on sandy soils due to better water retention.
Date X_{12} (Date2=X_{12}^2)	Continuous; date of planting in days (Mar.1=0)	Delayed planting may decrease yields; however early planting may be negatively correlated with yield if sparse early rains cause poor seedling development.
Variety X_{13}	Dummy Variable; length of growing cycle of variety seeded; short-cycle=1 long-cycle=0	Long-cycle varieties may be higher yielding on average; but little research has been done on traditional varieties at the crop research stations.
Tkgfert X_{14} (Fert2=X_{14}^2)	Continuous; total kilograms per hectare of chemical fertilizer applied	Added chemical fertilizer is expected to have a positive influence on yields (with sufficient rainfall), but it may not be large due to poor soils.
Tkgman X_{15} (Man2=X_{15}^2)	Continuous; total kilograms per hectare of manure applied	Added manure should have a positive effect on yields, although the residual effect may be more important.
Plowat X_{16}	Dummy Variable; deep plowing using animal traction=1 no plowing=0	Deep plowing should increase yields, but may sufficiently delay planting to have a negative effects.
Hrswd1 X_{21} (Hrswd1s=X_{21}^2)	Continuous; hours of labor spent on first weeding task;	Increased labor hours should increase yields; marginal productivity of weeding labor depends on date of planting, extent of plowing and the delay between planting and weeding.
Hrswd2 X_{22} (Hrswd2s=X_{22}^2)	hours of labor spent on second weeding task;	

Table 5.1 continued.

Name of Variable	Description of Variable	Expected Influence on Yields and Trade-offs Involved
Tothrswd X_{21} (Tothrs2=X_{21}^2)	total weeding hours.	
Pcarrepl X_{23} (Pcareas=X_{23}^2)	Continous; percentage of the area of the plot replanted	Replanting increases plant density but need for extensive replanting may indicate prior damage & poor plant development.
Dbplwdl X_{24} (Dbplwdls=X_{24}^2)	Continuous; delay in days between planting and first weeding	Yield losses occur when weeding is delayed, but will depend on date of planting, extent of plowing and type of soil.
Rainfall e	Continuous; total millimeters in first thirty days after planting	The amount of rainfall in the first stages of growth is expected to have a strongly positive effect on yields.

Interaction Terms

Name of Variable	Description of Variable
Rainrepl	Rainfall*Pcarrepl
Daterepl	Date*Rainfall*Pcarrepl
Varrepl	Variety*Rainfall*Pcarrepl
Plowrepl	Plowat*Rainfall*Pcarrepl
Manrepl	Tkgman*Rainfall*Pcarrepl
Fertrepl	Tkgfert*Rainfall*Pcarrepl
Dateweed	Date*Rainfall*Hrswdl

Rainfall is considered to be the major 'risky' variable influencing yields in the WASAT that is easily measured. The amount of rainfall in the first critical period of growth was included as an explanatory variable and is expected to have a strongly positive influence on yields. The variance of rainfall (i.e. Var(e)), as shown in chapter four, is also a major component of the value of information, as will be explored shortly.

5.42 Interaction Terms

This production function was felt to capture the nature of some of the input-output relationships involved because it allows the inclusion of interaction terms. The most critical interactions between explanatory variables were identified and included in the final fitted functions. A correct specification of the interactions and interdependencies for this type of sequential production process becomes complex very quickly. The final choice of included explanatory variables and interaction terms is included in Table 5.1. The third order terms included are 3-way interaction terms with the first stage input decisions, rainfall during the first period, and the second stage decisions. The interaction terms including the replanting decision is of particular interest, since as described in chapter three, it is hypothesized that the flexibility to replant is an important element in risk management strategies in the WASAT. That is, the x_1 decisions - what to plant, when to plant, whether to fertilize or to plow, are hypothesized to be affected by the knowledge that information about the major uncertainty, i.e. the rainfall, will be gained over period one, before stage two decisions are made (i.e. replanting, weeding).

5.5 Interpreting the Value of Information

The manner in which informational effects shift the input demand curves for the x_1 variables was described in section 4.6. Specific hypotheses as to the direction of these informational shifts for each x_1 decision are given in table 5.2.

Table 5.2. Value of Information with Respect to Choice of Techniques

1. Continuous x_1 Variables:

x_1 Decision	Hypothesized Sign of $\delta V/\delta x_1$	Explanation
Timing of Planting	Negative	The earlier planting is done, the more flexible a position is adopted and the higher is the value of information gained over period 1, V.
Application of Chemical Fertilizer and Manure	Positive	If fertilizer is applied and there is no rain, 'burning' can occur and increase the need for replanting, thus increasing V.
	Negative	If rainfall is good after the application of fertilizer, it should speed up growth and lead to good plant establishment and less need for replanting and thus a lower V.
	= 0	If manure is being applied very early in the season before any information can be gained, it may be that informational considerations are not important.

Table 5.2 continued.

2. Discrete x_1 Variables:

x_1 Decision	Hypothesized Δ V	Explanation
The Use of Short-Cycle Varieties	V higher than for long-cycle varieties.	Varieties with shorter cycles offer more options in terms of timing of planting and the opportunity to replant and thus new information has a higher value to the farmer than with long-cycle varieties.
Soil Preparation using Deep Plowing with Animal Traction	V lower than when soil preparation is done by hand-tool or not at all.	Plowing increases water infiltratrion, making the plant more drought-resistant and replanting or weeding less needed, implying a lower V. Since planting without soil preparation is more flexible and allows quick planting and replanting, one would expect a higher V for non-plowed fields.

5.6 Estimation of the Model

OLS was used to estimate the stagewise production function. With this sequential decision model, the second stage decision is assumed to be uncorrelated with the first stage error term. If there were reason to believe a correlation did exist, a simultaneous equation method of solving the model would be required. Since rainfall is included as an explanatory variable, rather than as part of the unexplained random error term, this assumption is felt to be justified in our case. That is, our second stage variables, replanting and weeding, are assumed to efficient, i.e. free of simultaneous bias (see Antle 1983, for a discussion of when simultaneous methods are required in dynamic models).

5.7 The Results

The first model to be explored was not estimated explicitly in order to derive V, the value of information. The results of the first set of estimated production functions are examined in terms of overall fit and significance of the included explanatory variables. A particular emphasis is put on the significance of the three-way interaction terms (the "information variables") due to the implications for the next stage, that is, examining the value of information. Next, a second model is estimated which allows the explicit derivation of V (section 5.9 explains the reasons for this). The implications of the value of information on production decisions is then explored with respect to several production techniques.

1) White Sorghum

The results of the fitted functions for sorghum in all three zones are found in table 5.3. The F-values were significant at the 1% level (leading to the rejection of the null hypothesis that all coefficients are zero), except in the northern region, where the null hypothesis was rejected at the 5% level of significance. The model did not seem to explain the variation of sorghum yields as well in the north, although there were fewer observations (only 75 plots) in this case than in the others. This was not surprising, since in this region sorghum is planted almost exclusively in the lowlands, which are subjected to

Table 5.3. Production Functions: Dependent Variable: Yield/ha. Sorghum

Variable		Northern Region:n=73	Central Region:n=459	Southern Region:n=251
Intercept		-486.03 *	258.57 ***	162.7 *
		(254.4)	(48.2)	(87.9)
Soiltype	X_{11}	169.4	110.2 ***	190.9 **
		(155.0)	(33.7)	(95)
Date	X_{12}	12.3 **	-1.5 ***	3.2
		(5.8)	(.44)	(2.05)
Variety	X_{13}	-173.8	-70.3 **	-12.7
		(286.7)	(35.1)	(76.4)
Tkgfert	X_{14}	-	.37	-1.42
			(.66)	(2.2)
Tkgman	X_{15}	-	.019 *	-
			(.01)	
Plowat	X_{16}	-	-	113.8
				(110.9)
Hrswd1	X_{21}	.75 **	.62 ***	1.08 **
		(.35)	(.19)	(.43)
Hrswd2	X_{22}	-.27	.92 ***	.78 **
		(.27)	(.19)	(.34)
Tothrswd	X_{21}	-	-	.814 ***
				(.234)
Pcarrepl	X_{23}	-	-.79	-
			(.51)	
Hrswd1s	X^2_{21}	-	-.00004	-.0007 *
			(.00001)	(.0004)
Hrswd2s	X^2_{22}	-	-.0004 ***	.00009
			(.0001)	(.0002)
Pcareas	X^2_{23}	-	-.000007	-
			(.0007)	
Rainfall	e	-.365	-	-
		(1.95)		
Rainrepl	$X_{23}e$	-	4.2 ***	-.11
			(1.05)	(.6)
Daterepl	$X_{12}eX_{23}$	-.008	-	.009
		(.04)		(.02)
Varrepl	$X_{13}eX_{23}$	14.9	3.2 ***	-1.6
		(16.5)	(.98)	(1.8)
Fertrepl	$X_{14}eX_{23}$	-	.04 ***	-
			(.01)	
Plowrepl	$X_{14}eX_{23}$	-	-	-1.38
				(2.25)
Dateweed	$X_{12}eX_{21}$	-	.00001 ***	-
			(.000006)	
R^2 Value:		.2072	.4440	.2620
F Value:		2.123 **	24.17 ***	6.498 ***

Standard errors are in parentheses.

Significance levels are: * .10; ** .05; *** .01

enormous stochastic soil water fluctuations (e.g. desert to flood) in a very short period. We would need more information on water flow, for example, and not just rainfall to more adequately explain sorghum yields in these areas. The values of the R^2 ratio for the estimated functions varied from .20 to .44, which are not unreasonable for this type of data (merged cross-sectional, time-series data) which exhibits such extreme variability in the dependent variable.

The soiltype variable was strongly significant in the central and southern regions, indicating the responsiveness of sorghum to better soil types (i.e. higher clay content, with better water holding capacity). The date of planting has a significant influence on sorghum yields in all three zones. The use of short-cycle traditional varieties showed up significantly only in the central region. Weeding hours were highly significant in all regions, verifying the importance of overcoming labor bottlenecks, allowing sufficient and timely weeding of sorghum to achieve better yields.

No chemical fertilizer or manure were used in the northern zone, and chemical fertilizers were not significant variables in the south and central regions, probably due to very low application levels. Manure use was significant in the central region. To a certain extent, our soiltype variable is probably "picking up" the influence of manure, since compound land (which receives most of the household manure) was included in the characterization of "good soil".

Squared variables were included in the central region (with 460 observations), and had the expected signs, with second weeding hours significant. This functional form gave the best results in the central zone, with an R^2 of .44 and with 12 out of 16 variables significant.

