Considering Production Risk And Whole Farm Risk In Identifying The Optimal Rate Of Nitrogen Fertilization In Field Crop Production

by

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CONSIDERING PRODUCTION RISK AND WHOLE FARM RISK IN IDENTIFYING THE OPTIMAL RATE OF NITROGEN FERTILIZATION IN FIELD CROP PRODUCTION

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DARRELL M. ZBEETNOFF

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

Nitrogen (N) fertilization is considered to be a risk increasing input in field crop production. As yield expectations increase with higher N, the probability of negative returns also increases due to the increasing variability of yield outcomes.

Farmers' efforts to account for production risk in their fertilizer decisions are hampered by an absence of suitable yield distribution data. Nevertheless, risk increasing properties imply unique statistical characteristics in crop yield populations which can be used to identify risk-efficient N rates.

Actual N rate choices are made more complex by the interaction of production risk with the risk of not obtaining critical levels of returns. Acceptable levels of returns depend on the financial circumstances of farming operations, where debt servicing costs can be a major factor.

This study examines how the assumption of increasing production risk as a function of N affects whole farm risk. The whole farm risk- efficient strategy for farmers with high minimum acceptable return requirements differs substantially from the N strategy for farmers with low minimum return requirements from crop production.

ACKNOWLEDGEMENTS

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An extensive literature review of fertilization strategy in that study, in particular, identified gaps in the information base and shortcomings in the decision making process recommended to farmers. The author is especially indebted to the project coordinator, Prof. Rea Josephson, for insights into the risk aspects of fertilizer use.

The author wishes to sincerely thank his advisor, Dr. L.M. Arthur, for her encouragement, insightful comments and useful advice in handling the difficulties raised by the approach used in this study.

Several professors and staff of the Department of Agricultural Economics and Farm Management have provided inspiration in bringing this thesis to term. My appreciation to all of them and just think, Vydehi, no more late registrations.

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1.0 INTRODUCTION

Lower commodity prices, smaller gross margins and high cash flow requirements have had many grain farmers in Manitoba asking agricultural experts what alterations they should make in their fertilizer and other input decisions to cope in the tighter economic climate. After crop selections had been made, there was the question of how much nitrogen (N) to apply to specific crops and what level of yield to target. Optimum rates would have been expected to change because of changed relationships between the prices of commodities and the cost of fertilizer. There were also other dimensions to this question in addition to efficiency considerations, such as down-side (risk of loss) and up-side (profit potential) financial considerations.

Exposure to the risk factor became of more concern as the perceived risk of not recovering costs of production became more likely. Many farmers, particularly those with high capital requirements or with high debt servicing loads, were not in a position to recover total costs of production from expected crop revenues. Under these circumstances, farmers were faced with the need to identify options in line with their more obvious risk preferences, critical loss thresholds and cash flow requirements. In reality, farmers were still seeking efficient strategies as before, but where the consequences of loss or failure were more severe.

1.1 How The N Fertilization Recommendation Is Made

N fertilization rates are recommended to prairie farmers on the basis of nutrient analyses of soil tests in relation to N x yield expectations for different possible moisture conditions. The approach of provincial soil testing laboratories in making N fertilization recommendations and the analysis used by private soil testing agencies are virtually identical. Initially, the profit maximizing "economic optimum" level of N fertilization is found on the crop yield production function. This point is identifiable as the point where marginal revenues from added yield due to N fertilization just equal the cost of the incremental increase in fertilizer required to get that yield. It is also where the gross margin between expected revenues and known costs of production is maximized.

Provincial soil lab recommendations retreat from the economic optimum by modifying the marginal revenue-marginal cost (MR:MC) ratio from 1:1 to 1.5:1 or 2:1. That is, it is deemed safer for farmers to sacrifice some profit potential to "... allow for the risk of less than optimum conditions in the use of the fertilizer." (Saskatchewan Agriculture, 1986:8).

Alberta Agriculture (1985:4) recommends to farmers that benefit-cost ratios "... in the range of 1.5 to 2.0 are generally considered to indicate sufficient potential gains relative to potential losses." In addition, "... the risk of not obtaining a profitable return increases at higher rates of application both because of a lower cost benefit ratio, and the amount of crop response is less predictable..." (and) " Such precautions as cutting back on the rate of nitrogen will provide a safeguard against possible losses, however, this will keep a producer from achieving maximum profit." (Alberta Agriculture, 1985:3-4). Alberta's benefit-cost ratio is identical with the definition of MR:MC at the target ratio.

Manitoba Provincial Soil Testing Laboratory (MPSTL) has recently modified its N recommendation in a manner that removes its former bias toward the inflated MR:MC ratio of 1.5:1 (see McGill,1988). This change has been welcome because of the arbitrary nature of the previous 'risk' adjustment, which may not have had its intended effect on level of risk exposure, anyway (see Zbeetnoff and Josephson, 1988b).

The farmer is no longer guided into opting for a N recommendation which may automatically adjust for 'risk' but is now presented with more N x yield data in what is assumed to be the relevant region of the production function. However, an alternate rationale has not been generated to assist him in making his specific N rate decision.

1.2 Advice Given Farmers To Manage Economic Stress

In the face of the additional complication of depressed commodity prices, agricultural extension specialists have been advising farmers to reduce N rates further to reduce risk caused by chasing high yields (at low prices) to meet high costs of production. One rationale for this advice: Since the price of a unit of N input had risen in relation to the value of the output generated, it would take more output units to maintain the same MR:MC ratio. Hence, it was deemed necessary to move down the production function to a point where the marginal return from incremental units of N was more substantial.

Other investigators (e.g. Josephson and Zbeetnoff, 1988a; Zbeetnoff and Josephson, 1988b) have been telling farmers to raise N rates to the economic optimum, representing the point at which there is the greatest chance of meeting costs of production and/or realizing a profit. The researchers suggest that attempting to achieve above average yields with reduced inputs is riskier than trying to produce average yields with "profit maximizing" input levels. The two points on the production function are not identical and, quite understandably, probably lead farmers to ignore the expert advice in their fertilization decisions.

Which advice is correct? Which assumptions about the distributional characteristics of N x weather interactions on crop yield are valid? Or are both recommendations valid for different groups of farmers depending on a host of factors, including the variance of yields with increasing N rate, risk attitudes of the producers and financial characteristics of farm operations?.

Conceptually, there can be no doubt that decision tools in the N rate selection process which are sensitive to decision factors employed by farmers will improve the accuracy of the recommendations. Moreover, changes in decision factors would be expected to be reflected in changes in optimality as relationships between variables change. In practical terms, this requires the application of the statistical parameters of crop yield populations to N rate decision frameworks which use profit and risk measures as objectives and constraints.

As one of the researchers to first incorporate risk in agricultural decision analysis observed, the neglect of risk in farm planning caused the expected income of the optimal plan in the absence of risk considerations to be more than 50% higher than the expected income of optimal plans with risk considered (Freund, 1956). This difference in optimality identification is reported to be characteristic of all empirical studies relating to the inclusion of risk in planning decisions (Boussard, 1984:66).

1.3 The Study Problem

Essential information needed to arrive at N fertilization recommendations is not being generated in Manitoba. Assumptions are being made about the implications of the dispersion of yields about mean expectations, with little evidence, empirical or subjective, generated to characterize those distributions. Appropriate actions of individual farmers are conditional on their attitudes to risk exposure and the risk characteristics of their farming operations, for which no allowances are currently being made.

The mixed advice provided about N rate recommendations has highlighted significant weaknesses in the methodology used to make those recommendations. These problems stem directly from gaps in the structure of the N rate decision framework and deficiencies in the field crop yield x N rate data base.

In contrast to the mechanics of calculating the soil test fertilization recommendation, the dual roles of profit and risk have been widely recognized as either objectives or constraints in the decision framework of numerous fertilizer decision models. Whatever the specific decision rules of the various fertilization models currently in existence, the fact is that the incorporation of both profit and risk into the decision process changes the loci of optimal and/or efficient choices.

Despite the overwhelming evidence of the need for better specification of the N fertilization decision process, analytical and definitional problems with respect to risk have delayed the transfer of improved decision aids to farmers. One expert has noted that "Agricultural economists have made little progress in analyzing or measuring production risk in ways that provide useful information for farm management" (Antle 1983:1099). More recently, other experts in the U.S. have noted that while "... various analytical approaches for decision making under uncertainty had become important methods in agricultural economics research focusing on decision problems of agricultural producers, ... concepts and procedures for decision making under uncertainty still have not been fully incorporated into extension programs and decision aids." (Knight et al., 1987:27).

The comments of a professional in the field, whose dated yield x N rate population data are still used to validate decision models, are instructive: "Until a science of yield probabilities can be developed, correct decisions in agriculture are virtually impossible." (Day, 1965:714). Or, as others have stated, "Needless to say, without probability distributions there can be no realistic discussion of risk in input decisions. Rather .... and until this is done .... farmers will continue to operate in a state of increased uncertainty and decreased efficiency." (Doll and Orazem, 1978:248).

1.4 Scope And Objectives

This study investigates the issue of improving the N fertilization decision in crop production. It brings several related concepts dealing with the optimal N fertilization decision together into a Manitoba context. The implications of yield distribution on farm management goals are discussed in terms of a representative field crop, wheat. In particular, the N rate decision is related to its impact on profit, production risk and whole farm risk using known qualitative characteristics of wheat yield.

A distinction between risk efficiency and risk optimality has been emphasized in this study. Anderson (1973:77) remarked, "Good risky decisions should be based first on an assessment of (fertilizer) response and its riskiness and second on the producer's attitude to income and risk." To this might be added, give farmers the best information available on the former and let them decide about the latter on their own. Accordingly, this investigation manipulates relevant yield probability characteristics into a framework which is capable of providing farmers with information bearing on interrelation of profit and risk considerations in the N rate decision.

1.5 Method

Efforts were made initially to use a Manitoba crop yield data base to empirically demonstrate dispersion characteristics reported in the literature. Wheat yield x N rate records were examined from the Manitoba Crop Insurance Corporation (MCIC) from the period 1976 to 1986. The data were further segregated by MCIC soil class and examined for its yield response and variability characteristics.

It became evident that reported characteristics of the N rate response were not being demonstrated in the MCIC database. First, average yield responses to N fertilization were indicated to be substantially below the production function estimates used by Manitoba Provincial Soil Testing Laboratory (MPSTL) and based on fertilizer trials conducted in the province. This, in itself, might be expected since average crop yields are depressed by many inputs which constrain the manifestation of yield x N rate potential, such as weather events, pests, variable soil capabilities, management ability, etc. However, lower N x yield expected values almost automatically imply smaller ranges of expression and have the statistical effect of masking true N x yield risk characteristics and patterns across different levels of N fertilization.

Secondly, the observed variation of MCIC yields about the means at various N rates does not exhibit dispersion increasing attributes associated with increasing N fertilization (see Roumasset, 1979:15). In view of the fact that MCIC yield dispersion characteristics were intended to provide some empirical legitimacy for the approach presented, this created a dilemma in demonstrating the applicability of the results to Manitoba or countering arguments that the results are contrived. Fortunately, yield dispersion characteristics are only one important element and not the sole factor affecting whole farm risk decisions.

There are three possibilities for the discrepancies between MCIC data and reported yield and dispersion characteristics of the N rate response. The first is that the Manitoba HRS wheat response to N is different than elsewhere. In this respect, although MCIC data indicate higher absolute standard deviations (SDs) with increasing N for most soil classes, corresponding coefficients of variation (CVs) are generally lower with increasing N rate.

A more likely second reason for the discrepancies is that other input factors of production are altering the observed yield response to N. Some of these factors, such as variety, region and seeding date, could be separated out through econometric modelling. Other input factors, such as pesticides and tillage practises, pest infestation, frost, hail, etc. would require special studies just to calibrate yield responses to level of use/impact. The suggests that the MCIC data are not suitable in their present form to support or refute the thesis of this study.

The third possibility is that the hypothesis that N is a risk increasing input in field crop production is erroneous. It is recognized that the literature supporting the hypothesis is limited in terms of empirical findings. At the same time, empirical research on the distribution characteristics of yield as a function of N fertilization has not been given the priority it deserves in view of its potential implications for risk efficient N use.

Other data bases were also considered in particular, fertility trials and provincial and federal crop variety trials. Because of various complications related to sampling sizes, cross-sectional versus time-series data characteristics, and the unavailability of yield data at incremental levels of N fertilization, the statistical validity of any associations identified was anticipated to be less than satisfactory. A decision was therefore made to present a conceptual approach for treating risk and profit jointly in the N fertilization decision and to leave it to subsequent researchers to generate the database required to identify specific optimizing points.

Price risk is not examined in this study despite its obvious bearing on the net revenues derived from given levels of production. First, once the crop selection has been made, price is in effect constant in all N-rate strategies in terms of its relative impact on different risk management scenarios. Second, once the crop is selected, fluctuations in crop and N prices, while unpredictable, are generally less influential than yield response variation on net income. This is particularly the case where forward pricing and Canadian Wheat Board marketing options establish the price prior to harvest, or in some cases, seeding. These options are also likely to be viewed favourably by risk-conscious producers.

As well, for the purposes of this study, financial risk is assumed to act upon the different debt scenarios in identical manner. The effect of higher leverage is to increase cash flow requirements needed to service loans, and therefore the costs of production of the farm firm, but not the interest rates related to loan acquisitions.

1.6 Outline

The background and importance of the topic of choosing the correct N fertilization rate in farm management decisions are presented in Section 1. The problem for investigation and the scope/objectives of the study are also detailed in Section 1.

In Section 2, the characteristics of the N input factors/variables which impact on the farmers' decision framework are reviewed. Since definitions of concepts are an integral part of the problem, working definitions are selected here.

Various models have been employed to operationalize production risk in farming decisions. These approaches are reviewed in Section 3 in terms of their suitability for assessing the risk associated with N fertilization in field crop production.

In Section 4, characteristics of yield response to N fertilization are examined in relation to specific risk concerns expressed by many Manitoba farmers. A risk definition and approach is selected to guide further analysis.

Section 5 illustrates how widely accepted characteristics of the variables involved can be used in a N rate decision framework. The results are discussed in terms of operationalizing the information base to allow individual farmers to make their own optimal decisions with regard to risk.

Conclusions and recommendations are presented in Section 6. The application of the hypothesis investigated is summarized. Needs for further information and research are identified. Finally, the findings have implications for the ways in which institutions and the grain industry can promote risk efficient fertilization strategies in field crop production.

2.0 CONCEPTS AND DEFINITIONS

2.1 The Concept Of Risk

Whenever decisions must be made with less than perfect knowledge of the eventual outcome, uncertainty is considered to be present (Boehlje and Eidman, 1984:439). If the probability distribution of random outcomes is known, however, the producer can make decisions under conditions where the chance of particular outcomes can be estimated.

The distinction between risk and uncertainty is based on whether this probability distribution is known or not (Knight, 1921) and therefore, has to do with the degree of uncertainty about the outcome of a given situation. Roumasset (1984:5) notes, "... risk is a piece of information about a frequency distribution that, together with expected value, serves as an imperfect substitute for the density function in prescribing or explaining choice under uncertainty."

According to Knight's concepts of risk and uncertainty, most farm decision problems are made in a state of uncertainty for which his definitions do not provide a theory of risk-optimal behavior (Doll and Orazem, 1984:256). Nevertheless, the theoretical distinction between risk and uncertainty in agricultural decision making is no longer regarded as critical since decision theories have been developed which can deal with "... more general states of ambiguity" (Hazell and Norton, 1986:77), i.e., where the objective probabilities are unknown or unavailable.

2.1.1 Defining Risk

Attaching probabilities to potential future outcomes requires knowledge and estimation of the range and distribution of events about expected values. In terms of the N x crop yield interaction specifically, the degree of interaction directly determines the statistical characteristics of the crop yield population. In practise, estimation has proved to be a difficult problem since suitable data for objectively estimating income or yield distributions are seldom available.

2.1.1.1 Characterizing Yield Populations

As Hazell and Norton (1986:77) note, the distinction between risk and uncertainty "... is not particularly useful in farm planning since data for estimating income distributions are usually restricted to relatively small time-series samples, or to subjective anticipations held by farmers." Difficulties are also reported in finding "... an appropriate sequence of observations over a time span of sufficient length to indicate yield variability" (Anderson, 1973:77). Efforts have been made to develop risk decision approaches which can use minimal data for estimating probability distributions of crop yields (Anderson, 1973; 1974) but these should not be regarded as optimal approaches.

Yield distributions of field crops do not appear to be easily described in statistical terms either. Crop yield distributions change by crop and N rate. In probably the most intensive published study, Day (1965:733) noted that all field crop distributions of Mississippi corn, oats and cotton examined were non-normal while the degree of skewness (in either direction) and kurtosis depended on the specific crop and N rate.

For example, increased N reduced positive skewness of corn yields and increased negative skewness for oats. On the other hand, corn yield frequency distributions exhibited platokurtosis with higher N rate while oats indicated leptokurtosis (Day, 1965:724,735).

In general, "... yield and profit distributions deviate substantially from normality and, in particular, fertilizer is often a significant factor in explaining skewness" (Roumasset, 1979b:95). The evidence also indicates that crop distributions are generally unimodal with S-shaped cumulative density functions (CDFs; Anderson, 1974) but that modal estimates of yields may be better estimates of N application forecasting than averages (Day, 1965).

Explanations of why field crop yields tend to have skewed and/or non-normal dispersions about their means are hampered by a lack of adequate empirical evidence. The possibilities that underlying weather variables may be non-normally distributed or that plant growth may involve a non-linear transformation of stochastic inputs into yield have been suggested (Day, 1979:400). Clearly, the solution is to generate more analysis of data specifically tailored to the N x crop yield problem.

2.1.1.2 Objective Versus Subjective Probabilities

Probability distributions of observed crop yields are generally not considered to be "objective" probabilities for other reasons, as well. The complexity of expression of weather phenomena and the infinite number of expressions theoretically possible, makes the expectation of particular weather outcomes extremely low, so low as to prevent any realistic predictive application. In addition, the sample represented by historical weather records is useless in

predicting future weather patterns, which may be changing macro-climatically in a non-random fashion over time anyway.

Correspondence between specific weather variable manifestations and yield outcomes may be positive, in an econometric sense, but also extremely weak because of the roles and effects of numerous other random variables and due to the complexity of weather-plant interactions (Watt and Arthur, 1987). Thus, predicting yield based on the probabilities associated with the expression of single random inputs may be statistically hopeless and predicting yields by modelling numerous random inputs may be hopelessly complex. However, this cannot not discredit the argument that farmers might want or require such information, which they could blend with their management capabilities, local conditions, and intuition to make better production decisions.

Similarly, other agents which systematically alter probability distributions of crop yields include the introduction of new varieties which respond differently to similar climates than do older varieties and other evolving cultural and management practises. In this light, probabilities calculated from historical yield experience are plagued with variable identification and measurement problems and can only serve as proxies for the probabilities of future yield expectations.

In practise, farmers make decisions about risk and uncertainty factors interchangeably and simultaneously. Farmers' "personal", "degree of belief", or "subjective" probabilities associated with the chances of particular outcomes are routinely based upon a combination of limited data, perceived management capabilities and experience (Boehlje and Eidman, 1984:441). Thus, the traditional notion of probability as a "... (long-run) limit value of a frequency ratio .... based on the notion that physical processes will generate frequency ratios that converge on definite values ..." has been modified to reflect the more realistic situation where the farmer must make a decision when "... he lacks information about all the outcomes and has no empirical evidence that suggests the magnitude of objective probabilities" (Doll and Orazem, 1978:255-6).

The expected utility theory (von Neuman and Morgenstern, 1944) or Bernoullian decision theory has emerged as the most relied upon approach to handling decisions under uncertainty. Knight's risk definition in terms of objective probabilities is replaced with one based on the distribution of personal probabilities. That is, "Bernoullian decision theory or expected utility theory 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 consequences" (Dillon, 1979:23).

"For a decision maker whose preferences do not violate the axioms of ordering, continuity and independence, there exists a function U, called a utility function, (a) by which cardinal values can be assigned to possible outcomes and (b) whose expected value in terms of the decision maker's probability distribution of outcomes under each choice alternative gives a comparative measure of attractiveness consistent with the decision maker's preferences for each of the available choice alternatives under uncertainty. It follows that, given a set of alternatives under uncertainty, acceptance of the axioms logically implies the decision maker should choose the alternative that maximizes his expected utility" (Dillon, 1979:24).

Expected utility is a weighted average outcome which incorporates risk/uncertainty considerations in subjective probability distributions by reflecting individuals' utility valuations of alternative plans. "Whatever the source of uncertainty, an individual's beliefs about the consequences of a particular act are assumed to be summarized by his personal probabilities" (Roumasset, 1979b:94). Risk is defined as some characteristic of the distribution of personal probabilities.

2.1.1.3 Risk As Variance

Risk may be defined as some measure of the dispersion of potential outcomes about the mean. With this interpretation, the relative dispersion is measured in terms of one or more moments of the distribution to indicate the riskiness among options. Typically, higher values or indices indicating greater relative dispersion are considered higher risk. Decisions to minimize risk exposure would require choosing plans with lower variance.

2.1.1.4 Risk As Chance Of Loss

From the frequency distribution, the cumulative probability of possible outcomes above and below a desired level of net income can be estimated. The chance of loss definition of risk is a measure of the likelihood that returns will fall below a specified target. Lower (higher) cumulative probabilities of shortfall indicate lower (higher) risk.

2.1.1.5 Risk As A Measure Of Aversion

Utility theory is characterized by a decreasing marginal utility of income or a concave utility function for all positive values of wealth. As such, the decision maker is expected to act in a risk averse manner by definition and farmers would prefer plans with higher net income expectations to plans with lower net income expectations only if the marginal increments of income became progressively large enough to compensate for the diminishing marginal utility of income.

As noted earlier, in expected utility decision theory the decision maker is assumed to make consistent utility rankings of these alternative outcomes in a cardinal sense. This assumption has been contested on the grounds that alternative plans with different expected outcomes cannot be assessed for riskiness without knowing the decision maker's utility function (Rothchild and Stiglitz, 1970). Since marginal returns to factors of production typically decrease at higher levels of input, i.e., exhibit the law of diminishing returns, the definition of risk from risk aversion depends on quantifying the degree of risk aversion (knowing the shape of the utility function) and then matching it to the increasing riskiness of alternative plans.

2.1.2 Types of Risk and Interrelationships

This study investigates the effect and interaction of production risk on the optimal N rate strategy. In order to do this, the spectrum of risks facing the producer need to be identified and their importance and characteristics established. As well, "optimal" has no meaning in this context without an articulation of the risk and profit objectives of the farmer (see following section).

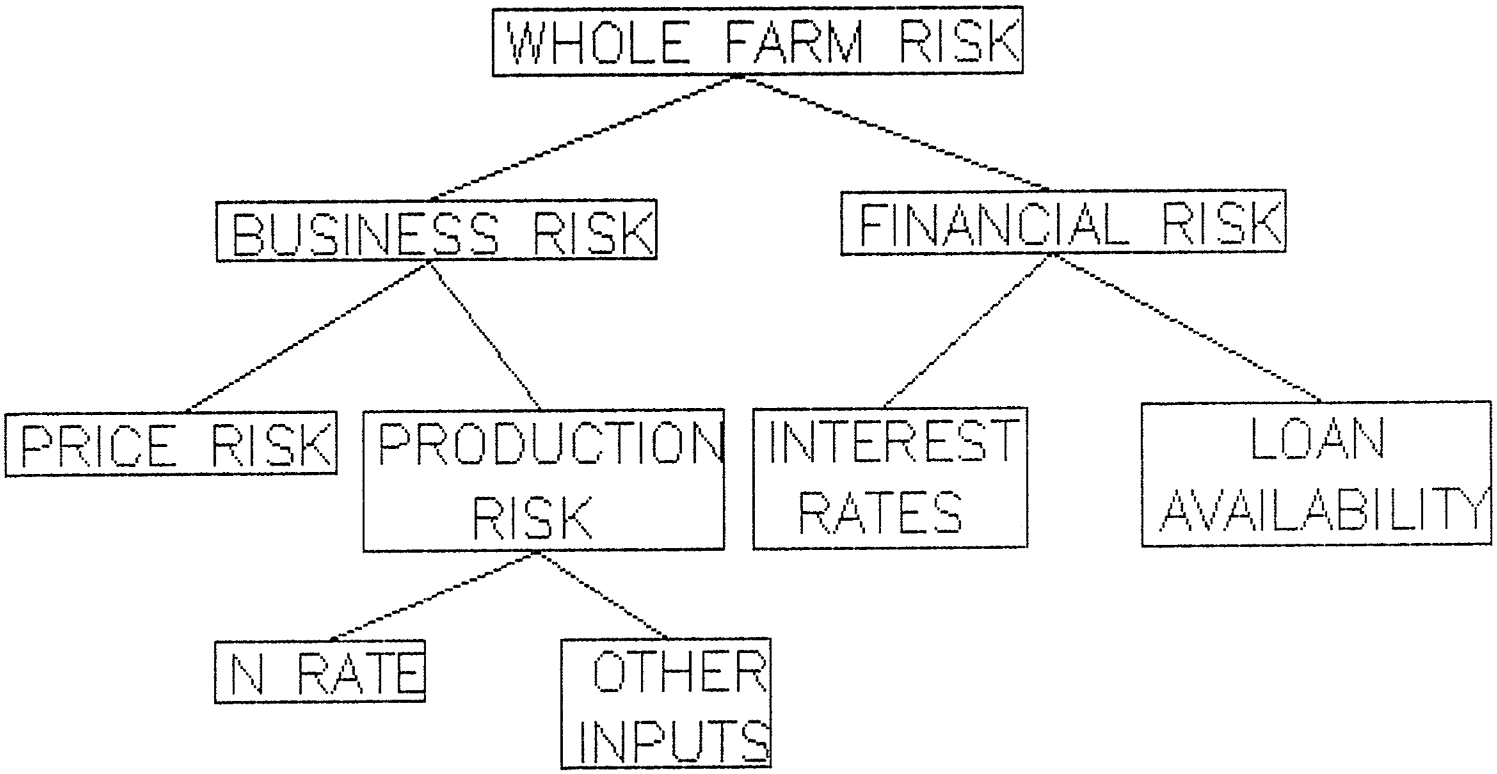
The risk terms may be organized into a risk taxonomy, as presented in Figure 1. In the conventional sense, two broad types of risk facing an enterprise are termed "financial" and "business", with the latter comprised of price risk and production risk. The composite expression of these risks has, for the purposes of this study, been termed "whole farm" risk.

2.1.2.1 Whole Farm Risk

While several factors simultaneously create risk for the farming operation, the focus of most risk decision modelling in the farm management literature has been at the whole farm level. Conventional techniques for managing whole farm risk directly are diversification and flexibility.

Diversification refers to the mixed selection of enterprises or cropping alternatives that are to some degree negatively correlated in terms of yield or pricing forces (Doll and

Figure 1: Types of risk (uncertainty) facing the farm operation.



Orazem, 1978:252). The whole farm risk objective is to maintain a greater degree of income stability by choosing negatively correlated production options in the overall farm plan, albeit with some loss of long-run income potential.

Flexibility, as a risk management response, refers to the ability of a farmer to shift cropping or enterprise plans in response to late developing yield or price changes (Heady, 1952). Interchangeability in commodities to be produced, equipment capable of versatile use and labor/equipment/capital substitutions in farm plans are generally how flexibility is accomplished. The effect of flexibility on whole farm risk is to facilitate shifts to lower risk production plans, but at a some loss in efficiency caused by the lack of production specialization.

In addition to the appeal of the techniques used to assess whole farm risk, there are other reasons for adopting the approach. First, the ultimate goal is to choose from farm plans that identify the risks associated with achieving acceptable levels of net income from alternative plans. The whole farm plan is the level of analysis which articulates risk in these terms.

Second, risk components of whole farm income risk (such as production, price and financial risk, below) all translate into income risk as a function of the yield, per unit value and borrowing related to producing the commodity for sale. Analysis of covariance relationships at the enterprise and cropping mix level, in particular, is a convenient application of mathematical properties of estimating functions (e.g. quadratic programming) which is considered "... fundamental for (identifying) efficient diversification among farm enterprises as a means of hedging against risk" (see Hazell and Norton, 1986:81).

2.1.2.2 Characteristics Of Production Risk

The production risk inherent in targeting specific yields varies as a function of the level of all inputs (controllable and uncontrollable) in the field and the costs of those inputs in relation to revenues expected to be generated (holding price constant). Production risk, therefore, is in part some measure of the uncertainty involved in targeting yield outcomes in the face of weather variables which randomly constrain the expression of yield potential.

Crop insurance clearly provides farmers with access to production risk sharing programs and has an influence on input decisions. The effect of a guaranteed minimum value of production is on level of production risk unless the insurance price exceeds the market price for the commodity insured. This has happened only rarely and unintentionally in the past.[1]

[1]For example, crop insurance commodity prices exceeded market prices for grains, such as wheat, in western Canada in 1986. This contradiction was inadvertently caused by the need to set insurance details without being able to anticipate the magnitude of the effects of European Economic Community and United States subsidy policies on world grain prices.

In terms of influence of crop insurance on the decision concerning level of inputs in crop production, the effect is complicated by the response of the producer to changes in risk. If crop insurance production guarantees are sufficient to offset the operating costs of production, then the production risk in recovering break-even yields is effectively zero. For those producers not able to recover costs of production from crop insurance coverage levels, the production at risk would be that portion of the yield distribution curve between the required yield and the insurance yield.

Clearly, the level of production risk would be reduced substantially by crop insurance and the production response could differ qualitatively from that observed with no crop insurance protection. For example, a producer would not be acting in a risk efficient manner were he to target a yield below his level of insurance coverage but could be managing risk exposure with the same production response if crop insurance were not accessed. Where crop insurance coverage is substantially below costs of production, risk exposure is less mitigable, but in the same manner as indicated above.

A recent study of the effect of crop insurance on farm financial risk in the U.S. suggests that the effect of insurance is by no means predetermined. Those farmers with high debt asset ratios may, in fact, be subject to increased risk with crop insurance if expected farm-level loss ratios are significantly less than 1.0 (see Skees and Nutt, 1988).

The effect of income stabilization programs, such as the Western Grain Stabilization

Program (WGSP), on production level decisions is similar to crop insurance, since depressed incomes relative to the average lead to payout by the program. However, the connection is less direct because the calculations for the payout are regional. This means that no payout may be forthcoming even when depressed production in localized areas is severe. On the other hand, when price prospects are severely depressed over a number of years, it is possible to predict that payout is forthcoming regardless of the level of production in the region.

As a result, it is clear that the WGSP influences the financial position of the farm firm, but not as apparent in regard to what the appropriate production decision should be. Since their is no relation between the size of the WGSP payment and current year costs of production, the amount of subsidization of current year production costs when payout is forthcoming is never known with accuracy. Under these circumstances, profit maximization options are likely determined by the large size of the payout but the risk exposure of a particular production decision is still determined by the production risk inherent in the output-variable input relationship. The risk orientation of the producer will determine whether he attempts to maximize his profit a priori, minimizes the risk of not recovering costs of production, or maximizes his chances for taking advantage of potential upward yield or price movements.

2.1.2.3 Characteristics Of Financial Risk

Financial risk refers to the added variability of net returns to owner's equity due to the financial obligations created by debt financing or leverage in the farm operation (Boehlje and Eidman, 1984:442). Important characteristics of financial risk are that it varies as a function of uncertain interest rates and availability of loan funds.

The role of financial risk on the level of N fertilization in the production decision would be most evident in terms of the availability of loan capital to finance the input decision, and the cost of that capital (interest). Farmers tend to negotiate operating loans on the basis of total loan requirements to follow a selected production plan thus, chances of being refused credit to implement an approved production plan are likely to be low in any one year. The fluctuating cost of borrowed capital for operating expenses may not be predictable, except that asset-rich farmers may be able to negotiate lower interest rates relative to more leveraged producers.

Adverse interest rate movements would increase the cash cost of production and, as such, might be expected to make the choice of the economic optimizing level of N fertilization more critical. The farmer who would maximize the potential net returns from N fertilization would be expected to best be able to withstand unanticipated additional demands on his gross margin.