No 3-way interaction terms were significant in the northern region. Interactions between (1) variety, rainfall and percent area replanted, (2) fertilizer use, rainfall and percent area replanted, and (3) date of planting, rainfall and first weeding hours, were all highly significant in the central zone. (1) was also significant in the southern region.

An hypothesis test of the significance of the included 3-way interaction terms was performed in the central and southern regions (i.e. to test the null hypothesis $c_1=c_2=c_3=0$, where c_i=estimated coefficients of the third order terms).

The ratio
$$R = \frac{(ESS_R - ESS_U) / d}{(ESS_U) / (n-k)}$$
was calculated, where:

ESS_U = error sum of squares from the unrestricted model.

ESS_R = error sum of squares from the restricted model.

d = difference in the number of parameters between the restricted and unrestricted models.

n = number of observations.

k = number of parameters in the unrestricted model.

Ho is rejected if R is greater than the value F (d,n-k) at a given level of significance. The results of the F-test are given in table 5.4.

Table 5.4. F-Tests for Significance of 3-way Interaction Terms

	Central Region	Southern Region
R	5.7	.51
5% level:	F(3,444)= 2.6	F(3,238) = 2.6
Result	Reject Ho	Do not Reject Ho

The rejection of the null hypothesis that the 3-way interaction terms are not significantly different than zero implies that information does influence x_1 decisions (see chapter four). In the central zone the hypothesis that information significantly influences production decisions is supported. The implications of this finding will be explored shortly.

Marginal physical products and elasticities of production are given in Tables 5.5. The prices of chemical fertilizer and output are known and wage rates have been imputed (given by Matlon, 1987), and these are listed in Table 5.6. The marginal product of weeding labor hours is very close to the ratio of Matlon's estimates of observed wage rates to output price (.6 in the central and .8 in the south). With a subsidized fertilizer price to output price ratio of approximately 1.02, an estimated marginal productivity of fertilizer of 2.5 seems reasonable in the central region, while in the south a negative marginal product implies that we are perhaps not capturing the true response of fertilizer with this variable. Most sorghum is grown in rotation with maize or cotton in the south, 5.5. Marginal Physical Products and Elasticities of Production for White Sorghum

	Central Region		Southern Region	
Variable	MPP[1]	E_p[2]	MPP	E_p
Date of Planting	-2.17	-.17	3.5	.2
Fertilizer	2.5	.05	-1.42	-.009
Manure	.018	.009	-	-
First Weeding	.6	.3	.85	.26
Second Weeding	.75	.3	.8	.2
Area Replanted:				
Long-cycle Varieties	72.5	.05		
With Plowing			-165	-.07
Without Plowing			41.8	.018
Short-cycle Varieties	562.1	.36		
With Plowing			-405	-.18
Without Plowing			-198	-.09
Rainfall:				
Long-cycle Varieties	1.45	.41		
With Plowing			-.37	-.1
Without Plowing			-.05	-.014
Short-cycle Varieties	2.57	.73		
With Plowing			-.74	-.21
Without Plowing			-.4	-.1

[1] $\delta y/\delta x$

[2] $(\delta y/\delta x)*(x/y)$; evaluated at mean input levels.

Table 5.6. Input Prices/ Wage Rates/Output Prices

Variable	North	Central	South
Fertilizer[1]	57	57	57
Labor[2]	75	53	27
Output Prices[3]	63	56	52

[1] Average subsidized fertilizer price, 1981-83.

[2] Average male wage rates for first weeding task, 1981-83; North and South regions include average payments in cash and kind; Central zone includes payments in cash only.

[3] Average price received for white sorghum (months of Oct., Nov., Dec., 1981-83). Source: Peter Matlon, ICRISAT.

and thus chemical fertilizers are not always applied to the sorghum crop, but the residual from last year's crop is instead utilized. The effect of residual fertilizer (from previous years) is difficult to capture.

The productivity of manure on sorghum fields appears to be very low, and to the extent there is no market for manure, this may be consistent with economic theory. However, the transport of manure seems to be a limiting factor to increased utilization (i.e. only the fields close to the compound are usually manured), thus one might expect to see a higher marginal product implying gains to higher levels of that input. There is also a residual effect to manure, and as mentioned earlier, our soiltype variable may in fact be capturing the benefits of manure on yields.

The elasticity of production with respect to rainfall is positive in the central zone with a value of .41, implying a 1% increase in the amount of rainfall during the first stage of growth would result in a .41% increase in yields for long-cycle varieties. Short-cycle varieties are even more responsive to rainfall, with an elasticity of production of .73.

A delay in planting implies an increase in sorghum yields in the southern zone, with a production elasticity of .2. In the central region, however, this elasticity is -.2, indicating that delayed planting can have detrimental effects on yields in areas of shorter growing seasons (such as the north and central zones).

The response in yields to an increase in the area replanted varies (it is positive in the central zone, and generally negative in the south). This can be expected, since replanting can increase yields due to increased plant density, but the need for extensive replanting may indicate prior damage or poor plant development (and in general a very poor year for rainfall).

2) Millet

The results of the fitted functions for millet in all three zones are found in table 5.7. The F-values were all significant at the 1% and the R^2 ranged in value from .31 to .38.

None of the x_1 variables were significant in the northern region. The number of hours spent on the first weeding task were insignificant, with the second weeding showing up significantly. Rainfall was included alone and in the three-way interaction terms (i.e. with date, variety and manure, all interacting with area replanted). It was positive and significant, as expected, as were the date of planting and variety interaction terms. These results suggest that in the north, the response of yields to factors such as manure or even weeding hours is not great, and the major limiting factor on yields is the amount of rainfall.

In the central zone, 13 out of 16 explanatory variables were significant, indicating this functional form works well in this region. Even so, an R^2 value of .31 indicates much of the variability in yields

Table 5.7. Production Functions: Dependent Variable: Yield/ha. Millet

Variable		Northern Region n=323	Central Region n=288	Southern Region n=125
Intercept		94.9 (61.7)	205.0 *** (47.3)	-126.5 (187.7)
Soiltype	X_{11}	26.6 (30.5)	46.3 (31.4)	187.1 ** (84.1)
Date	X_{12}	1.22 (1.65)	-1.8 *** (.6)	11.1 * (6.07)
Variety	X_{13}	-.73 (40.5)	84.4 ** (42.3)	137.1 ** (68.1)
Tkgfert	X_{14}	-	-.23 (.76)	-
Tkgman	X_{15}	.05 (.02)	.05 ** (.02)	-.27 (.18)
Date2	X^2_{12}	-	-	-.15 * (.09)
Man2	X^2_{14}	-	-	.0001 (.00008)
Hrswd1	X_{21}	.15 (.11)	.45 *** (.15)	-.44 (.39)
Hrswd2	X_{22}	.84 *** (.17)	.44 ** (.19)	.64 ** (.32)
Pcarrepl	X_{23}	-.49 (.47)	-2.5 *** (.85)	-.4 (2.2)
Dbplwd1	X_{24}	-	-	8.9 ** (4.1)
Hrswd1s	X^2_{21}	-	-.0001 (.00008)	.001 *** (.0005)
Hrswd2s	X^2_{22}	-	-.0004 ** (.0001)	-.0004 ** (.0002)
Pcareas	X^2_{23}	-	.002 ** (.0009)	.013 (.012)
Dbplwd1s	X^2_{24}	-	-	-.1 *** (.04)
Rainfall	e	.97 ** (.5)	-	.904 (.89)
Rainrepl	$X_{23}e$	-	3.6 *** (1.08)	-
Daterepl	$X_{12}eX_{23}$	.03 * (.015)	.02 * (.01)	-.04 (.04)
Varrepl	$X_{13}eX_{23}$	3.03 * (1.9)	-4.14 *** (1.32)	-4.17 (3.09)

Table 5.7 continued.

Variable	Northern Region	Central Region	Southern Region
Fertrepl $X_{14}eX_{23}$	-	-	-
Manrepl $X_{15}eX_{23}$	-.0004	-	-.004
	(.0009)		(.008)
Fertweed $X_{14}eX_{21}$	-	.000006 **	-
		(.000002)	
R^2 Value:	.3343	.3127	.3883
F Value:	14.24 ***	7.734 ***	3.77 ***

Significance levels are: * .10; ** .05; *** .01

is not explained by rainfall and the other included variables. Soiltype did not have a significant impact on millet yields in this region (or in the north), which makes sense due to the fact that millet is generally planted in the poorest soils. Since these soils do not retain water as well as the "sorghum" soils, it was expected that the amount of rainfall would have a strong influence on yields. This was found to be the case, with all the interaction terms including rainfall significant. Fertilizer use was not significant, which was not suprising since it is generally not used on millet plots. Manure, however, was a significant variable in the central region, suggesting that organic matter has a greater influence on yields in the central region than in the north.

The results from the southern zone were also quite good, with 9 out of 19 included variables significant. The estimated coefficients for soiltype, date of planting and variety were all significant, while manure was not. As was the case with sorghum in the south, it appears that capturing the influence of manure on yields was not successful in this region. This is likely due in part to residual effects which we did not capture, and also because of the way in which the variable soiltype was defined (i.e. to include compound plots). A variable intended to capture the importance of the timing of the first weeding (the number of days between planting and first weeding), however, was significant in the south.

The validity of the inclusion of three-way interaction terms was also tested for millet. The null hypothesis $c_1=c_2=c_3=0$, where ci=estimated coefficients for the third order terms, was tested. The results of the F-test are given in Table 5.8. The implications with respect to the value of information will be examined shortly.

Table 5.8. F-Tests for Significance of 3-Way Interaction Terms

	Northern Region	Central Region	Southern Region
R:	2.27	4.4	3.18
5% level:	F(3,312)=2.6	F(3,281)=2.6	F(3,109) = 2.7
Result:	Do not reject Ho	Reject Ho	Reject Ho

Marginal physical products and production elasticities are given in Table 5.9. In general, the signs and magnitudes are similar to those for sorghum. The production elasticity for weeding labor is quite low in the north and south compared to the results for sorghum,

Table 5.9. Marginal Physical Products and Elasticities of Production for Millet

Variable	Northern Region MPP[1]	Northern Region Ep[2]	Central Region MPP	Central Region E_p	Southern Region MPP	Southern Region E_p
Date of Planting	1.6	.2	-1.1	-.12	1.85	.14
Fertilizer	-	-	-.017	-.0003	-	-
Manure	.044	.03	.05	.03	-.33	-.107
First Weeding	.152	.06	1.98	.39	.043	.02
Second Weeding	.84	.21	.245	.15	.54	.17
Days Between Planting and First Weeding	-	-	-	-	-14.8	-4.8
Area Replanted:						
Long-cycle Varieties	124.9	.06	508.3	.39	-171	-.1
Short-cycle Varieties	406.7	.19	39.4	.03	-620	-.4
Rainfall:						
Long-cycle Varieties	1.2	.29	4.3	1.2	.63	.18
Short-cycle Varieties	1.8	.43	3.04	.85	-.29	-.08

[1] $\delta y/\delta x$

[2] $(\delta y/x)*(x/y)$; evaluated at mean input levels.

indicating that millet yields are not as responsive to the amount of time spent weeding as is sorghum. However, in the south, the timing of the first weeding appears quite important, with a production elasticity of -4.8, indicating that a 1% increase in delay of weeding (in days) leads to a 5% decrease in yields. It is interesting that this variable never showed up significantly in the north and central regions, where one would expect the weeding timing decisions to be quite critical as well.

The responsiveness of yields to fertilizer and manure is very low again, as is indicated by negative marginal products or marginally positive production elasticities. It should be noted that the three years of this study were all very poor in terms of amount of rainfall, and this may have been a factor (especially with respect to chemical fertilizer) in the extremely low response rates to fertilization. Of course, these results are not suprising either, given the extremely low levels of utilization of both these inputs.

The response to rainfall is the greatest in the central region, with a production elasticity of 1.2 for long-cycle varieties and .85 for short-cycle ones. The results in the southern region suggest the opposite (as did the results for sorghum), that is, that short-cycle varieties are more responsive to rainfall. Of course, these results were evaluated at average input levels and may not hold over a greater range of x. As was the case for sorghum, the elasticity of production with respect to rainfall was very small or negative in the south.

In verifying the significance of individual explanatory variables (i.e. T-statistics), it became evident that the inclusion of many interaction terms may have caused collinearity problems. Correlations of between .5 and .8 existed for some of the interaction terms, but did not lead to any absolute conclusions about how serious a problem collinearity was. For example, one of the variables of primary interest was the decision of how much area to replant. This term showed up in the linear form, as a squared term, and in interaction with the x_1 variables (i.e. date of planting, variety, fertilizer use). In some cases, this led to non-significance of the interaction terms as well as the squared term (which has strong consequences for the derivation of V, as will be discussed shortly). The results were considerably better in some cases when fewer squared and interaction terms were included, although this meant V could not be derived (see section 5.9). The results of the first model with all the squared and interaction terms contained interesting and valuable information that was presented for this reason. Since the 'true' model is not known for certain, more than one model was estimated, that is, separate regressions were run for the explicit derivation of V. These results are presented in section 5.9.

5.8 Determining V, the Value of Information

The conditional value of information, $V(x_1)$ is derived from the following:

(5.2) $V(x_1)=E \max_{x_2}\{p^*y(x_1,x_2,e) - r_2'x_2\} - \max_{x_2} \{E\, p^*y(x_1,x_2,e) - r_2'x_2\}$

and equation (4.4) takes the form:

(5.3) $\max_{x_1,x_2} \{ V(x_1) + E\, [p^*y(x_1,x_2,e) - r_1'x_1 - r_2'x_2] \}$

The first order conditions with respect to x_1 are:

(5.4) $\delta V/\delta x_1 + E\, [p^*\delta y(.)/\delta x_1] - r_1 = 0$

where: $\delta V/\delta x_1$ is the marginal valuation of information.

Recall from (5.1), our specified production function is:

$$Y(x_1,x_2,e)= ax_1 + x_1'\alpha x_1 + \beta x_2 + x_2'Ax_2 + (be + cx_1e)x_2$$

For this estimated production function, $V(x_1)$ can be derived and is equal to[4]:

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[4] see appendix B for a derivation of V.

(5.5) $V(x_1) = (-1/2)\ p\ \{ (A^{-1})(b + cx_1)^2 * \mathrm{Var}\ (e) \}$

where: A = is a diagonal matrix of coefficients for the x_2^2 term.
b = vector of coefficients for the two-way interaction terms between x_2 and e.
c = vector of coefficients for the three-way interaction terms between x_1, x_2 and e.
Var (e) = Variance of rainfall between decisions x_1 and x_2[5].

Thus V, the value of information is derived directly from the estimated coefficients of the production function. As discussed in chapter four, the magnitude of the value of information thus depends on the b and c coefficients, the variance of rainfall and the diagonal elements of the A matrix, which in our case (with no interaction terms between x_1 and x_2^2 included) are the coefficients from the x_2^2 term. The marginal value of information is equal to the following:

(5.6) $\delta V/\delta x_1 = (-1/2)\ p\ (A^{-1})\ \{(2bc + 2cx_1) * \mathrm{Var}(e)\ \}$

Thus the direction and the magnitude of the marginal value of information also depends on the parameters b, c, A, and the variance of rainfall. Significant parameter estimates for the two and three-way interaction terms imply that risk matters, not because of risk aversion, but because of flexibility considerations.

For these reasons, the F-tests of the null hypothesis $Ho{:}\Sigma c_i=0$ have implications for the actual derivation of V. Recalling tables 5.3

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[5] Since rainfall was defined as the total millimeters in the first thirty days after planting, rainfall was regressed on the date of planting. The variance of this residual was used to estimate the variance of rainfall - see Appendix C.

and 5.7, we found that in three of the estimated production functions we were able to reject the null hypothesis (that the coefficients of the third order terms were all equal to zero), implying that the models were properly specified with respect to the three-way interaction terms - these were millet in the central and southern regions and for sorghum in the central region.

In other words, evidence from the set of production functions estimated in tables 5.3 and 5.7 suggest that there is reason to believe that information does influence the first stage decisions. More specifically, the ex-ante choice of when to plant, what to plant, whether to plow or to apply fertilizer, are affected by flexibility considerations.

5.9 Estimation of V

The estimation of V requires that the A matrix is negative definite to satisfy concavity restrictions for the existence of a maximum, which means that the trace {A} is negative. Since A is a diagonal matrix in our case (i.e. we didn't include interaction terms between x_1 and x_2^2), this means that the coefficients from the x_2^2 variables must be negative. In the estimated production functions presented in tables 5.3 and 5.7, squared variables were not included in all cases, and thus V could not be estimated. Production functions which included the x_2, x_2^2 and x_1x_2e interaction terms of interest in the derivation of V (see table 5.1), and allowed a derivation of V (i.e. concavity restrictions were met), were also estimated. These restrictions were not met in all six cases. The production functions that met all restrictions for a derivation of V are presented in table 5.10.

In general, with the inclusion of the squared variables as well as the three-way interaction terms, the significance of the third order terms decreased. While the estimated functions reported in table 5.10 allowed the derivation of V, the results should be interpreted with caution. It was only in the case of sorghum in the central region that the three-way interaction terms (the "information" terms) were all significant.

F-tests were again calculated to test the significance of the inclusion of the information terms. Results of these are given in table 5.11. Rejection of the null hypothesis that the three-way interaction terms are not significantly different than zero implies that information does influence x_1 decisions. The null hypothesis was rejected only in the case of sorghum in the central region. Despite limited significance of the individual information terms and the negative results of the F-tests, V was derived for millet in the north and central zones and for sorghum in the central and southern regions from these parameter estimates. The value of information with respect to each choice of technique and the marginal values of information for each continuous x_1 decision variable are given in table 5.12.

Table 5.10. Production Functions for the Derivation of V.

Variable		Millet Northern Region	Millet Central Region	Sorghum Central Region	Sorghum Southern Region
		n=323	n=281	n=459	n=251
1) X_1 Variables (a coefficients)					
Intercept		-51.46 (187.0)	147.88 (246.6)	258.6 (48.2)	43.82 (109.9)
Soiltype	X_{11}	23.9336 (30.79)	47.498 (33.55)	110.2 *** (33.7)	209.3 ** (96.3)
Date	X_{12}	5.71969 (8.081)	-4.779 (9.584)	-1.5 *** (.44)	8.57 * (5.13)
Variety	X_{13}	7.92405 (41.06)	-50.067 (41.915)	-70.3 ** (35.1)	10.97 (79.7)
Tkgfert	X_{14}	-	-	.37 (.66)	3.85 (8.14)
Tkgman	X_{15}	0.02341 (.056)	.15482 ** (.0780)	.019 * (.01)	-
Plowat	X_{16}	-	-	-	146.4 (1.28)
2) X_i^2 variables (α coefficients)					
Date2	X_{12}^2	-.01645 (.084)	.0367 (.1019)	-	-.06 (.06)
Man2	X_{14}^2	.000009 (.00001)	-.00004 * (.00007	-	-
Fert2	X_{15}^2	-	-	-	-.08 (.10)
3) X_2 Variables (β coefficients)					
Hrswd1	X_{21}	0.53060 ** (.2256)	-	.62 *** (.19)	-
Hrswd2	X_{22}	1.11214 *** (.3322)	-	.92 *** (.19)	-
Tothrswd	X_{21}	-	.3389 *** (.125)	-	.814 *** (.234)
Pcarrepl	X_{23}	-.49839 (1.62)	219.684 * (128.45)	-.79 (.51)	-.216 (3.37)

Table 5.10 continued.

Variable	Millet Northern Region	 Central Region	Sorghum Central Region	 Southern Region
	n=323	n=281	n=459	n=251
4) X_2^2 variables (A coefficients)				
Hrswd1s X_{21}^2	-.00045 * (.0003)	-	-.00004 (.00001)	-
Hrswd2s X_{22}^2	-.00045 (.0005)	-	-.0004 *** (.0001)	-
Pcareas X_{23}^2	-.00105 (.0037)	-.00030 (.0003)	-.00007 (.0007)	-.01 (.009)
5) x_2e variables (b coefficients)				
Rainrepl $X_{23}e$	2.45039 (4.711)	2.6989 (2.113)	4.2 *** (1.05)	3.37 (3.79)
6) x_1ex_2 variables (c coefficients)				
Daterepl $X_{12}eX_{23}$	-.01012 (.0714)	-.0174 (.0439)	-	-.05 (.05)
Varrepl $X_{13}eX_{23}$	3.22876 * (1.949)	.88969 (.7937)	-3.2 *** (3.09)	-3.2 * (1.9)
Manrepl $X_{14}eX_{23}$	-.00064 (.0012)	.00029 (.0005)	-	-
Fertrepl $X_{15}eX_{23}$	-	-	.04 *** (.01)	.043 (.06)
Plowrepl $X_{16}eX_{23}$	-	-	-	-2.2 (2.5)
Dateweed $X_{12}eX_{21}$	-	-	.00001 *** (.000006)	-
R^2 Value:	.3391	.2173	.4440	.2647
F Value:	9.85 ***	5.296 ***	24.17 ***	5.286 ***

Significance levels are: * .10; ** .05; *** .01

Table 5.11 F-Tests for Significance of 3-Way Interaction Terms

	Millet		**White Sorghum**	
	Northern Region	Central Region	Central Region	Southern Region
R:	.94	.46	5.7	1.2
5% level:	F(3,307)=2.6	F(3,267)=2.6	F(3,444)=2.7	F(4.235)=2.4
Result:	Do not Reject Ho	Do not Reject Ho	Reject Ho	Do not Reject Ho

Table 5.12 The Value of Information, V.