2.1.2.4 Interrelationships Between Production And Financial Risk

A tendency in decision modelling of whole farm risk is to implicitly assume that the risk effects of production risk and financial risk are independent, or insignificantly correlated so as to produce negligible biases in identifying efficient whole farm plans. Moreover, the risk components are mostly considered to be additive or multiplicative or positively correlated to whole farm risk. That is, higher levels of production risk or financial risk are assumed, by specification, to create more whole farm risk. In this case, whole farm risk modelling is useful in estimating and comparing the absolute levels of risk exposure from competing farm plans.

Production risk and whole farm income risk are positively correlated from an absolute risk exposure perspective. That is, greater levels of production risk lead to numerically greater chances of unfavourable income outcomes for a given income target. However, yield expectations are created by the expression of random variables, such as weather factors, and non-random factors, such as N fertilization. Thus, targeting a higher yield as a function of random factors clearly increases the production risk while targeting a higher yield as a function of non-random factors may decrease or increase the production risk, depending on the input-output relationship. The combined result of these two production characteristics on whole farm income risk may not be readily apparent for specific inputs.

Changing the chances of attaining the expected yield by changing the level of inputs also affects the other risk components. Financial risk may be altered significantly by changes in the variability of yield response and increased capital requirements.

Financial risk associated with adverse interest rate movement is positively correlated with increased N fertilization. By adding to the variable costs of production, increased costs for capital would increase the absolute probability of not recovering those costs at any N rate. However, as indicated above, the chances of recovering specific costs of production at particular N rates are dependent on the variability characteristics of yield in relation to level of N fertilization. It is apparent therefore, that while the absolute level of financial risk increases with greater borrowed capital requirements, changes in the relative level of whole farm income risk as a function of increased financial risk are conditional on the characteristics of the N x yield frequency distribution.

2.1.3 Risk Attitudes

Implicit in decisions to manage risk exposure are attitudes toward bearing risk. Three general categories are commonly employed to describe the range of risk behavior, i.e. risk averse, risk neutral, and risk preferring. The risk behavior of farmers may change in response to market opportunities, weather pattern, financial position and personal objectives.

In terms of farm management strategies, the adoption of any particular risk attitude has implications for the yield targeting and hence, N-rate used in crop production. Probably more pertinently, the farmer must make an aggregate decision about "relative" risk taking by examining his chances of

(1) attaining target yields, and

(2) meeting the cash requirements of his enterprise.

Of the three types of risk attitudes a farmer might adopt, the risk preferring farmer is the least likely to utilize economic analyses which identify the probabilities of low yield outcomes. Similarly, this decision-maker may not even prefer economic options that maximize expected net returns but may strive for low probability yields which are associated with maximum possible net returns.

The risk neutral farmer is characterized as an individual who seeks to maximize expected returns regardless of the variance of possible deviations from expected. This farmer would be assisted with accurate information about average crop yields for given N-rates. A secure financial position of the farm enterprise and good price prospects might be expected to be correlated with a decision to pursue a risk neutral production strategy.

Finally, the risk averse farmer is the most cautious of the three types, seeking to minimize exposure to low income/loss events even though some profit potential may be foregone. This individual is most likely to utilize economic information about expected yield levels for given N-rates and the variance of alternative yields about the mean. With a depressed economic climate, irregular weather patterns and debt loads of a significant proportion, it is a risk attitude which could be prevalent among many current farmers, This suggests therefore, that a clear assessment of the interrelationship between production risk and financial cash requirements in making whole farm production decisions is most applicable at the present time.

"In general, farmers and other decision makers tend to exhibit more risk averse behavior when the financial consequences of an unfavourable outcome are very severe" (Boehlje and Eidman, 1984:444). The consequences of financial losses could very well lead to farm bankruptcy.

2.2 Characteristics Of Variables Producing Crop Yield

In this study, the number of variables considered may be reduced, since the objective is to analyze the nature of their effect not to model the crop production process. Essentially, three main types of factors determine the statistical characteristics and, hence, riskiness attributes of crop yield response to N fertilization. These have been termed random, controlled non-interactive and controlled interactive[2].

2.2.1 Random Versus Controlled Input Variables

Crop production occurs through the expression of numerous input variables which may be conveniently distinguished in terms of their 'random' and 'controlled' effects on crop yield. Most random inputs in physical crop production are uncontrollable in the sense that they are beyond the management capabilities of the farmer to alter. In

[2]This classification is borrowed from the approach of Doll and Orazem (1978), Chapter 8, pp. 237-247.

contrast, controlled inputs, such as fertilizer, pesticides and tillage, are applied at the time, level, rate that the farmer prescribes.

It is instructive to note that the effect of random inputs on the expression of controlled inputs is to create randomness. This means that net income as a function of controlled and random inputs is also random. In the present context, the task is to track the effect of a controlled input, N rate, on net income requirements in terms of the riskiness caused by the randomness of weather.

Random variables are numerically valued functions defined over a sample space (Mendenhall, 1979:96), i.e., the theoretical frequency distribution for the population of outcomes. Random variables exhibit a central tendency, in a statistical sense, about an expected value (a mathematical expectation). Importantly, the value of a random variable at any specific time cannot be predicted except in a probabilistic sense.

The major random variables affecting crop yields are weather related inputs, such as rain, temperature, wind, etc. For the purposes of this study, all these random variables and others are conceptually lumped into an aggregate, homogeneous, random input called weather, but could also be interpreted as a single influential input, such as rainfall.

2.2.2 Non-Interactive Versus Interactive Inputs

The concept of interaction in crop yield response refers to the presence of a marginal production relationship between two inputs which changes in a non-linear fashion with changes in the level of one input variable (see Figure 2). Thus, in the case of a controlled input, seeding rate, and a random variable, weather; there is no interaction if "total production increases with increases in the random input but the slope of the production function, measuring the marginal product of the controlled input, does not change" (Doll and Orazem, 1978:241).

The practical significance of a controlled non-interactive input (CNII) is in the manner in which the management decision is made respecting its use. Essentially, the optimal decision about level of CNII does not change with changes in the random variable.

As an example, seeding rate of wheat may be considered a CNII since seeding rates can vary over quite wide ranges without affecting yields, mainly because of the ability of plants to adjust tillering to variable growing conditions (Saskatchewan Agriculture, 1984:81). Farmers who do vary their seeding rates may do so to decrease weed competition, compensate for soil or seeding conditions or seed size/quality but generally not because of an interactive relationship between seeding rate and weather.[3]

[3]However, Doll's (1972:228) observations that a "... wide range of nitrogen and plant population combinations can be used to achieve about the same average profit" may suggest an interaction between seeding rate and weather for corn.

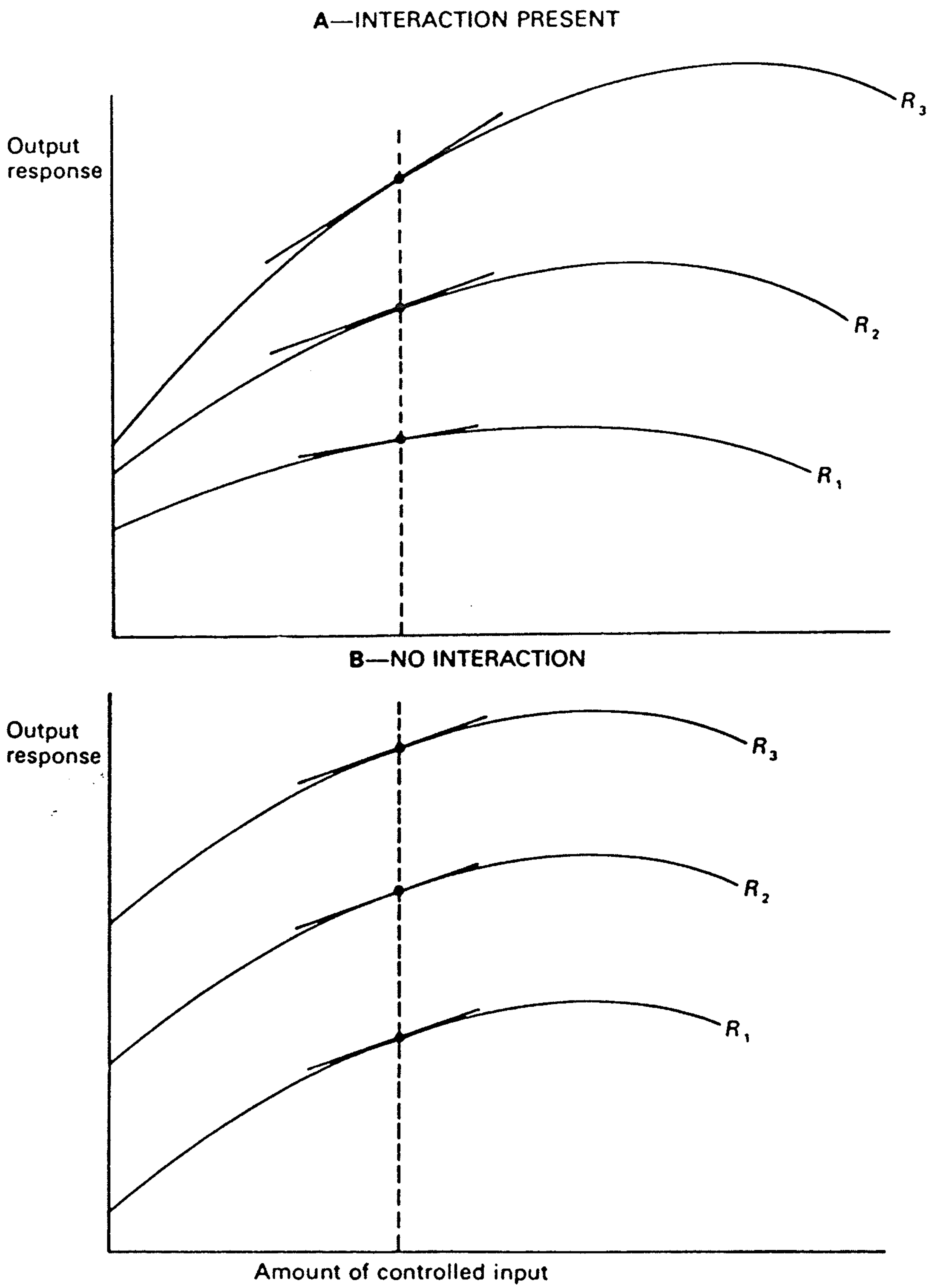


Figure 2: Comparison of input - output relationships as a function of interaction between random and controlled inputs (Source: Doll and Orazem, 1978:242).

With interaction, "Changes in the random input change not only the amount of yield resulting from a given amount of controlled input but also the marginal product or slope of the production function" (Doll and Orazem, 1978:241). In other words, the yield per unit of controlled input is higher as level of random input becomes more favourable. This is illustrated graphically in Figure 2.

Nitrogen fertilization and weather (in particular, rainfall) interact in the production process. The management implication is that the profit maximizing decision about N rate changes with level of expression of the random input, weather. And the efficient N rate, by association, is a random variable since the effect of the action of a random variable on a controlled variable is to make the outcome random.

In addition to the randomness of the N rate response, interaction attributes certain frequency distribution characteristics to the crop yield population. As shown in Figure 3, the absolute dispersion of crop yields is expected to increase as a function of the effect of the interactive variable, N rate.

2.2.3 Definition Of A Risk Increasing Input

Once dispersion of crop yields in relation to controlled interactive inputs is expressed in terms of moments about the mean, expectations of realizing specific yield or income targets can be expressed in a probabilistic sense. In this

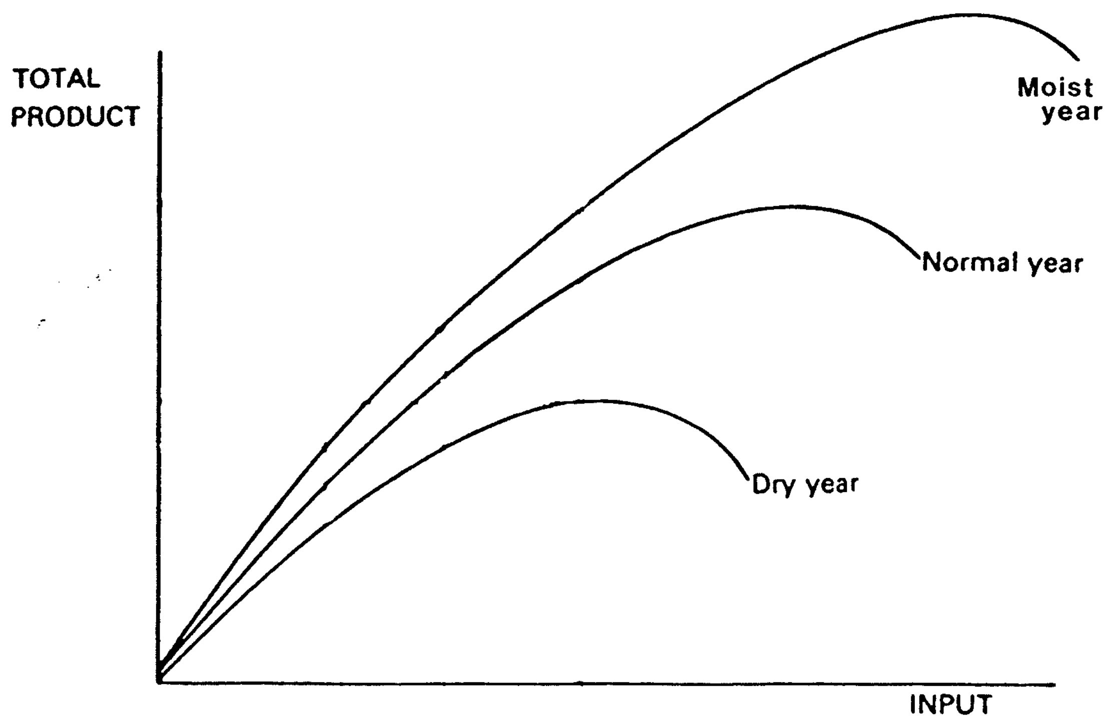


Figure 3: Typical yield x N rate interaction for field crops as a function of weather.

investigation, the effect of other controlled interactive inputs will be held constant to illustrate the pattern effect of N fertilization on the risk decision.

One appropriate statistic for assessing changes in the probability of attaining yield targets is the coefficient of variation (CV).[4] The CV is useful as a measure of the relative dispersion of frequency distributions with different means. In cases where the CVs of two populations are identical, the probabilities of outcomes within identical standard units from the mean are also identical.

An input which causes the CV of yield to increase continuously as the level of input increases may accordingly be described as risk increasing. Since CV is determined by the ratio of the standard deviation (SD) to the mean (Y), it is possible for the SD to increase absolutely without changing CV if Y also changes proportionately. Increases in variance or standard deviation do not automatically indicate whether the CV measure of relative dispersion is increasing, decreasing or constant (see Table 1, below).

Thus, in order for a N input to be risk increasing, SD needs to increase more rapidly than Y. That is, a risk increasing input is characterized by proportionately larger changes in the marginal variance than changes in the marginal expected value. Roumasset (1974:258), after Diamond and Stiglitz (1974), notes "... risk is what increases when a frequency distribution is changed by a 'mean-preserving spread' (i.e.

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[4]The coefficient of variation (cv) is defined as the standard deviation, divided by the mean, and multiplied by 100.

'a change in the distribution of a random variable which keeps its mean constant and represents the movement of probability density from the center to the tails of the distribution')."

Risk increasing in terms of whole farm risk depends critically on the definition of the components used to determine net income. The costs which stem directly from crop production, and may be used to target yields in relation to production risk, change with increasing N fertilization.

If additional costs need to be recovered from crop production to maintain the viability of the farming operation, such as interest on debt, taxes, credit repayment and living expenses, inclusion of these costs will increase the level of returns required and change the probability of expecting them. Thus, a practical measure of risk increasing in terms of whole farm risk would track the marginal changes in probability of attaining specific net income (yield) targets, with increasing N fertilization, in relation to marginal changes in the costs of production.

Table 1

Coefficients of variation (CVs) and standard deviations (SDs) associated with assumptions of increasing CV, constant CV and decreasing CV of yield distributions as N rate is increased (a).