	White Sorghum		**Millet**	
	Central	South	North	Central
V^o	385,312,729	1,371,271	1,470,836	4,032,630
V^1_p	-	162,075	-	-
$V^1_{s.c.}$	1,086,608,730	2,841	10,720,621	5,875,045
$\delta V/\delta x_{12}$	-43,589	-420,826	-417,905	-3,308,250
$\delta V/\delta x_{14}$	93,083,294	48,312	-	-
$\delta V/\delta x_{15}$	-	-	-115,121	229,484

Where:

V^o - Value of information, evaluated for long-cycle varieties (without plowing).
V^1_p - long-cycle varieties, with deep plowing using animal traction.
$V^1_{s.c.}$ - short-cycle varieties.
$\delta V/\delta x_{12}$ - the marginal value of information (MVI) with respect to timing of planting.
$\delta V/\delta x_{14}$ - MVI with respect to chemical fertilizer use.
$\delta V/\delta x_{15}$ - MVI with respect to application of manure.

5.10 Evaluating the Results of the Derivation of V.

The influence of informational considerations on the first stage decisions are what we are interested in. More specifically, the ex-ante choice of when to plant, what to plant, whether to plow, and whether to apply fertilizer have been suggested to be affected by flexibility considerations.

The magnitude of V is determined by the values of the b, c and A coefficients, and the variance of rainfall, e. In general, the latter is very large as is expected in this part of the world. Since the A coefficients are found in the denominator in the equation for V, a very small number implies values of V that can be extremely large. Small estimated values of the A coefficients[6] (which were generally insignificant) appear to be the major reason our estimates of V are so large, as can be seen in Table 5.12.

Despite high estimated values of V, the significance of the estimated production functions in general, and the significance of the three-way interaction terms as reported in tables 5.4 and 5.8, imply that knowledge of the direction of the influence of information, i.e. $\delta V/\delta x_1$, has interesting implications about choice of techniques, and these will be explored.

How informational effects shift the input demand curves was

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[6] There is no reason to believe the A parameter estimates are biased. If collinearity problems do exist, the result would be higher variance of the estimated coefficients, but not biased estimates.

described in chapter four. In our dynamic framework, accounting for information, at the optimum the following condition will hold:

$$E\ (P\ \delta y/\delta x) + (\delta V/\delta x) = r$$

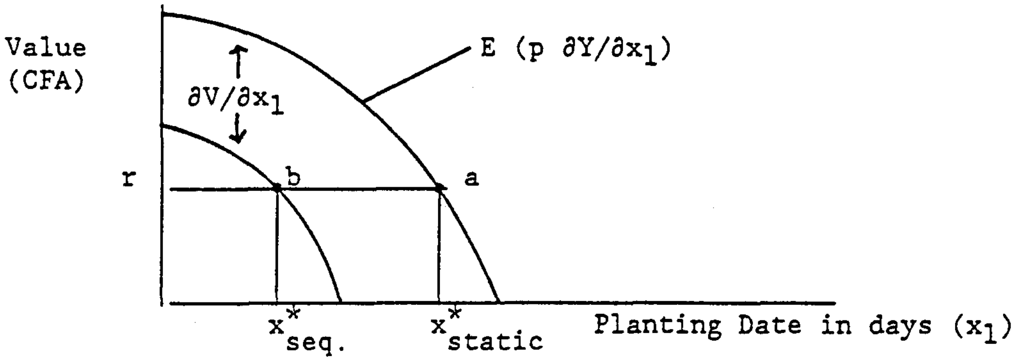
In the case where $\delta V/\delta x < 0$, the implication is that flexibility considerations will act to actually shift back the input demand curve for x, resulting in a lower optimum level of the input x than would be the case if information was not accounted for by the decision maker (with $\delta V/\delta x > 0$ the opposite is true). Thus the sign of the marginal valuation of information will determine the direction in the shift of the demand curve. The implications for each x_1 decision (i.e. the choice of technique) will be discussed.

5.11 Timing of the Planting Decision

Although the interaction terms with date of planting were not significant in any of the estimated functions in table 5.10, the marginal value of information with respect to the date of planting was derived, since earlier results suggested that the decision as to the timing of planting was influenced by informational considerations (it was significant in the north and central regions for millet in the original estimated functions).

The marginal value of information with respect to the date of planting is negative in all four cases in which V was derived (see table 5.12). These results verify the hypothesized sign of $\partial V/\partial x_1$ (see table 5.2). The optimum date of planting as determined by the static model would be later (pt. a in diagram 5.1) in the season than the optimum planting date when flexibility is explicitly taken into consideration in the sequential model (pt. b). The later a farmer plants, the less chance he has to replant and the lower the value of new information to him. By planting earlier, a more flexible position is adopted - allowing the farmer to take advantage of good early rains, and to have enough time to replant if those rains aren't sufficient, i.e. to better utilize information. The value of information here then is the value of the expected loss to the farmer of planting too late (to take advantage of the early season rains, or to be able to replant, for example).

Diagram 5.1.



5.12 The Decision to Apply Chemical Fertilizers or Manure

$\delta V/\delta x_1$ for the fertilizer decision is significant in the case of sorghum in the central region as demonstrated by a significant parameter estimate for the third order term for fertilizer in the fitted function in table 5.10.[7]

The marginal value of information with respect to chemical fertilizer inputs was found to be positive for sorghum in the south and central regions. That is, the application of fertilizer appears to increase the value of information. Optimum levels of fertilizer in the sequential problem are higher than the optimum levels in the static case. However, interpreting the value of information with respect to fertilizer use is difficult.

The application of fertilizer can increase the chance of seedling "burning" under dry conditions in the early stages of growth if the rain does not occur soon after application, and run-off problems occur with (common) torrential first rains. These circumstances increase the need for replanting and explain the increased value of information when fertilizer is applied as was hypothesized. However, under good rainfall conditions, fertilizer will tend to speed up plant growth in

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[7] In the northern region, there is reason to believe that the fertilizer decision may in fact be a second stage decision in that often it is not applied until the time of first weeding - this may also hold to a certain extent in the central region. This implies that information will not have an influence on this decision, at least not information gained over the first stage of growth.

the early stages leading to better seedling establishment and a reduced need for replanting - implying a lower value of information.

In the higher rainfall areas it is likely that once fertilizer has been applied, it becomes even more important to monitor that situation (so as not to lose the benefits of the fertilizer), utilizing new information regarding the weather and condition of the plants, and replanting if necessary. This would also explain our results - that is, a positive marginal value of information.

The application of fertilizer will also tend to increase the need for timely weeding since everything will grow faster, although the competition for nutrients may not be as strong. The parameter estimate for the interaction between fertilizer use, rainfall and weeding was significant for millet in the central region in the original production function (although V could not be estimated), verifying that informational considerations are important with respect to the weeding decisions as well.

Similar considerations of the response of manure to differing levels of rainfall can be expected, and we found that $\delta V/\delta x$ with respect to the application of manure was negative for millet in the north, and positive in the central region. Since neither of the interaction terms was significant, it may imply that information does not significantly influence the decision to apply manure. In the north, manure is generally applied to the soil very early, before any information can be gathered, and for this reason, new information may not be of great value to the decision. Information on intermediate output would greatly aid in determining if and how informational considerations affect the decision to apply manure or chemical fertilizers.

5.13 Valuation of Information for the Discrete Explanatory Variables

Since a marginal valuation of information is meaningless for non-continuous variables (i.e. our dummy X_1 variables), a comparison of the expected profits at the optimum input levels in each of the two cases (X_1=0 vs. X_1=1) must be made. That is, we wish to compare the following:

$$E\ [p\ y^* \ (I_0)] - r'x^* + V(I_0) \text{ and } E\ [p\ y^* \ (I_1)] - r'x^* + V(I_1)$$

where: I_0 represents short-cycle varieties or deep plowing

I_1 represents long-cycle varieties or not plowing.

The interaction terms with variety were significant in the north for millet, and the central and south regions for sorghum. Comparing the value of V derived when short-cycle varieties were planted with the case where long-cycle varieties were used (i.e. comparing $V^1{}_{s.c.}$ with V^o in table 5.11), we can see that V is higher for short-cycle varieties in the north and central regions.

Seed varieties that have a shorter growing cycle can be planted over a wider period than can long-cycle varieties. They will therefore offer more options in terms of timing of planting and the opportunity to replant. Our earlier results suggested that short-cycle varieties are more responsive to rainfall than long-cycle varieties (see tables 5.5 and 5.9). It is possible that shorter-cycle varieties are therefore less resistant to early-season drought[8], in which case the seeding of a short-cycle varity means a higher probability of replanting in poor rainfall years. This would increase the need for flexible plans and the value of information, explaining our results and verifying our hypothesis as to the direction of $\delta V/\delta x_1$ with respect to the varietal choice decision.

The incidence of deep plowing using animal traction for sorghum and millet was so low in this sample, it showed up significantly only in the southern zone for sorghum. The plowing interaction term did not show up significantly, however, suggesting that the decision to plow may not in fact be affected by informational considerations (i.e. $V=0$).

It was hypothesized that V would be lower when soil preparation was done by hand-tool or not at all. This was because seeding by hand allows more flexibility in timing of planting and replanting, and essentially the maintenance of more flexible plans allowing a quick response to environmental conditions, and thus the value of new information is more important. As well, it is possible that plowing increases water infiltration, making the plant more "drought resistant" and replanting or weeding less needed, so it may be expected that

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[8] Suprisingly, the ICRISAT research scientists knew very little about the characteristics of the local varieties.

plowing actually decreases the need for flexible plans. In fact our results (although not strongly significant) show that V is lower when deep plowing is performed. Unfortunately, we have an insufficient number of observations of plowed fields in the other regions to compare these results across regions.

5.14 Problems with the Estimation of V

Further analysis could be pursued, but the large values of V indicate that the extended quadratic specification may not be adequate for a more detailed examination of flexibility issues. This functional form appears sufficient in many respects to characterize the underlying technology (e.g. many of the parameter estimates and elasticities were of the right magnitude, with the correct sign), however problems arose with the inclusion of many interaction terms. These same interaction terms corresponded to the "information variables" that allowed an exploration of informational issues - that is, how the choice of x_1 variables (production techniques) are influenced by information.