N Rate	Expected Yield	Increasing CV		Constant CV		Decreasing	
		CV	SD	CV	SD	CV	SD
(Lbs/Ac)				(Bu/Ac)			
0	29.8	31.3	9.33	31.3	9.33	31.3	9.33
10	32.2	32.9	10.59	31.3	10.08	29.7	9.56
20	34.2	34.5	11.97	31.3	10.70	28.2	9.64
30	36.1	36.2	13.07	31.3	11.30	26.8	9.67
40	37.8	38.0	14.36	31.3	11.83	25.5	9.64
50	39.1	39.9	15.60	31.3	12.24	24.2	9.46
60	40.2	41.9	16.84	31.3	12.58	23.0	9.25
70	41.0	44.0	18.04	31.3	12.83	21.9	8.98
80	41.6	46.2	19.22	31.3	13.02	20.8	8.65
90	42.1	48.6	20.46	31.3	13.18	19.7	8.29
100	42.5	51.0	21.68	31.3	13.30	18.7	7.95
110	42.8	53.5	22.90	31.3	13.40	17.8	7.62
120	43.0	56.2	24.17	31.3	13.46	16.9	7.27

(a) Rates of increasing CV and decreasing CV are arbitrarily set at +5% and -5% per 10 lb. increment of N, respectively.

3.0 OPERATIONALIZING PRODUCTION RISK

The incorporation of risk in production decision making requires techniques to identify plans or outcomes which best meet the decision maker's objectives. Given the definitions of risk in subsection 2.1 above, several modelling approaches have been developed which correspond to these various formulations. Each has unique assumptions about the objective(s) of the decision maker, measurement and ranking of options, and attitudes toward risk and profit.

Roumasset (1979a:5) argues that the most appropriate measure of risk should evolve out of an understanding of what kind of information would be most useful in choosing between alternatives. Would it be helpful to know the probability that returns would be lower than some critical level for yield distributions at various N rates? Does a farmer require a body of information indicating the exact probabilities of loss implications of alternate production decisions, or an optimizing decision rule to enable him to select the most "efficient" strategy, or an explanation of the pattern of relationship between the variables involved so that he can identify his own "optimal" choice?

With these considerations in mind, the modelling undertaken by various researchers to operationalize risk is reviewed and an appropriate approach identified for the problem at hand in Section 4.

3.1 Methodological Background

Early developments in risk decision modelling have had a large part to play in determining the manner in which risk has been operationalized. First, Bernoullian utility theory, while sparking theoretical life into the possibility of using non-empirically generated frequency distributions in risk analysis under uncertainty, created operational nightmares for researchers wishing to validate their results through observations in the field. It also spawned attempts to identify risk explicitly rather than implicitly and in terms of decision process itself to account for the gaps between predicted and observed behavior. As a result, efforts to validate measures of risk exposure, risk preferences and risk attitudes have been more advanced than efforts to provide risk management tools to the farmer in the field.

Second, the extension of profit maximization techniques to utility maximization approaches in determining the efficient use of resource inputs in the production process has had the effect of promoting the treatment of risk implicitly in farm plan selection. As more explicit definitions and measures of risk have been generated, more sophisticated and computerized approaches have been applied to more encompassing risk issues while the earlier maximization techniques have tended to be retained for production input analysis.

Third, initial application of risk decision techniques stemmed from linear programming

(LP) modelling of optimal stock portfolio selection by Markowitz (1952), which optimized a weighted sum of expectation and variance based on a variance (risk aversion) parameter in the objective function. Subsequent application to agricultural decision problems also tended to focus on selections of crop/enterprise mixes which were capable of generating target levels of expected income at minimum risk. Moreover, a high priority in these approaches was to devise decision rules which produced holistic farm plans similar to those observed in the field.

Consequently, the specification of these models assumed average yield/variance expectations from alternate crops and enterprises to identify the optimal farm plan. Most importantly, the decision focus was on crop/enterprise selection to manage overall risk exposure, not on the contribution of variable levels of production inputs to individual crop or enterprise risk.

Selection of rate of N fertilization is considered a relatively simple exercise in the overall scheme of farm management. Typically, field crop farmers may consider the effect of varying the rate of N fertilization on income expectation when developing their farm plans. However, once cropping plans have been made, the role of variable levels of N fertilization is seldom re-examined in terms of its effect on other objectives of the farmer, such as those related to whole farm risk. The 'correct' N rate fertilizer decision has not been considered critical in farm risk strategies, even though the advice offered to farmers is characteristically normative, i.e. the recommendations are expected to indicate what should be done.

most appropriate for N rate risk decision modelling. The single attribute formulation consists of modelling of decisions under risk of the (k=1,t=1) type, i.e., where k = # of arguments, t = # of time periods. As such, the sophistication of this level of modelling is low compared to some of the more advanced models developed for predictive and analytical purposes (see Anderson, 1979:60). The models incorporating production risk (to varying degrees) are maximization approaches, differing in their measurement of risk and on what is being maximized.

3.2 Modelling Approaches Which Treat Production Risk Implicitly

The employment of maximization approaches to identify the optimal N rate in field crop production is common. Yet, the most popular decision models in this class do not recommend N fertilization strategies in explicit consideration of the interrelationships of production risk with other risks facing the farming operation.

3.2.1 Simple Profit Maximization

Probably the most naive approach to operationalizing risk in farm decisions is targeting the average outcome and interpreting risk as a measure of the probability of attaining the most likely outcome. In the simple profit maximization approach (such as used by MPSTL to recommend crop yield response to N), the average yield expectation is assumed to be the most likely. Thus, the average would be the lowest risk event and the selection of targets other than the average would be regarded as higher risk decisions.

This inference is correct only when the frequency distribution of the variable under consideration is symmetric about the mean, such as in the classic 'normal' distribution. If yield distributions are skewed about the mean, the average is no more than a measure of central tendency and does not identify a consistent ordinate probability attribute of the frequency distribution.

Limited data on crop yields indicate that the frequency distributions are skewed (Day, 1965) and therefore, that the simple average is not an accurate measure of even this unsophisticated risk indicator. Moreover, in his study of cotton, corn and oats yield distributions, Day found evidence of "... an interaction .... between the shape of the yield probability function and the amount of nitrogen applied to the given crop" (Day, 1967:713). In terms of uncertainty considerations, the simple profit maximizing approach does not consider variability characteristics which create risk. Thus, it is unable to rank plans with respect to risk exposure or select targets which are, in fact, most likely in non-normal frequency distributions.

3.2.2 Expected Profit As A Measure Of Risk

A modification to the simple profit maximization approach is the expected profit maximization approach, in which probabilities of specific yield or revenue outcomes are used to generate weighted expected values of profit. Although this approach uses yield distributions in its decision framework, the decision maker is assumed to be "risk neutral', i.e. orders preferences based only on expected profit.

Note that the expected profit maximization approach will use information on skew of yield distributions, i.e. where the mean and mode (most likely outcome) are different values, into account in the calculations by generating a weighted expectation of profit. However, this type of risk measure is not capable of identifying risk-efficient decisions from among farm plans with different frequency distributions and identical profit potentials.

3.2.3 Simple And Expected Utility In Measuring Risk

Utility maximizing approaches use the same approach as profit maximizing approaches except for the important difference that the assessments of yields or income expectations are generated by the farmer 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 consequences" (Dillon, 1979:24). Bayes' theorem may be used to modify prior probabilities by incorporating empirical data or forecast information, thereby generating posterior probabilities which are consistent with expected utility theory.

As discussed in subsection 2.1.1.2, above, production risk is assumed to be implicitly taken into account in the decision maker's valuations of outcomes and likelihoods.

Clearly, since individual expectations can be significantly affected by variations in soil type, level of management and technological uptake, utility maximization approaches using farmers' own yield expectations to predict input decisions have considerable support (Sriramaratnam et al., 1987:349). The approach however, suffers from difficulties in eliciting subjective probabilities and appropriate utility functions (if they exist), due to both interviewer and respondent bias, problems in having decision makers think in terms of probabilities and the concept of utility maximization with respect to wealth or money.

Most problematic, ranking farm plans on the basis of utility parameters assumes that farmers can consistently order utility preferences for yields at different N rates with changing ranges and distributional characteristics. And if these utilities are highly individualistic or fluctuate widely from one time period to another, modelling of risk decisions may provide little assistance in making production decisions at specific points in time.

A recent study of Texas grain sorghum producers indicates that actual fertilizer use was better described by expected utility than expected profit. However, although the difference in average optimal levels was small, both calculated maximizing levels were high compared to actual fertilizer use (SriRamaratnam et al., 1987:356).

Similar results have been obtained from a sample of Californian farmers in which neither profit or utility maximizing models predicted actual behavior well, "... with a strong tendency for ... models to predict more risky behavior than was in fact observed" (Lin et al, 1974:507). The applicability of the approach to the N fertilization decision in Manitoba has not been tested.

In addition to conceptual problems related to the treatment of risk considerations, utility maximizing approaches have fallen into disfavour for several reasons. First, as risk decision aids, they have not tended to predict accurately farming decisions actually made by farmers (Doll and Orazem, 1978:265). Second, breakthroughs in understanding farmers' probability perceptions, utility functions and behavior under uncertainty have not occurred. As a result, a debate continues about whether deviations in farm plans from maximizing optima are due to problems in operationalizing concepts or due to model misspecification (see Roumasset, 1979a:13ff; Dillon, 1979). Finally, more advanced techniques have been developed which treat risk and risk preferences explicitly in model formulations (see reviews in Anderson, 1979; Hazell and Norton, 1986:76-111).

3.3 Models Using Explicit Measures Of Production Risk

What may be noticed about the models presented above is that the implicit treatment of production risk in the optimizing criterion is also assumed to provide the risk optimal whole farm solution. That is, the correlation between production and whole farm risk is considered positive and equal to one. Reductions (increases) in production risk are assumed to automatically reduce (increase) whole farm risk.

Models that use risk measures have the capability of explicitly addressing the validity of this one-to-one correspondence between production and whole farm risk. In particular, these approaches are desirable and necessary if they allow evaluation of the relationship between yield risk and whole farm income risk. However, employing these models is accompanied by a number of measurement, data adequacy, conceptual and theoretical problems.

Explicit measures of risk in decision models inherently embody assumptions about farmers' risk attitudes and risk preferences. Making assumptions to calibrate risk attitudes and preferences in modelling the decision process is called a "behavioral" approach because the assumptions are intended to be based on practical decision rules which may limit the feasibility of some plans (known as the principle of bounded rationality). This is in contrast with profit and utility maximization approaches (above) which do not pretend to represent the decision process itself and identify full optimality solutions under conditions of unconstrained rationality (see Roumasset, 1979a:6 for discussion).

The concepts of 'risk attitude' and 'risk preference' are often used interchangeably in the literature in reference to methods and/or techniques to identify optimal farm plans. In this study, the two terms are kept distinct since they tend to apply to different stages (but not necessarily sequential) or facets of the risk decision process.

3.3.1 Operationalizing Risk Attitudes

Risk attitude is defined here as the orientation of the decision maker with respect to risk exposure. Using the conventional classification (section 2.3, above), a farmer may be risk averse, risk neutral or risk preferring. The question of what farmers risk attitudes really are has been gauged mainly by attempts to represent farmers' actions in the field.

In general, the argument for assuming underlying risk aversion characteristics of farmers is based on research in the field and an appeal to the logic of "... if it's not risk aversion, what is it?" to explain the tendency for utility and profit maximization approaches to overestimate farmers' production responses. As Hazell and Norton (19-86:76) state, "Numerous empirical studies have demonstrated that farmers typically behave in risk averse ways." (or alternatively) "Ignoring risk-averse behavior in farm planning models often leads to results that are unacceptable to the farmer, or that bear little relation to the decisions he actually makes."

Applied to the production risk problem, the objective of targeting a level of risk exposure in striving for any particular level of expected yield outcome appears reasonable. There are two ways in which the risk attitude parameter can be operationalized. First, empirical studies have attempted to derive actual values of farmers' risk aversion parameters through direct elicitation (e.g. Dillon and Scandizzo, 1978) and by imputing values in decision models which generate the patterns of observed risk behavior. A popular way of characterizing the risk aversion parameter is in terms of the probabilities of outcomes at selected standard measures of deviation from (usually below) the mean. The values that have been obtained empirically tend to support the notion of varying degrees of risk aversion but some work suggests that risk preferences are not important (see Hazell and Norton 1986:93 for discussion).

From a interpretive perspective, if a specific risk aversion parameter can be derived to calibrate risk attitude, the effect is to identify as risk efficient all plans that meet the parameter criterion. However, risk aversion parameters (like utility functions) do not appear predictable and may change at different levels of expected income. They are considered most efficient when the risk is small relative to the farmer's wealth, are affected in unknown ways by risk reducing agents such as crop insurance and are critically dependent on the specification of the decision model (Hazell and Norton, 1986:93).

The second approach to calibrating risk attitude is to assume absolute risk aversion by the decision makers. Thus, instead of specifying a specific risk aversion parameter, the decision modelling targets the lowest risk plan for different levels of targeted income (yield), thereby narrowing down the range of possible options into a risk efficient set. This has conventionally meant adopting a definition of risk as variance or as probability of loss in relation to an income objective.

The risk efficient set, defined in terms of income or yield variance and assuming absolute risk aversion, is identified by mathematical arguments of the following type: Minimize variance for each possible level of expected income while retaining feasibility with respect to the available resource constraints (Hazell and Norton, 1986:81). Using the probability of loss criterion, the risk efficient set is defined as those plans which attain various income objectives with the minimum chance of adverse (below-target) outcome.

3.3.2 Operationalizing Risk Preferences

The farmer's risk preference, as defined here, depends on the shape of his utility function in relation to the set of feasible options. Essentially, identification of risk preference makes possible the selection of the risk optimal farm plan from the risk efficient set.

3.3.2.1 Measuring Utility

Efforts to measure farmers' utility functions of money/ wealth are recognized to be plagued with problems related to elicitation, measurement and continuity. Utility curves are expected to be irregular shaped and/or kinked, exhibit highly individualistic characteristics, and intertemporal inconsistency (Roumasset, 1979a).

Similarly, an optimal production plan may be selected from a risk efficient set generated by numerical risk aversion parameters if the decision makers' utility function can be estimated. Here, researchers may assume that the plan with highest income maximizes utility since the risk aversion parameter already acts as a measure of the decision maker's utility function.

An alternative formulation of this approach is to apply the risk aversion parameter directly to a set of risk efficient plans which minimize absolute variance at various expected income levels. In this case, the elicitation of a utility ranking of candidate plans is necessary to identify the risk optimal strategy and more recognizable as the traditional trade-off required between levels of expected income and risk exposure.

Measured utility functions and optimal decision-model solutions may be substantially less important at the farmer's decision making level. Paradoxically, although utility is only measurable at the individual farmer level, generalized utility functions based on group data are likely to be inappropriate for most decision makers. Some researchers recognize the practical value of "... obtaining the set of efficient farm plans and allowing the farmer to make the final choice" (Hazell and Norton, 1986:81) and the need to identify "... 'risk-efficient' actions (fertilizer rates), in contrast to 'risk-optimal' actions which depend on particular (and individual) preferences" (Anderson, 1974:569).

3.3.2.2 Formulating Decision Rules

Modelling of risk-optimal decisions using maximization techniques has been pursued through development of decision rules which attempt to replicate the decision making process. The main types of arguments modeled which have direct applicability to the production risk decision include the following:

1. minimizing (maximizing) the probability that net income falls below (above) a pre-specified "disaster" level.

2. maximizing expected net income subject to a pre-specified chance of adverse outcome.

There are a number of practical and theoretical problems associated with the use of these techniques. First, for any particular formulation, there is the possibility that no feasible solution exists, making the selection of proper maximizing technique crucial to generating a decision but open to criticism that the optimal solution is manufactured. Second, these decision rules imply positive utility for values above the threshold, target or break-even level of income and zero for those outcomes which fall below (Anderson, 1979:47). It is unusual, to say the least, to expect to find this utility characteristic occurring about arbitrarily defined thresholds of perceptions of outcomes or negative net incomes.

Third, the generality of the solutions obtained from the decision rules can be suspect. For instance, one decision maker might be willing to accept a higher risk for the same disaster level than another. Alternatively, the disaster level for different decision makers may be different for the same level of risk exposure. In this context, it is difficult to attribute risk optimality to a decision rule if it does identify optimal decisions for all producers consistently.