Collinearity problems become likely when many variables are included, especially when interaction terms include variables that have already showed up in linear and squared terms as in the quadratic case. The presence of multicollinearity will not in general bias the parameter estimates, but will increase the variance of the estimated coefficients. For this reason, there is no reason to believe that the small A estimates are biased.

Problems with collinearity are associated with poor experimental design. In our case, it is likely that passive data doesn't provide sufficient variation in the particular interaction variables we are interested in. For example, a primary focus in this study was the decision to replant (and how information is important to this decision). An experimental design that allowed us to better identify the exact sequence of events - for example, what factors motivated the decision to replant and the exact timing of the decision - would perhaps allow a more precise specification of the production function.

Information on intermediate products at each stage may also solve some of the problems encountered. In our case, we only had data on the final output. In fact, most available production data do not contain data on intermediate outputs (or on inputs by production stage or operation). One of the reasons is because measuring intermediate ouputs is so difficult for most crops, especially at the farm-level.

A more appropriate experimental design to study the phenomena of incorporating new information into a series of sequential decisions might be a "decision-tree" approach to the questioning process (see Gladwin 1976). To better capture the exact sequence of the decisions and the motivations for each choice, the questions could be structured in an "if-then" manner, forming a decision tree (e.g. if early rains are good, plant a long-cycle variety of sorghum; if not, plant a short-cycle variety). The problem with this approach is that it tends to "mushroom" very quickly. As can be seen from the description in chapter three, planting decisions, for example, are not only based on rainfall but on soil type, position in toposequence, rotational considerations, etc.

The issue of experimental design also highlights the fact that survey data from a highly variable environment, where the major factors affecting yield are difficult to control or measure, are inadequate if precise relationships must be estimated. Given our large estimates of V, this data set appears to be insufficient for a more precise focus on flexibility issues. However, the highly controlled experiment station estimates do not always result in coefficients that are realistic under farmers' conditions - indeed the issue of flexibility will not be nearly as critical on research station plots that are managed at much higher input levels.

A compromise that offers a degree of experimental control to the farmer's fields are "farmer-managed" trials (recently instigated by both ICRISAT and FSU in Burkina Faso). Farmers are given new technologies and certain recommendations - however, they do all the work, under the 'loose' supervision of a technician. Applying our methodology to data from farmer-managed trials in which new technologies are employed would be a very useful undertaking.

Thus it is likely that a combination of factors, including (1) poor experimental design, (2) lack of information on intermediate outputs, and (3) data problems, led to problems in the derivation of V.

Chapter Six: Conclusions

This dissertation has explored the issue of how sequential decision making allows a producer to incorporate new information into the decision making process. This has been demonstrated to be an important method of dealing with extreme environmental risk in food production in the West African Semi-Arid Tropics. It was found that the ability to maintain flexible production plans that allow the incorporation of new information about rainfall into a sequence of input decisions as the cropping season progresses is a vital way in which these farmers deal with risk.

Traditional risk studies in the agricultural economics literature have focused on producer's attitudes towards risk and ignore the existence of active risk management strategies. The preservation of flexibility when faced with uncertainty is a neglected aspect of behavior under risk. This study attempts to look at the issue of how producers deal with risk without the traditional emphasis on an individuals' attitude towards risk. Our results suggest that the degree of risk aversion may not be as important as the ability of farmers to respond to new information.

One of the most effective ways of dealing with risk or uncertainty is to gain as much information relevant to the decision as possible and to be in a position to utilize it. Producers in the WASAT have been found to do just this. Input decisions are made sequentially and in response to the timing and amount of rainfall. Chapter three describes both passive and active techniques of risk management which have been observed in the behavior of farming households in Burkina Faso. This data set has provided unique and detailed insights into actual farmer behavior over a three year period.

A methodology to capture the importance of incorporating new information into the decision making process is described in chapter four. At a theoretical level, the value of information, or flexibility, is related to the comparative performance of decision making processes given different levels of information. That is, the essential difference between the static problem and the sequential solution to a decision problem is that the sequential decisions enable the decision maker to utilize new information. By estimating a sequential production function, an empirical measure of this value of information in monetary terms is derived.

The value of information (or flexibility to make sequential decisions and utilize new information) is important to a farmer in the technologies he chooses to employ. If the ability to make cropping decisions sequentially as the season progresses is an important risk management device, the farmer will not be interested in new techniques that do not allow such flexibility to respond to environmental conditions. It was hypothesized that farmers will attach a value or premium to the flexibility of a particular technique. The results not only support this hypothesis, but also suggest that the magnitude of this premium can be very large.

One of the motivations for this study was the observation that the adoption of new technologies in West Africa has been extremely slow or non-existent, despite increasing efforts to increase productivity by international donors and research agencies as well as by the governments of these countries (although with limited resources). Our results point to some reasons for the lack of success, and suggest that alternate objectives and methods may be required before this can be changed.

Techniques that were examined included the application of chemical fertilizers, the use of animal traction for plowing, and the utilization of traditional varieties with differing crop cycle lengths. The primary objective was to determine whether these techniques limited the amount of flexibility a farmer had in his sequential management steps and enabled him to use information gained about rainfall before further decisions were made.

1) Chemical Fertilizers

The use of chemical fertilizer in the WASAT remains the lowest of any developing region in the world. Major factors explaining low use rates have been identified as: (1) costs of foreign exchange; (2) high transport costs to and within land-locked countries; (3) low and variable response rates to local cereal varieties; (4) poorly developed extension and distribution systems; and (5) inadequate farm-level liquidity (Matlon 1987).

This study suggests another factor that should be taken into consideration - how the choice of whether to apply chemical fertilizers is affected by informational considerations. Our results suggest that the application of fertilizer appears to increase the value of information to a farmer - that is, the more fertilizer he applies, the higher is the value of new information and the ability to revise production plans. This implies the ability to remain flexible after the application of fertilizer is an important consideration in the decision of whether to fertilize a plot.

The implications of these findings for research scientists is the need for greater fertilization options and a better understanding of how chemical fertilizers interact with other inputs in the production process. Knowledge of these interactions is especially important when technological "packages" - including improved varieties, fertilizer and plowing, for example - are being recommended by research and extension agents. If technologies such as new seed varieties, that are being introduced in conjunction with chemical fertilizers, do not allow the revision of cropping patterns as the season unfolds (for example, replanting)[1], none of the components may be adopted. The expected yield of these new varieties using new techniques such as fertilizer will have to be large enough to compensate for the loss of flexibility

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[1] For example, ICRISAT crop breeders have been focusing on varieties that are photo-sensitive. This property limits the effective period in which planting occurs (the planting "window"). If planted too late, or in bad years, yields are very poor.

in production plans that in effect act as self-insurance devices against risk.

Increasing farmers management options should be a primary goal, not the reduction of options due to the introduction of narrower goals or techniques that do not allow the maintenance of flexible risk management techniques. Research needs to be done on increasing the types of chemical fertilizers available[2], on learning the effects of different doses applied at various times in the growing cycle, and on different soil types.

It is important that this be done at the farm level to the extent possible. That is, alternative formulas that provide the nutrients required for different cereals under different soil and climatic conditions, as well as under different management levels, need to be developed. Farmer-managed trials studying the application of varying dosages of chemical fertilizers at different times would be a useful application of the methodology developed in this study. The availability of data on intermediate outputs would also allow a more detailed examination of informational considerations on the fertilization decision.

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[2] In Burkina Faso, extension service recommendations for sorghum and millet are based on a complex fertilizer for cotton, despite evidence that this NPK formula can actually reduce cereal yields after several years of continuous application (Matlon, 1987).

2) The Use of Animal Traction

The use of animal traction is still very limited throughout the WASAT, and when animals and equipment are owned, they are usually under-utilized. Scarifiers and shallow plows for land preparation are the only tools that have been adopted in the northern region, with the deeper plows for the heavier soils of the south the only cultivation equipment adopted in this zone. There are no rental markets for plowing and weeding equipment except in the south, where more cash cropping is done (with institutional support), and higher rainfall levels mean a longer growing season.

Jaeger (1985) found the primary benefit to animal traction was the acreage effect (i.e. it can allow a substantial increase in the amount of land sown), especially when used for weeding, potentially enabling operators to overcome a labor bottleneck at the time of first weeding. Higher benefits were found in the southern regions where an expansion of cash cropping was possible. He also found evidence that plowing can delay planting sufficiently to have a negative effect on yields. The disadvantages of late plant development and the risks of insufficient rain at the end of the season for flowering and seed-set can outweigh the potential yield increasing effects of plowing.

The value of information was determined to be lower when deep plowing with animal traction was performed than when soil preparation was done by hand-tool (or not at all). That is, plowing decreases the need for flexible plans. In this sense, the decision to plow using animal traction appears to be more irreversible than hand-tool soil preparation operations, where planting and replanting are done relatively quickly and with less labor hours expended. The use of animal traction does not allow quick planting. On the other hand, once planting is finished, there appears to be less of a need to replant and thus the incorporation of information as to rainfall during the season becomes less important.

The importance of the complementarity between technical factors arises in regard to successful adoption of animal traction. The development of short-cycle varieties could be used in combination with animal traction to reduce the early season plowing/planting bottleneck. In the long run, increasing the incidence of deep plowing requires putting back some nutrients into the soil, therefore an increase in the use of chemical fertilizers and manure becomes even more vital to maintaining soil fertility and yields.

3) Crop Improvement

Our results show that the decision as to the timing of planting is a critical one, and that there is a value to a farmer of being flexible as to when he plants. It was found that the later in the season a farmer plants, the lower is the value of information. By planting earlier in the season, a more flexible position is adopted - allowing the farmer to take advantage of good early rains, and to have enough time to replant if those rains aren't sufficient. The value of information here can be thought of as the value of the expected loss to the farmer of planting too late in the season to maintain sufficient flexibility to replant or to capture the benefits of early season rainfall.

The value of information, V, was examined with respect to the use of traditional short-cycle varieties as opposed to long-cycle ones. V was found to be higher in the north and central regions for short-cycle varieties. This suggests that short-cycle varieties of millet and sorghum offer more options in terms of the timing of planting and the opportunity to replant if necessary. These findings support the idea that in terms of flexibility, shorter cycle varieties are beneficial, even if expected yields are lower. That is, in considering the benefits and costs of a particular variety, it is important that flexibility (i.e. how well it fits into the farmers sequential risk management strategy) be considered, and not only expected yield (the traditional focus of crop breeders) and yield variability (as suggested in the risk literature).

A comparison of traditional versus modern varieties may show, for example, that traditional varieties have a higher value of information associated with them - that is, they offer a higher degree of flexibility to deal with risk. Modern varieties may very well have to offer high enough yields to compensate for both their 'riskiness' (as measured by yield variability) and their lack of flexibility.

The use of 'farmer-managed' data (or farm-level data that includes the use of modern varieties, which ours did not) would again be useful for this methodology.

In the past, priority has been given to management-dependent high yields, to the practical exclusion of other possible breeding goals (Matlon 1987). Breeding goals that are more content with moderate yield increases and higher stability may in fact be of greater benefit in both the short and long run. In terms of flexibility, this study suggests that the development of varieties with a wider range of agronomic characteristics is desirable. Matlon (1987, p.72) suggests such characteristics as reduced crop cycle or modified plant structure. These could increase farmers' management options by opening new intercrop or relay cropping possibilities by permitting late planting without yield loss. Breeding for drought resistance, pest and disease resistance, and for improved seedling vigor also fit into modified breeding objectives that would enhance flexibility rather than restrict it.

More interdisciplinary research at the farmers' level is needed before new varieties that answer the needs of these producers are developed and adopted in the WASAT. Matlon (1987) points out that farmers should be involved at several stages of the breeding effort and not just at the final stage of pre-extension screening as is conventionally done. National governments need to continue to invest in agricultural research and indeed put further emphasis on it. A multi-year time frame is required for the type of research that is needed. Due to the short-term nature of many donor projects, international funding should focus on setting up more national research stations.

In part it is flexibility considerations that are the strongest arguments against the "top-down" approach to development. The transfer of genetic materials from other areas (such as India in the case of ICRISAT) is an approach that has been taken in various parts of Africa. There are several constraints found in the WASAT that are not present in the Indian SAT, which have been cited as inhibiting the successful transfer of technologies (a "Green Revolution") in Africa.[3] Beyond physical limitations, an examination of production systems has illuminated an important fact - these people have adopted remarkably flexible systems that deal with extremely variable weather conditions and poor soils very well. To disrupt these systems (that effectively, to the extent possible, manage risk) by the introduction of new techniques that do not allow such flexibility is in fact to introduce more risk into their environment.

Limitations of this Study and Areas of Further Research

The production data used in this study were useful since each stage of input use was identified, allowing a sequential production function to be estimated. However, it was limiting in allowing a more exhaustive examination of informational effects. Data on intermediate

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[3] These include poorer soils, more variable rainfall, etc. (see chapter one).

outputs as well as inputs may have solved some of the problems encountered. The accuracy of the data coming from this part of the world is unlikely to be extremely high, mainly due to measurement errors (since standardized measures are not used). For example, the variability in yields tends to be much higher on the very small plots, and the degree to which this is true, or due to measurement errors, is unknown. A high percentage of the plots sown are very small in size (i.e. less than .25 hectares).

Applying the approach developed in this dissertation to data from farmer-managed trials (which employ new techniques and varieties under the supervision of research scientists) would yield valuable information. The data used in this study did not include the use of improved varieties, and information as to the flexibility of such varieties (e.g. those being introduced by ICRISAT in the WASAT), would be tremendously useful.

This study did not attempt to address the issue of factors varying across households (beyond controlling for the type of soil and choice of technique used on each plot). A household approach which looks at the extent to which factors of production such as labor vary across households and the influence on behavior and risk management techniques, would be a complementary use of this type of data. Until such a study is undertaken, all of the reasons for the "yield gap" between farm and research station plots will not be known. This study has attempted to illuminate one of the factors that should be accounted for in evaluating the reasons for this gap, and that is the need for the maintenance of flexible production plans to deal with risk.

The approach taken to deriving the a priori value of information to the decision maker was to evaluate costless and perfect information - that is, information that resolves all uncertainty about the stochastic variable. This framework can also be used to evaluate information that is not costless, or information that allows a reformulation of probabilities, and does not necessarily resolve all the uncertainty. The latter could be done in a Bayesian framework, for example. The particular phenomena studied here - farmers' observations of rainfall and the incorporation of this knowledge into a sequential set of decisions - allowed a relatively uncomplicated derivation of V. However, even with this relatively simple problem, a high level of a priori information about the technology, the nature of the objective function, and a characterization of the uncertainty, is required.

More research needs to be done at both the theoretical and empirical level into how individuals (and firms and governments) make decisions and how they incorporate new information into decisions as a method of dealing with risk. All types of investment decisions are affected by informational considerations, and as yet, little research has been done focusing on this issue. The information literature has tended to concentrate on a 'market value' approach to information, and not on how it affects decisions, and thus how it is valued by decision makers.

Appendix A. Derivation of V, the Conditional Value of Information.

From the definition of the value of information, $V(w, x_1)$ in (9), we can derive an explicit formulation for V. Recalling that x_2^* solves the stagewise optimization problem, and $\bar{x}_2$ solves the static ex-ante choice of x_1 and x_2, we can use the mean value theorem and define for some ξ between 0 and $(x_2^* - \bar{x}_2)$:

(1)

$$U(w,x_2^*,x_1,e) = U(w,\bar{x}_2)+U_{x_2}|_{\bar{x}_2}(x_2^*-\bar{x}_2)+1/2(x_2^*-\bar{x}_2)'U_{x_2x_2}|_{\bar{x}_2+\xi}(x_2-\bar{x}_2)$$

where: $U_{x_2} = \delta U/\delta x_2$ and $U_{x_2x_2} = \delta^2 U/\delta x_2^2$

For some θ between 0 and V, we can define:

(2)

$$U(w+V,\ \bar{x}_2(w+V),\ x_1,\ e) = U(w,\ \bar{x}_2,\ x_1,\ e) + (U_w + U_{x_2}\,\delta\bar{x}_2/\delta w|_{w+\theta,\bar{x}_2}) * V$$

where: $U_w = \delta U/\delta w$

Recalling (4.8), where:

$$E\ U(w,\ x_1,\ x_2^*(.),\ e) = E\ U(w+V(.),\ x_1,\ \bar{x}_2(w+V,x_1),\ e)$$

We can take the expected value of (1) and (2) and solve for V, the difference between the two:

(3)

$$EU(w,x_2^*,x_1,e)=EU(w,\bar{x}_2)+EU_{x_2}|_{\bar{x}_2}(x_2^*-\bar{x}_2)+1/2E(x_2^*-\bar{x}_2)'U_{x_2x_2}|_{\bar{x}_2+\xi}(x_2^*-\bar{x}_2)$$

(4) $EU(w+V,\bar{x}_2,x_1,e) = EU(w,\bar{x}_2) + E(U_w + U_{x_2}\,\delta x_2/\delta w)|_{w+\theta,\bar{x}_2} * V$

Solving for V:

(5)
$$V = \frac{\mathrm{Cov}\,(U_{x_2}|_{\bar{x}_2},x_2^*) + 1/2(x_2^*-\bar{x}_2)'U_{x_2x_2}|_{\bar{x}_2+\xi}(x_2^*-\bar{x}_2)}{E\ U_w\ (w+\theta,\ x_1,\ \bar{x}_2(w+\theta,\ x_1),e\ )}$$

which is an exact measure of the conditional value of costless information. We know $V \geq 0$, and by assumption $U_w > 0$, therefore the denominator of (5) is positive and thus the numerator must be positive also.

$\delta^2 U/\delta x_2^2 < 0$ since it is a negative semi-definite matrix, so:

$$(x_2^* - \bar{x}_2)\, U_{x_2 x_2} (x_2^* - \bar{x}_2) \leq 0 \tag{6}$$

which makes the second term of the numerator positive. The first term of the numerator, Cov $(U_{x_2|\bar{x}_2}, x_2^*)$, must therefore be positive and dominate the second term, i.e. Cov $(U_{x_2|\bar{x}_2}, x_2^*)$ is larger than (6). From expression (5), the properties of the conditional value of information can be explored. However, we cannot use (5) in general in empirical work without knowing ξ and θ (as well as $\bar{x}_2$).

Appendix B. Deriving V for an Extended Quadratic Production Function

$Y = a(x_1, e) + 1/2\, x_2'A(x_1)x_2 + x_2'b(x_1, e)$ is a quadratic production function in x_2 (but not necessarily in x_1). p = output price; r_1 and r_2 = input price vectors for x_1 and x_2 respectively. $A(x_1)$ is a negative definite matrix. $b(x_1,e)$ is some functional form.

The decision maker maximizes expected profits, $E(py - r_1x_1 - r_2x_2)$, that is we assume risk neutrality.

The ex-ante choice of x_1, x_2, is derived by solving:

(1) $\max\limits_{x_1,x_2} \; E(py - r_1x_1 - r_2x_2)$

The sequential optimization problem is:

(2) $\max\limits_{x_1} E \max\limits_{x_2} (py - r_1x_1 - r_2x_2)$

If the decisions x_2 are made at $t=1$, solving (1), we get:

$D1 = \max E \{p (a(x_1,e) + 1/2\, x_2'A(x_1)x_2 + x_2'b(x_1,e)) - r_1x_1 - r_2x_2\}$

where D1 is the value of the indirect objective function for the one-stage optimization problem.

$D1 = \max \{p (E\, a(x_1,e) + 1/2\, x_2'A(x_1)x_2 + x_2'E\, b(x_1,e)) - r_1x_1 - r_2x_2\}$

The first order conditions are:

$$\partial D1/\partial x_2 = px_2A(x_1) + p\, E\, b(x_1,e) - r_2 = 0$$

$$\bar{x}_2 = r_2\, (pA(x_1)^{-1}) - E\, b(x_1,e)\, A(x_1)^{-1}$$

If the decisions x_2 are made at $t=2$ when the uncertainty, e, has been resolved; that is, e is known, we solve the problem:

$D2 = \max p\, (a\, (x_1,e) + 1/2\, x_2'A(x_1)x_2 + x_2'b(x_1,e)) - r_2x_2$

The first order conditions are:

$$\partial D2/\partial x_2 = pA(x_1)x_2 + b(x_1,e) - r_2 = 0$$

$$x_2^* = r_2 \, (pA(x_1)^{-1}) - b(x_1,e) \, A(x_1)^{-1}$$

To simplify the notation, let:

$b = b(x_1,e)$; $A = A(x_1)$; $\bar{b} = E \, b(x_1,e)$; $\bar{a} = E \, a(x_1,e)$.