3.3.3 Expected Income-Variance (E,V) Models

The ancestor of risk programming approaches is the E,V model, with "... the longest history of both theoretical argument and empirical application" (Anderson, 1979:54). Despite this, the selection of single attribute models that can incorporate measures of risk in the production decision related to N fertilization is limited and does not include the E,V approach.

The E,V and E,S (below) models have their advantages in that "... they take explicit account of the covariance relations between activity gross margins" (Hazell and Norton, 1986:99). This indicates, probably more than anything else, that the advancement in techniques of production risk decision making has suffered from the preoccupation of researchers with more sophisticated modelling approaches concerned primarily with the concepts of whole farm risk management.

Operationalizing risk in terms of E,V modelling assumes that a farmer's objective is to select from risk efficient plans that exhibit the lowest income variance associated with different target levels of expected income. The optimal plan is selected on the basis of the individual decision maker's risk preference (utility function). If a direct correlation is made between income and yield, the decision process distils into one where the production plan exhibiting the smallest absolute variance at the target yield where utility is maximized is the preferred option.

Unfortunately, the E,V criterion cannot be applied to the N rate fertilization decision to identify risk efficiency. Although there is first, a set of plans with different yield outcomes and second, a set of variances associated with each, each fertilization plan has a different expectation of yield and there is only one fertilization plan at each expectation level. Nevertheless, this has not deterred some agricultural experts from suggesting in the past that it might be more feasible to strive for an above-expected yield outcome at a low N rate rather than an expected outcome at a higher N rate. Obviously, that variety of risk recommendation violates the efficiency criteria used in E,V modelling, i.e., that "... the farmer should rationally restrict his choice to those farm plans for which the associated income variances are minimum for given expected income levels" (Hazell and Norton, 1986:78).

There are conceptual problems associated with the use of E,V models related to its association with a quadratic utility function for income (i.e. increasing absolute risk aversion) and the normality assumption about the shape of the frequency distribution. With regard to the former, the specification of a farmers' utility function as quadratic mathematically translates into a decision rule based solely on expected income and income variance, and characterized by having a point at which the marginal utility of income turns negative (see Hazell and Norton, 1986:81 for details).

With regard to the latter, the use of variance as the measure of risk (i.e. implied normality assumptions) results in imposed symmetrical treatment of dispersions above and below the mean. As Boussard (1979:67) notes, "... decision makers may be risk averse, but not windfall profit averse."

Use of semivariance (E,SV modelling) as a risk measure identifies the risk efficient set by the size of squared deviations below the mean. This formulation makes intuitive and practical sense when the characteristics of the frequency distribution which cause risk are also found in the lower tails. As will be detailed later however, the upper tail of the yield or net income distributions can also be important to the assessment of risk at different N rates.

Semivariance approaches suffer from the same analytical limitations caused by the absence of reliable statistical data as E,V modelling. For this reason, the Chebychev inequality has been employed in E,V and E,SV approaches. This theorem establishes the 'at least' fraction, or minimum percent, of observations that will lie within 'k' standard deviations of a mean of any distribution of measurements (Mendenhall, 1979:47). Thus, based on only knowledge of a finite variance and mean, the upper limit on the probability of an outcome 'k' standard deviations about (E,V) or below (E,SV) the mean can be calculated (Berck and Hihn, 1982:298).

The main drawbacks to using the Chebychev theorem are in relating the arbitrary and inflexible calibration of probability prescribed by the theorem (i.e. multiples of the standard deviation) to meaningful risk decisions and in comparing plans with probabilities that are intermediate between 'k' units from the mean. Nevertheless, application of the theorem within the E,SV context is indicated to provide better probability estimates of outcomes at 'k' intervals than variance alone, particularly when the assumption of normality is tenuous. Berck and Hihn (1982:299) conclude that "Day's conclusion that 'decisions for maximizing profit or minimizing risk must be based not only on expected yields and variance but upon skewness as well' .... can be restated as: risk-minimizing decisions should not be based on mean and variance but, rather, on mean and semivariance."

3.3.4 The Mean-Standard Deviation (E,S) Model

The E,V model is ancestral to models that can be applied to the production risk decision. In particular, when variance in an E,V efficient set is replaced by the standard deviation, the set of risk efficient farm plans of E,V and E,S models are identical (Hazell and Norton, 1986:90).

The two models differ in terms of the decision rule invoked to identify risk optimal outcomes, with the E,S approach couched in terms of the probability characteristics of the lower tail of the yield distribution. The two main adaptations of E,S modelling which lead to identical solutions are:

1. maximize expected income for a pre-specified level of risk exposure associated with a given percentile of that income. The percentile is determined by estimating a risk aversion parameter.

2. maximize the value of a percentile of expected income for a pre-specified risk aversion parameter (level of risk exposure).

The E,S approach is least subject to criticism where the frequency distributions can be assumed normal and therefore, completely characterized by the first two moments, mean and variance/standard deviation. The main problem is in developing the rationale for applying a specific risk aversion parameter to the decision process used by a specific decision maker, since the value of the parameter ultimately determines the level of targeted production.

The practicality of E,S modelling for the N fertilization decision is evident only if the probability of attaining some percentile of expected income (yield) has relevance to the decision process used by the decision maker. However, in terms of recent Manitoba fertilization decisions, a focus on optimizing the probability of attaining a low percentile of expected incomes might not be expected to be particularly useful unless minimum returns required from production investment are also covered.

Moreover, the farmer is not provided with explicit information on how to relate yield risk to whole farm income risk in optimizing according to E,S decision rules.

3.3.5 Safety First Modelling

"The safety first principle involves minimizing the probability that some attribute, usually profit, falls below a specified "disaster" level ..." (Anderson, 1979:47). In a production decision context, safety first approaches can focus on the security concerns of farmers to maximize chances of achieving critical levels of returns from targeted levels of production. Moreover, the decision framework lends itself to being able to specify a whole farm level of income probability in the context of a N rate production response.

Hazell and Norton (1986:100) indicate that "safety first models are most appropriate where the risk of catastrophe is large, either because of an inherently risky environment, or because the farmer is poor and has minimal reserves to fall back on in a bad year." In other words, the farmer might be expected to act in a safety first manner when the probability of suffering a loss is significant or his ability to survive without meeting certain cost recovery targets is in question. These concerns appear to describe closely the primary context of N rate decisions made by Manitoba farmers recently (Zbeetnoff and Josephson, 1988a; Zbeetnoff, 1989).

Safety first modelling of the N rate fertilization decision may be approached in two general ways, which differ in terms of their reliance on probabilistic characteristics of the income (or yield) population. One approach (Roy, 1952) uses statistical measures to develop the probability estimates of the likelihoods of outcomes. Roy's safety first criterion appears particularly suited to the N fertilization decision since the decision rule is based on the desire to select a farm plan that minimizes the probability that (net) income falls below a critical level.

The biggest difficulty in using this approach is in choosing or estimating the statistical characteristics of the population. In the absence of good reliable yield x N rate data, normally distributed populations of income or yield are generally assumed in spite of indicators to the contrary (as discussed earlier). When normality is assumed, the risk efficient set from which Roy's risk optimal solution is selected is found in the efficient E,V set of farm plans (Hazell and Norton, 1986:100).

The second approach, because statistical data on yield and income often can be unreliable, uses a focus-loss concept (Boussard and Petit, 1967) which hypothesizes that farmers maximize expected net income subject to the possibility (as opposed to probability) of being "very surprised" to realize a "ruin" level of income. Since, as Boussard and Petit (1967:873) note, "... there is no evidence that farmers' expectations result from probability estimations", they assume that farmers' behavior under uncertainty is to keep the possibility of realizing a "ruin" level of income so small that it can be neglected.[5] Accordingly, the decision framework is intended to place the attention of the decision maker "... on the risk taken rather than on possible gains" (Boussard and Petit, 1967:871).

Operationalization of the focus-loss approach requires measures of "ruin" and "negligible possibility of ruin." Boussard and Petit (1967) present an attractive definition of "ruin" which includes both fixed and variable "unavoidable" costs of

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[5]Boussard and Petit indicate that their approach is lexicographic, i.e., first meet the safety first constraint then maximize expected income. Lexicographic preference ordering assumes that the decision maker "... first screens out all acts which are not viable in the sense of satisfying the risk constraint and then uses the criterion of expected profits to choose the best of the viable acts" (Roumasset, 1979b:99).

production. "Negligible possibility of ruin" is defined in relation to a concept of focus-loss level of income which a farmer would be "very surprised" to experience.

There are problems with applying this approach to determining a risk optimal N rate. First, whether there is a "negligible possibility of ruin" level of N use depends critically on crop prices relative to costs of production, risk attitudes of farmers and the risk characteristics of N fertilization. If "substantial" possibilities of ruin need to be risked, e.g. among highly leveraged farmers in the current economic climate, the definition of the focus-loss is critical and may not be sufficient to offset "ruin" levels of costs.

Efforts to derive a relative focus-loss measure of income from historical data or experts, e.g., a minimum net income experienced once in ten years, are susceptible to sampling error, challenges of relevance, trend effects. This suggests that other risk decision approaches might be more appropriate.

Second, the modeller could identify N rates which came closest to the focus-loss criterion, i.e. plans that violate the risk constraints the least. In this case, if there is a problem with the focus-loss concept, it is even more doubtful if farmers make N rate decisions by focusing on the degree of violation of unattainable ideal levels of risk exposure.

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4.0 SELECTION OF AN APPROPRIATE RISK MODEL

The conclusions from the previous chapter are an appropriate springboard for investigating risk decision modelling of N application rate in Manitoba. It is noted that, in

Manitoba, consideration of production risk by soil testing laboratories occurs by means of application of the simple profit maximization approach. This approach has been demonstrated to be conceptually inadequate for expressing production risk and a poor method of characterizing the N rate question in the whole farm risk decision.

4.1 Specification Of A Risk Attitude

The discussion of explicit risk measures and models reveals that modern approaches assume risk aversion on the part of the decision maker (Dillon, 1979:25). This assumption has been pivotal in defining the concepts of risk efficiency and risk optimality. In fact, "The question of the risk aversion coefficient is so important that one could not imagine building a model of behavior under risk without considering risk explicitly in the model" (Boussard, 1979:83). Field studies in developing countries also indicate that farmers exhibit varying degrees of risk aversion in their farming decisions (e.g Binswanger, 1980; Dillon and Scandizzo, 1978).

4.2 Risk Efficiency Versus Risk Optimality

Having encountered so many theoretical and practical obstructions to the objective of generating the risk optimal solution, it is important to re-emphasize the distinction between risk efficiency and risk optimality. The identification of risk efficient plans requires a frequency distribution and a definition of risk attitude in relation to expected income and some dispersion measure. Risk optimality involves the application of a measure or indicator of the decision makers' risk preference to the risk efficient set. As Anderson (1974:571) concludes, "To the extent that relevant probability distributions can be specified, analysis of risky decisions confronting farmers can proceed a fair way without assuming anything very controversial about their attitudes toward risk." Risk efficient plans should be available to farmers even if sophisticated decision models cannot predict which plans they may pick.

4.3 Choosing A Suitable Definition Of Risk

The choice of an appropriate risk definition discussed in Section 2.2.1 has been shown to be related to the way in which risk is operationalized in N fertilization decision modelling (Section 3). Because of the serious problems in identifying farmers' risk preferences, except in consultation with individual farmers, definitions of risk as aversion are not appropriate to the analysis at hand.

Definitions of risk based on measures of variance (or the standard deviation) have been shown to be useful in identifying risk efficient plans from among plans which have the same expected value, by minimizing the absolute value of variance. Risk assessment of N fertilization options for a selected field crop, however, does not involve the comparison of plans with identical expected yield (income) outcomes. As such, risk efficient plans may be obtained for each level of N but variance measures provide no help in choosing among them. Variance measures of risk therefore, cannot be considered appropriate for identifying the risk efficient choice in the N fertilization decision process.

This leaves the definition of risk as chance of loss. Despite problems of whether farmers actually use probability concepts in making decisions, it is seen that chance of loss measures of risk most accurately articulate the risk consequences of different N fertilization options. First, risk assessment of the N decision must be undertaken with regard to the risk of some level of loss. For determining the level of production risk exposure in N fertilization of field crops, this requires an assessment of the chances of obtaining a target yield.

Second, the chance of loss measure of risk facilitates comparison of risk at different target yield levels, reflecting differing objectives and/or financial circumstances of farmers. And third, it is also important that the decision aid provide farmers with the flexibility to compare risk characteristics across different N use levels. Again, the chance of loss is most appropriate for comparing fertilization plans with different expected yield outcomes.

4.4 Dealing With N x Yield Data Deficiencies

The most limiting difficulty in applying risk approaches to the Manitoba N fertilization decision is the simple data deficiency related to N x crop yield production response. Having already detailed the pitfalls of employing simplifying assumptions about real frequency distributions in risk modelling, it is ironic that it is necessary to attribute normality to N and yield variables to illustrate implications of the decision framework itself. Despite this problem, the need for better information should be separated from basic flaws in risk approaches.

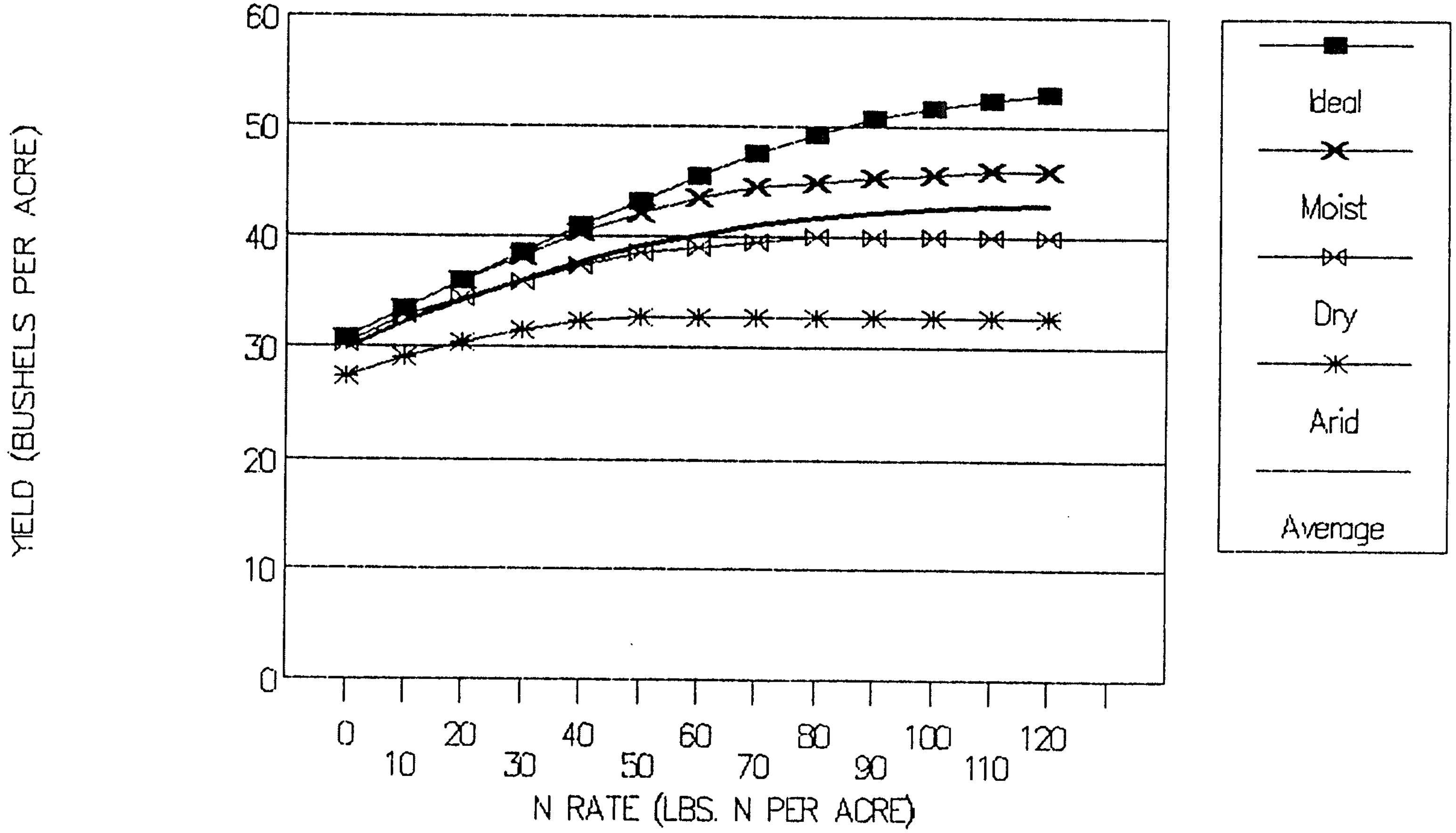
Subsection 2.2 above, indicates that the interactive characteristic associated with N fertilization of field crops has implications for the dispersion of crop yield distributions. In particular, this characteristic implies that N use is risk increasing in its effect on crop yield distributions.