Substituting the optimal value $\tilde{x}_2$ into the D1,

we get:

$$L1 = p \left\{ \left(\bar{a} + 1/2 \left(\frac{r_2}{pA} - \frac{\bar{b}}{A} \right)' A \left(\frac{r_2}{pA} - \frac{\bar{b}}{A} \right) + \left(\frac{r_2}{pA} - \frac{\bar{b}}{A} \right) \bar{b} \right\} \right.$$

Substituting x_2^* into D2, we get:

$$L2 = p \left(a + 1/2 \, E\left(\left(\frac{r_2}{pA} - \frac{b}{A} \right)' A \left(\frac{r_2}{pA} - \frac{b}{A} \right) \right) + E \left(\left(\frac{r_2}{pA} - \frac{b}{A} \right) b \right) \right)$$

Defining $\varepsilon = b - \bar{b}$

where: $E(\varepsilon) = 0$

$E(\varepsilon^2) = \mathrm{Var}(b)$

So L2 becomes:

$$L1 = p \left\{ \left(\bar{a} + 1/2 \left(\frac{r_2}{pA} - \frac{\bar{b}+\varepsilon}{A} \right)' A \left(\frac{r_2}{pA} - \frac{\bar{b}+\varepsilon}{A} \right) + \left(\frac{r_2}{pA} - \frac{\bar{b}+\varepsilon}{A} \right) \bar{b}+\varepsilon \right\} \right.$$

$$= p \left\{ \left(\bar{a} + 1/2 \left(\frac{r_2}{pA} - \frac{\bar{b}}{A} \right)' A \left(\frac{r_2}{pA} - \frac{\bar{b}}{A} \right) + \left(\frac{r_2}{pA} - \frac{\bar{b}}{A} \right) \bar{b} \right\} + \frac{1}{2A} E(\varepsilon^2) - \frac{1}{A} E(\varepsilon^2) \right)$$

and $L2 - L1 = p \, (1/2A - 1/A) \, E(\varepsilon^2)$

Therefore, V, the conditional value of information is:

$-(1/2)p \; \mathrm{trace} \; \{ A(x_1)^{-1} \, \mathrm{Var} \; b(x_1,e) \} \geq 0$, since A is a negative definite matrix, and the marginal value of information, $\partial V / \partial x_1$, can be negative, zero or positive depending on how $A(x_1)$ and the variance of $b(x_1,e)$ vary with x_1.

For our specific functional form:

$$Y(x_1,x_2,e) = ax_1 + x_1'\alpha x_1 + \beta x_2 + x_2'Ax_2 + (be + cx_1e)x_2$$

we have: $b(x_1,e) = (be + cx_1e)$

and $\text{Var } b = (b + cx_1)^2*\text{Var } e$; where $\text{Var } e$ = Variance of rainfall.

Therefore,

$$V = (-1/2)\ p\ (A^{-1})(b + cx_1)^2*\text{Var } e$$

and $\partial V/\partial x_1 = (-1/2)\ p\ (A^{-1})(2bc + 2cx_1)*\text{Var } e$

since in our particular case, A is not a function of x_1.

Appendix C. Estimation of the Variability of Rainfall

Rainfall was defined as the total millimeters that fell in the first thirty days after planting. Thus rainfall was regressed on the date of planting, and the variance of the residual (the mean square error term), was used to estimate the variance of rainfall.

Dependent Variable: Rainfall

1. Sorghum - Southern Region

Variable	Parameter Estimate	Standard Error	T-Statistic
Intercept	87.4	5.65	15.5
Date of Planting	2.03	.15	13.15

Mean Square Error: 2527
F Value: 173
R Squared: .39

2. Sorghum - Central Region

Variable	Parameter Estimate	Standard Error	T-Statistic
Intercept	92.98	8.27	11.24
Date of Planting	1.4	.18	7.5

Mean Square Error: 2442
F Value: 57
R Squared: .11

3. Millet - Central Region

Variable	Parameter Estimate	Standard Error	T-Statistic
Intercept	87.4	7.95	10.9
Date of Planting	.59	.18	3.3

Mean Square Error: 1211
F Value: 10.8
R Squared: .04

4. Millet - Northern Region

Variable	Parameter Estimate	Standard Error	T-Statistic
Intercept	-28.4	6.18	-4.6
Date of Planting	2.5	.13	20.3

Mean Square Error: 830
F Value: 412
R Squared: .56

Appendix D. Average Input Use and Average Yields by Region

Crop: Millet	North	Central	South
Kgs/ha. Manure	229	281	119
Kgs/ha. Fertilizer	.15	7	1.7
No. Hours 1st Weeding	163	315	160
No. Hours 2nd Weeding	97	244	118
Date of Planting	48	46	28
Percent Area Replanted	17	31	22
Rainfall (mm.)	93	113	107
Number of Plots	325	343	128
Area (hectares)	844	192	179
Yield (kgs./ha.)	383	402	366

Crop: White Sorghum	North	Central	South
Kgs/ha. Manure	0	279	484
Kgs/ha. Fertilizer	0	12	3.2
No. Hours 1st Weeding	242	259	162
No. Hours 2nd Weeding	172	224	137
Date of Planting	53	42	31
Percent Area Replanted	22	35	24
Rainfall (mm.)	92	153	149
Number of Plots	75	586	253
Area (hectares)	40	366	237
Yield (kgs./ha.)	397	541	516

References

Abalu, G.O.I. "A Note on Crop Mixtures under Indigenous Conditions in Northern Nigeria." Journal of Devel. Studies 12 (April 1976).

Anderson, J.R. and J.L. Dillon and B. Hardaker. Agricultural Decision Analysis. Ames: Iowa State Press, 1977.

Anderson, J.R. "Perspective on Models of Uncertain Decisions." Chapter 3 of Roumasset et al.(eds.), Risk, Uncertainty and Agricultural Development, New York: Agricultural Development Council, 1979.

Antle, J.M. "Sequential Decision Making in Production Models." Amer. J. Agric. Econ. 65, No.2 (May, 1983) 282-290.

Antle, J.M. and S.A. Hatchett. "Dynamic Input Decisions in Econometric Production Models." Amer. J. Agric. Econ. (Nov. 1986) 939-949.

Arrow, K.J. Essays in the Theory of Risk-Bearing. Markam, Chicago, 1971.

Balcet, J. "Adoption of New Farm Technology by Subsistence Farmers in Northern Nigeria." World Bank, 1982.

Barry, P.J. ed. Risk Management in Agriculture. Ames: Iowa State Press, 1984.

Baumol, W.J. Economic Theory and Operation Analysis. Englewood Cliffs, N.J. Prentice Hall, 1972.

Binswanger, H.P. "Risk and Uncertainty in Agricultural Development: An Overview" in Roumassett et al.(eds), Risk, Uncertainty and Agricultural Development. New York: Agricultural Development Council (1979a) 383-398.

Binswanger, H.P. and N.S. Jodha and B.C. Barah, "The Nature and Significance of Risk in the Semi-Arid Tropics." in Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture, ICRISAT, Hyderabad, India, Feb. 1979b.

Binswanger, H.P. "Attitudes Towards Risk: Experimental Measurement Evidence in India." Amer. J. Agric. Econ. 62 No.3 (Aug. 1980) 395-407.

Binswanger, H.P. "Attitudes Towards Risk: Theoretical Implications of an Experiment in Rural India." Econ. Journal 91 (1981) 867-890.

Binswanger, H.P. and D.A. Sillers. "Risk Aversion and Credit Constraints in Farmers' Decision-Making: A Reinterpretation." Journal of Devel. Studies 20 (1982) 5-21.

Burt, O.R. and J.R. Allison. "Farm Management Decisions with Dynamic Programming." J. Farm Econ. 45 (1963) 121-136.

Chavas, J.P. "The Role of Risk in Sahelian Agriculture." A proposal by the Dept. of Ag. Econ. and the Office of Intl. Ag. Programs, U.W. Jan. 1985a.

Chavas, J.P. "The Theory of the Competitive Firm under Uncertainty When Initial Wealth is Random." Southern Econ. J. (Jan. 1985).

Chavas, J.P. "On the Role of Information in Ex-Ante Cost-Benefit Analysis", unpublished paper, 1986.

Chavas, J.P. and S.R. Johnson. "Supply Dynamics: The Case of U.S. Broilers and Turkeys." Amer. J. Agric. Econ. 64 (1982) 558-564.

Chavas, J.P. and R.D. Pope. "Information: Its Measurement and Valuation." Amer. J. Agric. Econ. 66 No.5 (Dec. 1984) 705-710.

Chavas, J.P. and J.B. Kliebenstein and T.D. Crenshaw. "Modelling Dynamic Agricultural Production Response." Amer. J. Agric. Econ. 67 (Aug. 1985) 636-646.

Chavas, J.P. "On Risk Modeling and Its Implications for Economic Analysis".

Day, R. H. "Directions for Research on Economic Uncertainty", in Roumasset, J. and J.M. Boussard and I. Singh. (eds) Risk, Uncertainty and Agricultural Development. New York: Agricultural Development Council, 1979.

de Janvry, A. "Optimal Levels of Fertilization Under Risk." Amer. J. Agric. Econ. 54 (1972) 1-10.

Delgado, C. Livestock Versus Foodgrain Production in Southeast Upper Volta, Ann Arbor: CRED, University of Michigan, 1979.

Delgado, C.L. and J.W. Mellor. "A Structural View of Policy Issues in African Agricultural Development." Amer. J. Agric. Econ. 66 No.5 (Dec. 1984) 665-670.

DeWilde, J.C. and F.M. McLoughlin and A. Guinard and T. Scudder and R. Maubouche. "Experiences with Agricultural Development in Tropical Africa: The Synthesis, Vol. I." Baltimore:John Hopkins Press, 1967.

Eicher, C.K. and D.C. Baker. "Research on Agricultural Development in Sub-Saharan Africa." East Lansing, MSU International Development Papers, No.1, 1982.

Epstein, L.G. "Production Flexibility and Behavior of the Competitive Firm under Price Uncertainty." Review of Econ. Studies 45 (1978) 251-261.

Fawcett, R.H. "Toward a Dynamic Production Function." J. Agric. Econ. 24 (1973) 543-555.

Feder, Gershon. "Farm Size, Risk Aversion, and the Adoption of New Technology Under Uncertainty." Oxford Econ. Papers. 32 (July 1980) 263-283.

Feder, Gershon. "Adoption of Interrelated Agricultural Innovations: Complementarity and the Impacts of Risk, Scale and Credit." Amer. J. Agric. Econ. 64 No.1 (Feb. 1982) 94-101.

Gladwin, C. "A View of the Plan Puebla: An Application of Hierarchical Decision Models." Amer. J. Agric. Econ. 58 No.5 (Dec. 1976) 881-887.

Gould, J.P. "Risk, Stochastic Preference and the Value of Information." J. Econ. Theory 8 (1974) 64-84.

Haggblade, Steve. "An Overview of Food Security in Burkina Faso." A Report Prepared for USAID/Burkina Faso, Ouagadougou, 1984.

Heady, Earl O. Economics of Agricultural Production and Resource Use. Prentice-Hall, Inc. New York, 1952.

Heady, E.O and John L. Dillon. Agricultural Production Functions. Iowa State University Press: Ames, Iowa, 1961.

Herath, M.G. and J.B. Hardaker and J.R. Anderson. "Choice of Varieties by Sri Lanka Rice Farmers: Comparing Alternative Decision Models." Amer. J. Agric. Econ. 64 No.1 (Feb. 1982).

Hess, James. "Risk and the Gain from Information." J. Econ Theory 27 (1982) 231-238.

Hirshleifer, J. and John G. Riley. "The Analytics of Uncertainty and Information - An Expository Survey" J. Econ. Literature (Dec.1979) 1375-1421.

ICRISAT (1979) Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture. Hyderabad, India, Feb. 1979.

ICRISAT. Annual Reports, Ouagadougou, Burkina Faso, various years.

Jaeger, W.K. Agricultural Mechanization: The Economics of Animal Traction in Burkina Faso. PhD. Thesis, Stanford University, 1985.

Jodha, N.S. "Effectiveness of Farmers' Adjustments to Risk." Economic and Political Weekly, Review of Agriculture, June 1978, A38-A46.

Just, Richard E. "Risk Aversion Under Profit Maximization." Amer. J. Agric. Econ. 57 No.1 (Feb. 1975) 347-352.

Just, R.E. and R. Pope. "Stochastic Specification of Production Functions and Econometric Implications." J. Econometrics. 7 (Mar. 1978) 67-86.

Just, R.E. and R. Pope. "Production Function Estimation and Related Risk Considerations." Amer. J. Agric. Econ. 61 (May 1979) 276-284.

Kahneman, D. and A. Tversky. "Prospect Theory: An Analysis of Decisions Under Risk." Econometrica. 47 (1979) 263-291.

Kamien, M.E. and N.L. Schwartz. Dynamic Optimization: The Calculus of Variations and Optimal Control in Economics and Management. Amsterdam: Elsevien/North Holland Publishing Co., 1981.

Kihlstrom, R. "A Bayesian Model of Demand for Information about Product Quality." International Economic Review. Vol. 15, No.1. (Feb. 1974).

Knight, Frank. Risk, Uncertainty and Profit. New York: Houghton Miffler Co., 1921.

Lang, M.G., M. Roth and P. Preckel. "Risk Perceptions and Risk Management by Farmers in Burkina Faso." Paper presented at the Farming Systems Research Symposium, Kansas State University, Manhattan, Kansas, Oct. 1984.

Lavalle, I.H. Fundamentals of Decision Analysis. New York: Holt, Rinehart and Winston, 1978.

Lele, U. "The Role of Risk in an Agriculturally-Led Strategy in Sub-Saharan Africa." Amer. J. Agric. Econ. 66 No.5 (Dec. 1984) 677-683.

Luce, R. Duncan and Howard Raiffa. Games and Decisions: Introduction and Critical Survey. New York: Wiley, 1957.

Machina, M. "The Economic Theory of Individual Behavior Toward Risk: Theory, Evidence and New Directions." Technical Report No.433, Institute for Mathematical Studies in the Social Sciences, Stanford University, Oct. 1983.

Marschak, Jacob and Koichi Miyasawa. "Economic Comparability of Information Systems." Int. Econ. Review 9 (June 1968) 137-174.

Marschak, J. "Economics of Information Systems." in Frontiers of Quantitative Economics. Edited by Michael D. Intriligator. Amsterdam: North-Holland, 1971, 32-107.

Marshak, J. and W.J. Andrews. "Random Simultaneous Equations and the Theory of Production". Econometrica, 12 (1944), 143-205.

Matlon, P.J. "Local Varieties, Planting Strategies and Early Season Farming Activities in Two Villages of Central Upper Volta." ICRISAT publication, June 1980.

Matlon, P.J. and R. Contrell and D. King and M. Benoit-Cattin, eds. Coming Full Circle: Farmers Participation in the Development of Technology. IDRC, 1983.

Matlon, P.J. "The Technical Potential for Increased Food Production in the West African Semi-Arid Tropics." Paper presented at the Conference on Accelerating Growth in Sub-Saharan Africa, Zimbabwe, Sept. 1983.

Matlon, P.J. and S.C. Spencer. "Increasing Food Production in Sub-Saharan Africa: Environmental Problems and Inadequate Technological Solutions." Amer. J. Agric. Econ. 66 No.5 (1984) 671-676.

Matlon, P.J. "The West African Semi-Arid Tropics" in Accelerating Food Production in Sub-Saharan Africa. Edited by J.W. Mellor, C.L. Delgado and M.T. Blackie. Baltimore: John Hopkins Press, 1987.

Moock, J.L. (ed.) Understanding Africa's Rural Households and Farming Systems. Westview Press, 1986.

Newbery, D.M. and G.E. Stiglitz. The Theory of Commodity Price Stabilization: A Study in the Economics of Risk. Oxford: Claredon Press, 1981.

Norman, D.W. "Rationalising Mixed Cropping under Indigenous Conditions: The Example of Northern Nigeria." Journal of Devel. Studies 11 (1974) 3-21.

Norman, David W. "Rationalising Mixed Cropping Under Indigenous Conditions: The Example of Northern Nigeria. Journal of Development Studies. (1974) 2-21.

Norman, D.W. and M. Newman and I. Ouedraogo. Farm and Village Production Systems in the Semi-Arid Tropics of West Africa: An Interprative Review of the Research. Research Bulletin No. 4, Volume 1, 1984. Patancheru, Andnra Pradesh, India: ICRISAT.

Ohm, Herbert W. and Joseph G. Nagy (eds.) Appropriate Technologies for Farmers in Semi-Arid West Africa. Purdue University, 1985.

Pope, R. and J.P. Chavas and R.E. Just. "Economic Welfare Evaluation for Producers Under Uncertainty." Amer. J. Agric. Econ. 65 No.1 (Feb. 1983) 98-107.

Pratt, John W. "Risk Aversion in the Small and in the Large." Econometrica. 32 (1964) 122-136.

Prudencio, Y. A Village Study of Soil Fertility Management and Food Crop Production in Upper Volta: Technical and Economic Analysis. University of Arizona, Dept. of Ag. Econ. Unpublished Ph.D. dissertation, 1983.

Rae, A. N. "Stochastic Programming, Utility, and Sequential Decision Making Problems in Farm Management." Amer. J. Agric. Econ. 53 (1971).

Raiffa, Howard. Decision Analysis: Introductory Lectures on Choices Under Uncertainty. Reading, Mass.: Addison-Wesley, 1968.

Rausser, G.C. "Active Learning, Control Theory, and Agricultural Policy." Amer. J. Agric. Econ. Aug. 1978.

Rausser, G.C. and E. Hochman. Dynamic Agricultural Systems: Economic Prediction and Control. Amsterdam: Elsevier/North Holland Publishing Co. 1978.

Rothschild M. and J. Stiglitz. "Increasing Risk I: A Definition." Journal of Econ. Theory. 1970, 225-243.

Roumasset, J. Rice and Risk: Decision Making Among Low-Income Farmers. Amsterdam: North-Holland, 1976.

Roumasset, J. and J.M. Boussard and I. Singh. (eds) Risk, Uncertainty and Agricultural Development. New York: Agricultural Development Council, 1979.

SAFGRAD, Farming Systems Research Unit. 1984 Annual Report. Purdue University - IER/IPIA.

Sanders, J.H. and Joseph Nagy and Barry Shapiro. "Developing and Evaluating New Agricultural Technology for the Sahel: A Case Study in Burkina Faso." mimeograph, Purdue University, Nov. 1985.

Sandmo, A. "On the Theory of the Competitive Firm under Price Uncertainty." American Economic Review, 61 (1971), 65-73.

Savage, L.J. The Foundations of Statistics. New York: John Wiley and Sons, 1954.

Scandizzo, P.L. and John L. Dillon. "Peasant Agriculture and Risk Preferences in Northeast Brazil: A Statistical Sampling Approach." in Roumasset et al. (eds), Risk, Uncertainty and Agricultural Development. New York: Ag. Development Council, 1979, 133-159.

Schlaifer, R. Analysis of Decisions Under Uncertainty. New York: McGraw-Hill, 1969.

Stoop, W.A. and J. Ph. van Staveren. "Adaptation to Toposequence Land Types in West Africa of Different Sorghum Genotypes in Comparison with Local Cultivars of Sorghum, Millet and Maize." Field Crops Research, 11 (1985) 13-35.

Spencer, D.S. "A Research Strategy to Develop Appropriate Agricultural Technologies for Small Farm Development in Sub-Saharan Africa." in Ohm, H. and Nagy, J. (eds.): Appropriate Technology for Farmers in Semi-Arid West Africa. Purdue University, 1985.

Vierich, Helga. "Agricultural Production, Social Status, and Intra-Compound Relationships", in J.L. Moock (ed.): Understanding Africa's Rural Households and Farming Systems, Westview Press, 1986.

Vierich, Helga. Guide to ICRISAT Villages. Mimeograph, ICRISAT, 1987.

von Neumann, John and Oscar Morgenstern. Theory of Games and Economic Behavior. Princeton, N.J.: Princeton University Press, 1944.

Walker, Thomas S. and N.S. Jodha. "How Small Farm Households Adapt to Risk", in P. Hazell, C. Pomaredo and A. Valdes (eds.): Crop Insurance for Agricultural Development:Issues and Experience. John Hopkins University Press, 1986.

Watts, M. Silent Violence. Berkeley: Univ. of California Press, 1983.

Watts, M. "On the poverty of theory: Natural hazards research in context," in Interpretations of Calamity, ed. by K. Hewitt, Allen University Press, Boston, 1983.

World Bank. "Accelerated Development in Sub-Saharan Africa: An Agenda For Action." Washington, D.C. 1981.

World Bank. "Sub-Saharan Africa: Progress Report on Development Prospects and Programs." Washington, D.C. 1983.

World Bank. "Towards Sustained Development in Sub-Saharan Africa." Washington, D.C. 1984.

Zellner, A. and J. Kmenta and J. Dreze. "Specification and Estimation of Cobb-Douglas Production Function Models." Econometrica 34 (1966), 784-795.