The "climate-modified" N response curves for HRS wheat used by the Manitoba Provincial Soil Testing Laboratory (MPSTL) in making N recommendations are presented in Figure 4. It may be noted that the absolute spread of expected yields for the four moisture-yield curves about the average of all moisture-yield curves increases with increasing N rate, indicating that Manitoba HRS wheat yields may possess risk increasing characteristics about the average values as a function of moisture. However, this would also require the presence of specific statistical attributes in the yield population, which cannot be determined from MPSTL's target yield tables.

4.5 Significance Of N As A Risk Increasing Input

A limited, but significant body of literature indicates that N is a dispersion increasing input for some field crops in farm production. In Australia, work with wheat yields indicates that while different fertilization strategies may have small effects on expected

Figure 4: "Moisture-modified" wheat yield x N rate curves, Manitoba.



profits, the predicted variance of those profits is considerably more sensitive to varying levels of controlled inputs, such as increased rates of N (Anderson, 1973:81).

Colyer (1967:149) has found the variance of Missouri corn yields to be a linear function of the rate of N fertilization. Similarly, Smith and Parks (1967:1514) report empirical probabilities of net returns from N fertilized millet in Tennessee which are consistent with attributing risk increasing characteristics to N fertilization.

Other less dramatic, but nevertheless supportive evidence, is also present. Roumasset (1979a:15) notes, "Although agronomic arguments can be constructed to show that fertilizer either increases or decreases variance, it appears that in most situations, fertilizer does increase the variance of profits but only slightly ..." And in terms of production risk, fertilizer is reported to have a variance-increasing effect on yield although the marginal variance contribution is smaller than estimated by conventional production functions (Just and Pope, 1979:283).

Roumasset (1979a:13) also indicates that application of nitrogen to drought prone corn has resulted in variation-increasing input effects. Considering that areas of Manitoba are subject to periodic drought conditions (certainly recently if not so noticeably in the past), this is evidence of the existence of risk increasing N effects under comparable climatic regimes.

The probable presence of risk increasing effects of N in field crop production in

Manitoba has particular significance for the pattern of risk exposure faced by farmers. In contrast to N x yield distributions possessing constant or decreasing CV characteristics, an increasing CV indicates a more dispersed yield population as N level is increased. The risk efficient N decision under increasing CV assumptions will be shown, below, to vary in a unique manner as a function of the increasing spread of the yield population and the level of yield (income) targeted.

4.6 The Risk Decision Framework Adopted In This Study

Reports in the literature of the risk increasing attributes of input variables have been accompanied by risk efficient decision modelling approaches. Colyer's (1969) fertilization decision framework using Missouri data is based on the probability of returns falling below a specified level, in which the probability of shortfall is shown to decrease with increasing N rate up to a point below the profit maximization level. The work of Smith and Parks (1967) using N x millet yield data from Tennessee, predicts the probability of obtaining specified yields at different levels of N application, finding N rate to be positively correlated with the probabilities of achieving progressively higher net returns (net of fertilizer costs).

Roumasset's results of investigations of rice fertilization in the Philippines indicate that the risk of not getting high critical levels of return is reduced at N rates above zero, sometimes more than the level which maximized expected profits (Roumasset, 1974:284). Finally, the Savoie and Kabay (1980) approach correlates higher seeding density of dwarf beans in Rwanda, Africa with increased likelihood of exceeding the expected worst profit, before levelling out and subsequently decreasing profitability expectations.

It is the risk increasing characteristic discussed above and applied to whole farm risk that generates these outcomes. And there is no reason to believe the results obtained by those researchers may not be characteristic of the N x crop yield production response of at least some field crops in Manitoba.

The decision framework to be used in the next chapter may now be outlined. The definition of risk used is that of the chance of not obtaining a target yield or income level. Following the approaches of Colyer (1969), Smith and Parks (1967), Roumasset (1974) and Savoie and Kabay (1980), the risk decision rule is assumed to be to maximize the probability of achieving returns from crop production which recover costs. These specified target returns vary first, as a function of the level of N fertilization and second, as a function of the target requirements of the farm.

The approach adopted here is Roy's safety first risk modelling (see subsection 3.3.5, above) in that it uses the probability of an 'disaster' outcome as a decision criteria and the level of the 'disaster' is sufficiently high so as to cause catastrophe if it occurs. In addition, the probability of suffering a loss is significantly high. These concerns appear to describe closely the primary context of N rate decisions made by Manitoba farmers recently (Zbeetnoff and Josephson, 1988a; Zbeetnoff, 1989).

While focus-loss decision modelling (subsection 3.3.5, above) is also of the safety first type, which circumvents the need for actual measurement of the statistical parameters of yield and income populations, 'ruin' levels and 'negligible' possibility of ruin are highly individualistic concepts. In applying the methodology to the N fertilization risk decision, this approach would appear to be most reasonable when the "negligible" possibility of ruin is relatively large, but this remains to be validated as a decision rule in the field. Because of variations among individuals with respect to risk preferences and levels of "ruin" (unavoidable expenses), it may be unlikely that the tool would be used to recommend N fertilization practises to farmers at large.

For reasons discussed previously, in calculating the probabilities of realizing specific yield or income targets, it is assumed that N x yield populations exhibit normality characteristics at all N levels. Statistical parameters are derived by applying increasing CV assumptions to yield data for HRS wheat.

The N rate which minimizes the chance of target shortfall is considered risk efficient. Given this information, risk optimal fertilization plans which take factors other than production risk and whole farm risk into account can be identified by individual - farmers.

5.0 APPLICATION TO THE MANITOBA SITUATION

For the purposes of further investigation, a N x crop yield data base relevant to Manitoba and possessing dispersion increasing characteristics was constructed as outlined below. The context of the risk decision process is the typical N rate problem facing producers of hard red spring (HRS) wheat on stubble acreage in the province in the 1980's.

5.1 The Crop Yield Data Base

Average wheat yield responses to N fertilization are used by the MPSTL to make soil test fertilizer recommendations to farmers. The data base for five major field crops, i.e. wheat, barley, oats, canola and flax, consists of four production curves for each of the crops corresponding to ideal, moist, dry and arid growing conditions. The production functions presented in Table 2 for wheat are calculated from Manitoba Provincial Soil Testing Laboratory (MPSTL) information in 10 lb. per acre applied N increments, based on initial or spring soil N reserves of 50 lbs. N per acre.[6]

[6]This value is the provincial average of spring soil N reserves on stubble over the 8 year period, 1979-80 to 1986-87 (see McGill, 1987:177).

Table 2

"Climate - modified" wheat yield responses to applied N under varying moisture conditions in Manitoba. (Source: Manitoba. Provincial Soil Testing Laboratory, 1982).

	Yields by Moisture Condition				
N Rate	Ideal	Moist	Dry	Arid	Average Yield
(Lbs/Ac)			(Bu/Ac)		
0 (a)	30.8	30.8	30.3	27.4	29.8
10	33.4	33.4	32.8	29.1	32.2
20	36.0	36.0	34.4	30.4	34.2
30	38.5	38.2	35.9	31.5	36.1
40	41.0	40.4	37.3	32.3	37.8
50	43.2	42.1	38.5	32.7	39.1
60	45.4	43.5	39.0	32.7	40.2
70	47.5	44.5	39.5	32.7	41.1
80	49.2	44.9	40.0	32.7	41.7
90	50.7	45.3	40.0	32.7	42.2
100	51.7	45.6	40.0	32.7	42.5
110	52.4	45.9	40.0	32.7	42.8
120	53.0	45.9	40.0	32.7	43.0

(a) Spring soil N reserves assumed to be 50 lbs. N per acre.

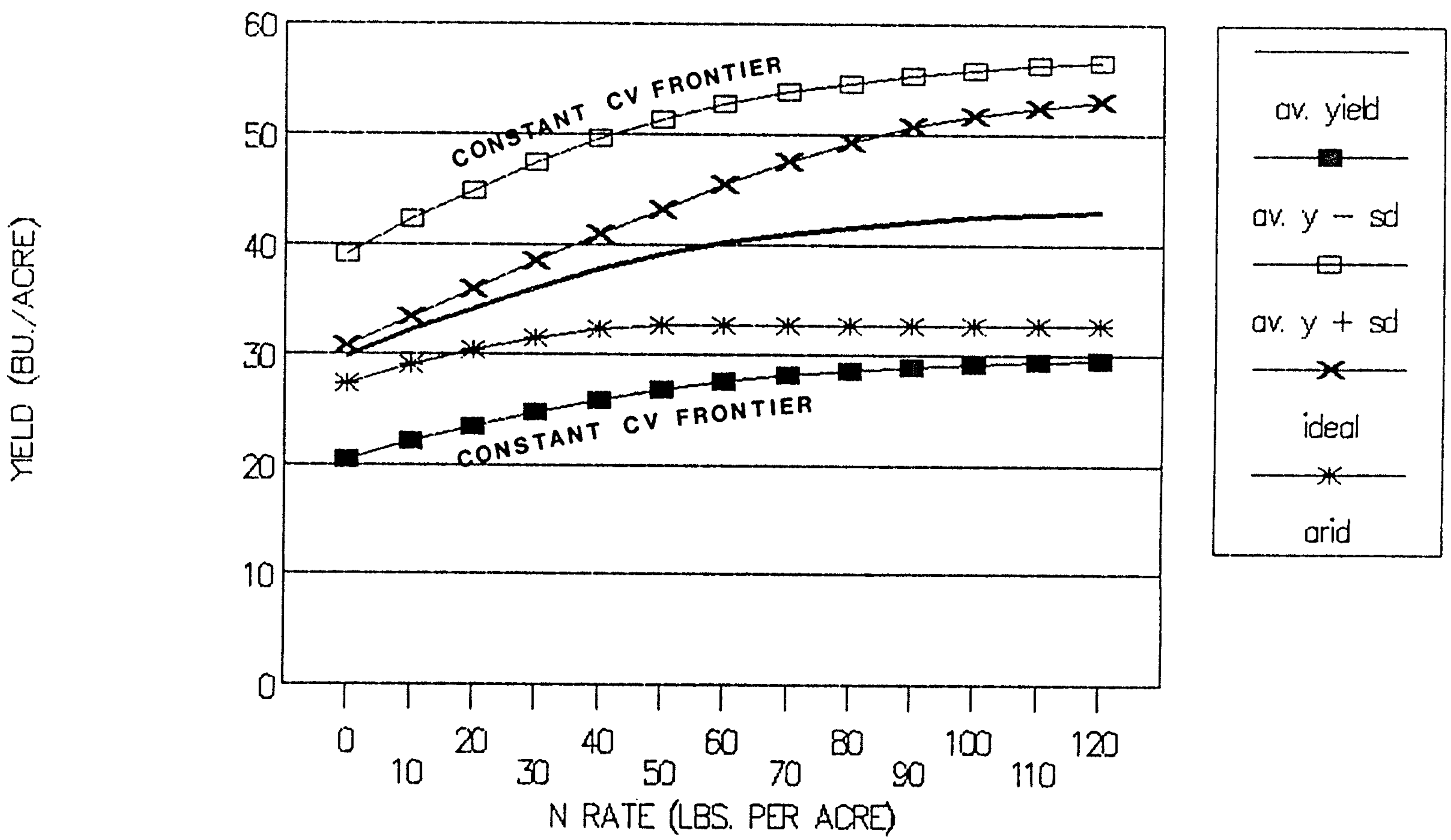
An estimate of yield SD at 1-10 lbs. N per acre was obtained from the MPSTL data base. This has been applied as a base estimate of SD in the CV framework discussed earlier. Over the period 1981-1986, inclusive, the average SD across soil classes provincially was 9.33 bushels/acre (bushels/acre). This was then applied to the MPSTL production functions to statistically characterize the frequency distribution of wheat yields in Manitoba at each specified N rate.

It is noted, however, that the expected yields of all 'climate-modified' yield curves tend to converge at zero N rate. Thus, it would appear reasonable to assign the average SD value to the average production function at that point. That is, the expected yield for all 'climate-modified' curves is practically the same at zero N rate. Using CV statistical parameters, it is possible to generate risk characteristics of N fertilization reported in the literature.

To facilitate interpretation of the risk concepts discussed, a band about the means was created (Figure 5) indicating the threshold level of SD beyond which CV's would increase. Points along the band represent SD's at each N rate which generate a constant CV, i.e. neutral in terms of changes in production risk. Points interior of the frontier of the band indicate SD values which would imply production risk reducing attributes to N fertilization.

An increasing yield dispersion distribution with increasing N rate was selected for investigation. The increasing CV characteristics of yield were arbitrarily selected at

Figure 5: Constant CV in relation to ideal and arid yield x N rate curves.



+5% per 10 lb. N increment, starting from a base of 29.8 bushels/acre yield at zero N rate, SD=9.33 bushels and CV=31.3 (see Table 1, subsection 2.2, above).

5.2 Minimum Recovery Costs (MRCs)

Using the statistical characteristics of the normal distribution, the likelihood of achieving yields at any level in the range of the frequency distribution was calculated. The yield equivalents of crop production costs are of particular interest since those costs need to be recovered to insure that the equity/financial position of the enterprise does not deteriorate from one year to the next.

Minimum recovery costs (MRCs) are defined to include normal variable operating costs plus fixed costs such as land taxes and interest on debt other than that associated with operating costs. In some instances, it could also include the costs of custom hiring and principal repayment on loans if they were being recalled. It is not critical what individual farmers regard as their costs of production so long as they have an idea of their minimum acceptable recoverable level. It would be predicted that farmers with higher MRCs might possess one or more of the following characteristics:

- higher debt/lower equity, through the use of leverage to finance expansion or equipment purchase plans.

- more intensive, in terms of use of controlled inputs, because of continuous cropping, use of new technology and/or more comprehensive management.

- undercapitalized, if using high levels of inputs but relying on custom operations.

On the other hand, farmers with lower MRCs might possess the following traits:

- debt free, possibly because of an extreme aversion to debt or being well established in the industry.

- low input user, due to higher levels of production risk aversion.

- less intensive farmer, if using short cropping rotations and relying on summerfallow to replenish N requirements.

The MRC scenarios are based on a typical 1000 acre grain farm in Manitoba under a range of financial situations. Operating costs estimates have been obtained from the 1988 Manitoba Farm Planning Guide (Manitoba Agriculture, 1988). Interest costs associated with the various financial structures involving debt have been calculated at 14% per annum on medium and long term loans, 15% per annum for 6 months on operating costs of production.

As shown in Table 3, eight (8) MRC scenarios are considered,
ranging from 0% debt and 0% borrowed operating (Scenario 1) to 50% debt, 100% borrowed operating and living expenses (Scenario 8). The associated recovery MRCs are presented for zero N rate in Table 4 and for varying N rate in Table 5. For example, the farm recovery costs which, at a minimum, pay for the expenses of a Scenario 3 farmer (i.e., with 10% debt and requiring financing of operating, but not living expenses) at 60 lbs. N per acre are $97.12 per acre (Table 5).

5.3 Risk As A Function of N Fertilization

While Table 1 presents the wheat yield distribution characteristics which, under the assumption of normality, are

Table 3

Components of minimum recovery costs (MRCs) for each production scenario.

		% Costs to be Recovered from Crop Production				
Scenario #	Debt to Assets	Operating Costs	Operating Interest	Land Taxes	Interest on Debt	Living Expenses
1	-	100%	0%	100%	0%	0%
2	-	100%	100%	100%	0%	0%
3	10%	100%	100%	100%	100%	0%
4	10%	100%	100%	100%	100%	100%
5	20%	100%	100%	100%	100%	100%
6	30%	100%	100%	100%	100%	100%
7	40%	100%	100%	100%	100%	100%
8	50%	100%	100%	100%	100%	100%

Table 4

Farm recovery costs[a] associated with crop production on a 1000 acre farm for the various debt scenarios and financing requirements. These costs apply to HRS wheat production at zero N rate, total assets (real estate, inventories, machinery, etc.) assumed at $600,000.

	Scenario #[b]							
Cost Item	#1	#2	#3	#4	#5	#6	#7	#8
	Costs ($ per acre)							
Seed Treatment	5.31	5.31	5.31	5.31	5.31	5.31	5.31	5.31
P Fertilizer	8.25	8.25	8.25	8.25	8.25	8.25	8.25	8.25
Chemicals	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
Fuel	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Machinery Operation	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Insurance	5.86	5.86	5.86	5.86	5.86	5.86	5.86	5.86
Miscellaneous	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Land Tax	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
Operating Interest	--	4.91	4.91	4.91	4.91	4.91	4.91	4.91
Debt Interest	--	--	8.73	8.73	17.46	26.19	34.92	43.65
Living Expenses	--	--	--	1.50	1.50	1.50	1.50	1.50
Totals	65.42	70.33	79.06	80.56	89.29	98.02	106.75	115.48

(a) Recovery costs are defined as those minimum costs that need to be recovered if the farm is to pay expenses incurred in current year production.
(b) See Table 3 for explanations of farm financial scenarios.

(Source: Modified from production costs estimates in Manitoba Farm Planning Guide, 1988.)

Table 5

Recovery costs for the farm financial scenarios at N rates from zero to 120 lbs. N per acre.

N Rate Lb/Ac[b]	Recovery Costs per Scenario ($ per acre) Scenario #[a] #1	#2	#3	#4	#5	#6	#7	#8
0	65.42	70.33	79.06	80.56	89.29	98.02	106.75	115.48
10	73.22	78.71	87.44	88.94	97.67	106.40	115.13	123.86
20	75.02	80.65	89.38	90.88	99.61	108.34	117.07	125.80
30	76.82	82.58	91.31	92.81	101.54	110.27	119.00	127.73
40	78.62	84.52	93.25	94.75	103.48	112.21	120.94	129.67
50	80.42	86.45	95.18	96.68	105.41	114.14	122.87	131.60
60	82.22	88.39	97.12	98.62	107.35	116.08	124.81	133.54
70	84.02	90.32	99.05	100.55	109.28	118.01	126.74	135.47
80	85.82	92.26	100.99	102.49	111.22	119.95	128.68	137.41
90	87.62	94.19	102.92	104.42	113.15	121.88	130.61	139.34
100	89.42	96.13	104.86	106.36	115.09	123.82	132.55	141.28
110	91.22	98.06	106.79	108.39	117.02	125.75	134.48	143.21
120	93.02	100.00	108.73	110.23	118.96	127.69	136.42	145.15

(a) See Table 3 for explanation of scenarios.
(b) Costs of applied N include cost of application ($6.00 per acre), N at 18 cents per lb., and interest costs, where applicable.

necessary and sufficient for calculating the expected probabilities of specific yields, the actual yield target decision of farmers has been shown to require a joint assessment of profit potential and risk exposure. The probabilities of achieving MRCs is related to the value of those costs and the dispersion characteristics of yield at increasing N rates.

The calculated MRCs for each of the 8 scenarios at different N rates have been converted into break-even yield equivalents in Table 6. For example, in order to pay MRCs of a Scenario 4 farmer who uses 60 lbs. N per acre, a wheat yield of 28.2 bushels/acre is required. The probabilities of attaining this yield equivalent is indicated for the CV increasing yield distribution in Table 7.

Therefore, considering the same Scenario 4 farmer, the expected probabilities of achieving at least MRC while fertilizing at 60 lbs. N per acre are calculated at 77.3%.

5.3.1 Production Risk And The N Rate Decision

The definition of production risk adopted is the probability of recovering those costs directly related to production. In the scenarios indicated in Table 3, the production costs of a Scenario 1 farmer are totally represented by what are conventionally regarded as variable costs, except for land taxes which are often considered fixed farm costs.[7] It

[7]It should be noted that where the investment decision includes the issue of whether to rent additional land, land taxes may well be variable costs of production. The Manitoba Farm Planning Guide, 1988 considers land taxes to be operating costs of production for planning purposes.

Table 6

Yield equivalents of farm recovery costs[a] at a HRS wheat price of $3.50 per bushel.

N Rate (Lb/Ac)	Break-even yield equivalents per scenario (bu./ac.) Scenario #[b] #1	#2	#3	#4	#5	#6	#7	#8
0	18.6	20.1	22.6	23.0	25.5	28.0	30.5	33.0
10	21.0	22.5	24.9	25.5	27.9	30.3	32.9	35.4
20	21.5	23.0	25.6	26.0	28.4	31.0	33.4	36.0
30	22.0	23.7	26.1	26.5	29.1	31.5	33.9	36.5
40	22.5	24.2	26.6	27.1	29.6	32.0	34.6	37.0
50	23.0	24.7	27.3	27.6	30.1	32.7	35.1	37.5
60	23.5	25.2	27.8	28.2	30.7	33.2	35.6	38.2
70	24.0	25.8	28.3	28.7	31.2	33.7	36.3	38.7
80	24.6	26.4	28.8	29.3	31.8	34.3	36.8	39.2
90	25.1	26.9	29.4	29.8	32.3	34.8	37.3	39.9
100	25.6	27.5	30.0	30.3	32.9	35.4	37.9	40.4
110	26.1	28.0	30.5	31.0	33.4	35.9	38.4	40.9
120	26.6	28.5	31.1	31.5	33.9	36.5	39.0	41.5

(a) See Table 5 for explanation of farm recovery costs for each scenario.

(b) Descriptions of scenarios are found in Table 3.

Table 7

Probabilities of attaining break-even yield equivalents of the various minimum recovery costs (MRCs) when HRS wheat yields exhibit a 5% CV increase with each 10 lb. increment of N, assuming a normal yield distribution.

	Expected Probability of Achieving MRCs (in %)							
	Scenario #[(a)]							
N Rate (Lb/Ac)	#1	#2	#3	#4	#5	#6	#7	#8
0	88.5*	85.1*	77.9*	76.7	67.7	57.5	46.8	36.7
10	85.5	82.1	75.5	73.6	65.9	57.1	47.2	38.2
20	85.7	82.6	76.1	75.5	68.4	60.6	52.8	44.0
30	86.0	82.9	77.9*	76.7	70.5	63.7	56.8	48.8
40	85.8	82.9	78.2	77.3*	71.6	65.5	58.7	52.4
50	84.9	82.1	77.6	77.0	71.9*	65.9	60.3	54.0
60	83.9	81.3	77.0	76.1	71.2	66.3*	60.6*	54.8
70	82.6	80.0	75.8	75.2	70.5	65.5	60.3	55.2*
80	81.1	78.5	74.9	73.9	69.5	64.8	59.9	54.8
90	79.7	77.0	73.2	72.6	68.4	64.1	59.1	54.4
100	78.2	75.5	71.9	71.2	67.0	62.9	58.3	54.0
110	76.7	74.2	70.5	69.9	65.9	61.8	57.5	53.2
120	75.2	72.6	68.8	68.4	64.8	60.6	56.8	52.4

(a) See Table 3 for description of scenarios.

* = Indicates the approximate N rate which produces the highest probability of attaining MRC for each scenario.

is easily seen in Table 4 that, at zero N rate, Scenarios 2 through 8 farmers have identical production costs to a Scenario 1 farmer with the exception of additional interest costs, since operating requirements are financed.

When N fertilization is considered (Table 5), the same pattern is observed. The cost differences in N use between Scenario 1 and Scenarios 2 through 8, with increasing N rate, are attributable to the extra interest costs associated with borrowed operating requirements. It is apparent that these financing costs are small in comparison to total operating costs and thus, have little impact on the level of production costs and hence, the production risk which farmers from all the scenarios face at specific N fertilization rates.

Referring to Scenario 1 and 2 farmers (Columns 1 and 2) in Table 7, it may be seen that the probabilities of attaining recovery cost levels decline with increasing N fertilization. Note that the minimum recovery costs associated with these two scenarios most clearly reflect the conventional definition of operating costs of production.

The implication of CV increasing N x yield distributions for the selection of risk efficient fertilization strategies, when risk is totally represented by measures of production risk, is for the farmers to choose zero N rate.[8] This highlights the classic

[8]Note that this relationship is evident for Scenario 1 and 2 farmers in Table 7. Farm recovery costs for Scenarios 3 through 8 farmers include debt interest and living expenses in those tables hence, the production costs are masked but are identical to those of Scenario 2 for reasons discussed above.

dilemma in fertilization recommendations wherein advice to farmers to increase profit potential through increasing N use can often be construed as telling farmers to be greater risk takers. This type of recommendation may not go over well when farm operations are already under economic stress.

5.3.2 Whole Farm Risk And The N Rate Decision

A more realistic economic decision framework for at least some Manitoba farmers concerns long and/or intermediate term debt load in the farm operation. In these cases, the level of MRCs depends on the total financial obligations of the farmer. The chances of recovering minimum costs depends on the level of costs, field crop yield expectations and frequency distributions in relation to N rate. Since the differences in MRCs are substantial among the scenarios, it follows that the level of whole farm risk in each scenario is not a function of production risk, alone.

Since some portion of the MRCs of the farm consists of production costs, the probabilities of attaining those costs (i.e. the level of whole farm risk) includes the probabilities associated with production risk. In order to choose the risk efficient N rate, the farmers would minimize the combination of risks in relation to his MRCs.

For yield distributions which display CV increasing characteristics, the risk efficient strategy varies substantially depending on MRC requirements. The risk efficient N rate decision for a Scenario 1 farmer, having zero debt and no financing costs related to production, is to choose zero N rate, where the probability of realizing MRCs is highest (i.e., 88.5% in Table 7). In fact, zero N rate is indicated to be the risk efficient fertilization strategy for the first three scenarios, if debt is also included in the decision framework.

In contrast, the risk efficient N rate choice for a Scenario 4 farmer, with 10% debt and borrowed operating capital, is estimated at 40 lbs. N per acre (77.3% chance of a favourable outcome in Table 7). And in general, as MRCs increase from Scenario 1 to Scenario 8, the risk efficient N rate also increases. As MRCs become comprised of debt financing charges related to leverage in the farm operation, whole farm risk is less and less influenced by production risk considerations, alone.

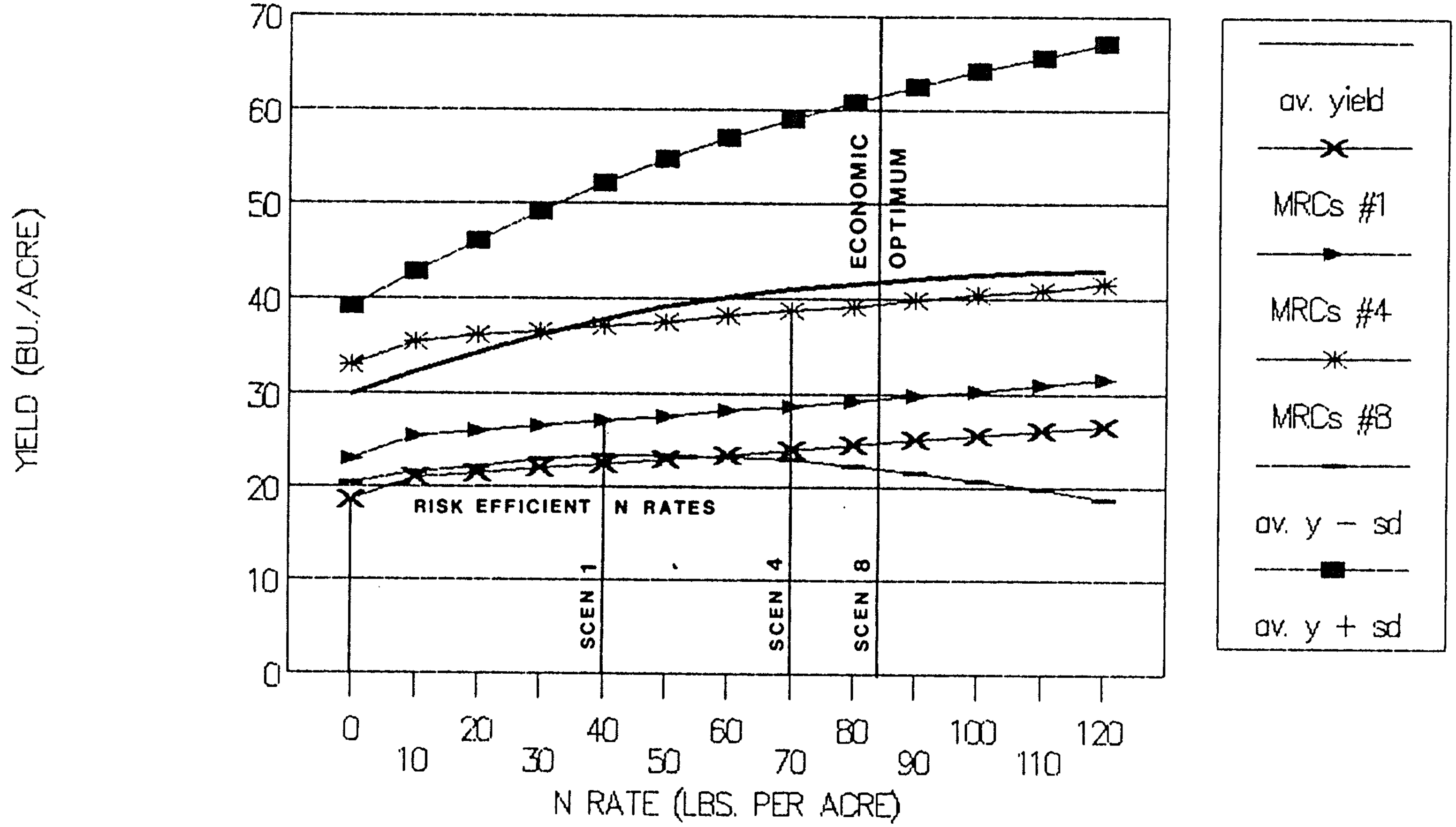
Scenarios 4 through 8 (Table 7) suggest that it is often less risky to aim for MRCs with higher N rates than with lower N rates (over some range of N). At the extremes (i.e., comparing Scenarios 1 and 8), the risk efficient N rate differs by 70 lbs. N per acre (zero versus 70).

Finally, as MRCs increase from Scenario 1 to Scenario 8, the absolute level of risk exposure also increases. That is, the absolute level of whole farm risk increases because the probabilities of obtaining higher yields to meet those progressively higher MRCs are lower.

A graphic representation of the N fertilization decision for the CV increasing yield distribution is presented in Figure 6. It is seen that the Scenario 1 farmer minimizes the tail of the yield distribution below his MRC curve at a N rate equal to zero.

Similarly, the Scenario 4 farmer maximizes his chances of achieving MRCs at the point where the highest percentage of

Figure 6: Risk efficient N rates under Increasing CV yield assumptions.



the expected yield distribution is above the cost curve. Thus, at 40 lbs. N per acre, 77.3% of the yield outcomes will be favourable (Table 7).

In comparison, the Scenario 8 farmer's MRCs are significantly higher. In fact, at low N rates, the relevant probabilities of recovering those costs are derived from the upper bounds of the yield distribution (see zero N rate, Figure 6). At a N rate of 70 lbs. per acre, the probabilities of realizing yields above the cost curve are maximized at 55.2% (Table 7).

5.4 Risk Efficient Versus Profit Maximizing N Rates

Given the range of risk efficient N fertilization strategies for the different wheat yield distributions, it is interesting to compare risk efficient N rates with those calculated by profit maximizing techniques. A conventional marginal analysis approach has been used to generate Table 8. For the 8 scenarios considered, it is important to note that there are really only two marginal cost calculations involved.

In Scenario 1. the marginal cost per 10 lb. increment of N is \$1.80 (18 cents per lb.) and the economic optimum (profit maximizing N rate) is between 80 and 90 lbs. applied N per

Table 8

Profit maximizing levels of N fertilization for the farm financial scenarios as identified by marginal analysis.

N Rate (Lb/Ac)	Marginal Yield (Bu/Ac)	($/Ac[a])	Marginal cost of N fertilization ($ per acre) Scenario #1	Scenarios #2 - #8
0				
10	2.4	$8.40	$7.80	$8.38
20	2.0	7.00	1.80	1.94
30	1.9	6.65	1.80	1.94
40	1.7	5.95	1.80	1.94
50	1.3	4.55	1.80	1.94
60	1.1	3.85	1.80	1.94
70	0.8	2.80	1.80	1.94
80	0.6	2.10	1.80	1.94
90*	0.5	1.75*	1.80	1.94
100	0.4	1.40	1.80	1.94
110	0.3	1.05	1.80	1.94
120	0.2	0.70	1.80	1.94

(a) Wheat priced at $3.50 per bushel.

* = Profit maximizing N rate identified between 80 and 90 lbs. N.

acre. Spring soil N reserves are identical to those assumed in the calculations of minimum recovery costs (MRCs) earlier, i.e., 50 lbs. N per acre.

In Scenarios 2 through 8, the incremental cost of N increases by 14 cents per 10 lb. increment to $1.94 due to interest costs on borrowed operating capital. Nonetheless, the profit maximizing N rate is also between 80 and 90 lbs. N, although slightly lower than for Scenario 1 (see Table 8).

Assumptions concerning CV increasing yield distributions result in risk efficient N fertilization strategies which range over the whole spectrum from zero N rate to 70 lbs. N per acre. The risk efficient N rate is highly sensitive to the level of MRCs. The profit maximizing approach to choosing N rate clearly establishes the upper bound of the range of feasible N rates whenever whole farm risk exposure is less than 50%. Fertilization decisions intermediate between the risk efficient and profit maximizing points require trade-offs between risk efficiency and profit potential. Debt-free farmers would have a wider range of trade-offs for consideration than highly leveraged farmers. Overall, Figure 6 illustrates that the profit maximizing approach to choosing N rates is a better approximation of risk efficient N rate decisions for highly leveraged farmers than for unleveraged farmers. Considered another way, as leverage and MRC levels increase, the farmer takes on more and more whole farm risk. As that risk approaches 50%, his fertilizer decisions exhibit a tendency toward risk neutral preferences, even though he may be basing that decision on risk efficiency considerations. At a MRC level representing 50% risk, the risk efficient N level is identical to a risk neutral decision and synonymous with a profit maximizing N fertilization strategy. And finally, in most extreme cases where MRC requirements exceed even those presented in this study, it is possible for the risk efficient N rate to be found at levels exceeding the economic optimum for CV increasing yield distributions.

5.5 Discussion

The preceding discussion is supported by findings in the literature which indicate that the traditional perception of conflict between risk aversion and profit seeking objectives of farmers needs to be qualified. This argument has been extended to the N fertilization decision using wheat yields in Manitoba and assuming a CV increasing yield frequency distribution. Suitable Manitoba yield data are not presently available to empirically demonstrate the existence of statistical characteristics used in this study.

The interaction of three factors needs to be evaluated before risk efficient N fertilization decisions may be identified or recommended for individual farmers. Risk efficient N rates may or may not coincide with profit maximizing rates, depending on the absolute value of risk exposure involved in obtaining minimum recovery costs (MRCs).

5.5.1 N x Yield Dispersion Determines Production Risk

The first factor is the dispersion characteristic of the yield population, also a measure of the production risk associated with the fertilization decision. As noted earlier, Scenarios 1 and 2 exhibit production costs which are conventionally used to quantify production risk in N fertilization decision and for this reason, give good indication of the behavior of production risk in the assumed distribution. Scenarios 3 to 8 farmers are exposed to the same production risk, but representing a smaller proportion of whole farm risk.

Increasing yield CV's result in decreased chances of meeting production costs with increasing N rate. This is illustrated by comparing absolute probabilities for low and high N rates in Table 7. However, while production risk determines whole farm risk characteristics for low debt farmers, the effect of higher MRCs on whole farm risk among higher debt farmers overpowers the influence of production risk.

5.5.2 Minimum Recovery Costs (MRCs) Determine Whole Farm Risk

As MRCs increase for the farm operation, the yield equivalents required to break even also increase. Debt servicing, characteristically, represents a large component of these additional costs.

The probabilities of attaining these higher MRCs declines noticeably from Scenarios 1 to 8. The level of whole farm risk increases appreciably with higher MRC requirements even though the level of production risk remains constant across the scenarios.

This dual effect is significant. Where variable costs of production used to estimate production risk are lower than the MRCs of farmers, the use of production risk to recommend risk behavior in N fertilization decisions will tend to underestimate whole farm risk exposure. This tendency would be manifested in greater degree among more leveraged farmers (i.e., Scenarios 4 through 8).

5.5.3 Production Risk Efficient Versus Whole Farm Risk Efficient

The most interesting facets of this investigation hinge on the lack of correspondence between production risk efficient and whole farm risk efficient N fertilization strategies. First, the analysis consistently indicates that farmers with higher MRCs should make different N fertilization choices than farmers with low MRCs. Consideration of production risk in the decision alone, in contrast, would target almost the same risk efficient N rates for all scenarios.

Second, the pattern of production risk created by the dispersion characteristics of yield and N interaction is different than the pattern of whole farm risk. Statistically, the effect of MRCs which exceed expected yield values at lower N rates is to shift the focus on relevant probabilities in the upper tails of low N rate yield distributions and then to the lower tails of high N rate yield distributions. The importance of the upper region of these frequency distributions for risk assessment has been largely neglected in the literature.

The identification of whole farm risk efficient N levels under these conditions is a function of the rate at which the expected yield increases in relation to the probabilistic significance of the rate of change of MRCs. When the two rates equate, the risk efficient N strategy is identified.

The probabilities associated with a CV increasing N x yield distribution are presented in alternate fashion in Figure 7. A possible use of Figure 7 in N fertilization decisions would be for a farmer to determine his MRC along the horizontal axis. For a specific MRC, the farmer could establish the probability of a favourable yield outcome along the vertical axis and using the curves for different rates of N.

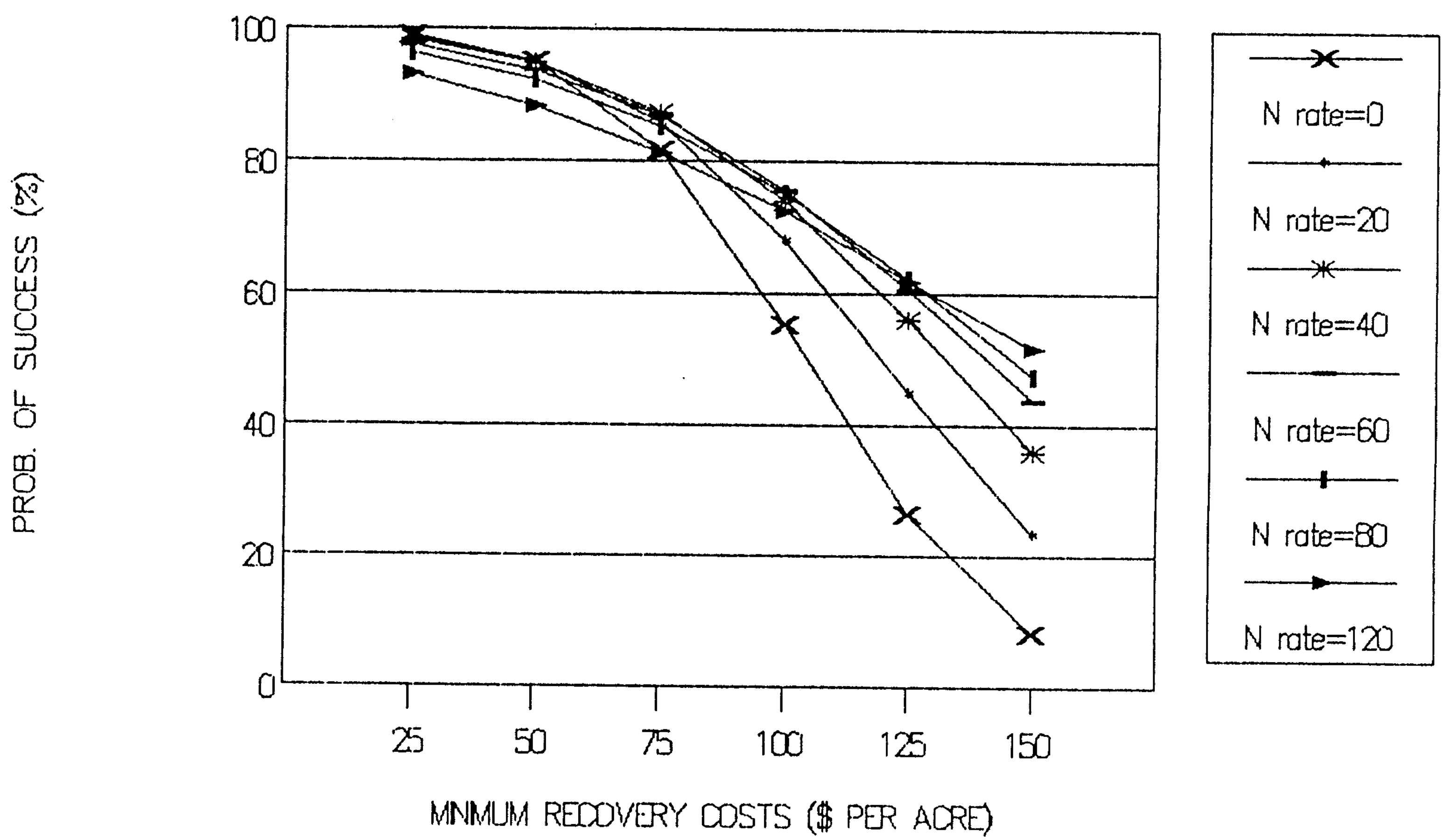
For example, the chances of attaining MRC of $100 per acre are only 36.7% at zero N rate while the chances of realizing the same MRC are increased to 55.2% at 70 lbs. per acre (additional operating costs are accounted for). The 70 lbs. N rate would be the risk efficient strategy.

If level of risk exposure is less critical to a farmer, he may choose his MRC independently of the risk efficient level and more in relation to maximum profit potential. Recall that the feasible region for trade-offs is found in Figure 6 between the risk efficient N rate and the economic optimum.

Figure 7 facilitates a comparison of this trade-off for a Scenario 4 farmer who is contemplating using 90 lbs. N per acre rather than the risk efficient rate of 40 lbs. N per acre. At 90 lbs. N, the probability of attaining MRCs drops 4.7% from 77.3% to 72.6% (Table 7) while his MRCs would have increased from $94.75 to $104.42 per acre (Table 5). At the same time, the 90 lbs. N yield of 42.1 bushels/acre would return $147.35 per acre gross ($42.93 net) compared to a 40 lbs. N yield of 37.8 bushels/acre grossing $132.30 and netting $37.55 per acre. Is the 4.7% increase in risk worth the extra $5.38 per acre?

Similarly, a Scenario 1 farmer with no financing requirements might prefer a higher level of risk exposure than that estimated at the risk efficient rate of zero N (Table 7). At 90 lbs. N per acre (approximately the economic optimum), his probability of obtaining MRCs has dropped 8.8% from 88.5% to 79.7% (Table 7) while his MRCs have increased from $65.12 to $87.62 per acre (Table 5). At the same time, the expected yield of 42.1 bushels/acre (at 90 lbs. N) amounts to a gross target level of return of $147.35 per acre (net = $59.73 per acre) compared to the yield expectation of 29.8 bushels/acre (at zero N rate) and gross return of $104.30 per acre (net = $38.88

Figure 7: Probabilities of achieving target returns at different N rates.



per acre). Is the 8.8% increase in risk worth an expected increase in profit of $20.85 per acre?

Optimality decisions are seen to require trade-offs among the objectives of profit seeking, risk efficiency and risk preferences of farmers. The risk efficient strategy and economic optimum analysis identify the upper and lower bounds (interchangeable depending on CV assumptions) of the feasible fertilization options. N rates outside of the interval, which differs in width for particular scenarios as illustrated in Figure 6, are both less risk efficient and less profitable to the farmer. N rates within the range trade off risk efficiency for economic efficiency, depending on the level of risk exposure acceptable or necessary for the decision maker. The extent of that range is considerably reduced for those farmers in high whole farm risk situations.

It may also be seen that the most leveraged scenarios have MRC curves that straddle the expected yield curve and risk efficient N rates close to the economic optimum (see Scenario 8, Figure 6). Where would the risk efficient point be if the price of wheat suddenly escalated (or MRCs suddenly dropped)?

In answer, this development implies lower production risk and lower whole farm risk in the new situation, possibly to the position of a Scenario 6 farmer over a short period of time. Graphically, the farmer's risk efficient N rate would decline along the curve joining the risk efficient N rates of all the scenarios in Figure 6. In effect, the analysis has already told us that lower whole farm risk causes N fertilization decisions to be risk efficient at lower N rates.

Finally, there would appear to be other practical applications of the approach used here. Farmers might examine the marginal increase in risk with increasing N rate in relation to potential investments in other enterprises, operations and investments, on or off the farm.[9] Absolute levels of risk exposure for specific ventures may be lower and with more profit potential than N fertilization, or vice versa.

Uptake of new technology which changes per acre MRCs could be assessed in terms of risk and economic impacts. And techniques or methods which lower per acre MRCs or promote national policies such as soil conservation could be evaluated in terms of risk and profit potential prior to being recommended for uptake to farmers.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Identifying The Risk Efficient N Fertilization Option

The foregoing analysis has presented information on the implications of the dispersion of field crop yield frequency distributions with increasing N rate for risk facing

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[9]Of course, there is the probability that some farmers may already undertake this type of analysis in allocating their production budgets and would help explain sub-optimal fertilization strategies.

farmers. The concept of whole farm risk is useful in clarifying what is put at risk in the production decision.

The approach advocated is that most relevant risk assessment criteria with respect to N fertilization consist of the expectation of target yields and/or the probability of recovering investment costs per unit of production. Risk efficiency implies the choice of N rate which provides the lowest probability of adverse yield outcome in relation to targeted MRCs.

The use of whole farm risk facilitates analysis by estimating the chances of recovering specified costs from current year production. The level of whole farm risk at different N rates may not be positively correlated with the level of production risk, depending on the distribution characteristics of yield and level of MRCs. In response to the question raised at the outset about whether farmers should be increasing or decreasing N rates in response to lower expected returns from field crop production, the suggestion is that, N use is CV increasing, the risk efficient N rate decision should vary among individual farmers, depending on their financial situations.

6.2 Yield Distribution Characteristics Crucial

The more important results of this study are predicated on the possibility that wheat yields exhibit more dispersion about expected values with increasing N rate. More precisely, in view of the gaps in the yield data base, the conclusions stem equally from uncertainty about N x yield interactions in Manitoba. The extent of this dispersion, in a statistical sense, probably varies by field crop, geographic location, field practises and numerous other factors not discernable from the literature.

6.3 Farm Financial Characteristics Influential

Overall, the increasing CV assumption has less effect on the risk efficient N rate as MRC requirements increase. That is, as the chances of obtaining yields which meet MRCs approach 50%, the risk efficient N rate converges on the risk neutral N rate, which is the economic optimum. The implication is that the profit maximizing N rate will be closer to risk efficient for farmers in high whole farm risk situations.

6.4 A Need For Yield Probability Information

In the context of this investigation, identifying risk efficient options requires more data on crop yields, estimations of dispersion parameters and shapes of the yield density functions, specifically with respect to N. From a larger perspective, probability information would be useful for decisions about numerous other inputs influencing yield distributions, such as varieties, new machinery/technology, cultural practises, soil characteristics, chemical use, seeding date, methods, etc. Fertilizer recovery efficiency, for example, is one area of investigation in which improvements may not only reduce the spread of yields but also increase the expected values associated with specific N rates (see Josephson and Zbeetnoff, 1988b).

Additional yield probability information may be expected to be useful whether generated objectively through research and analysis, or subjectively by the farmer himself. However, while one author may regard even sparse data as more reliable than purely subjective estimates (Anderson, 1973; 1974), another author may emphasize that serious misallocations of fertilizer are likely if based on recommendations from fertilization trials at only a few sites (Roumasset, 1974:284). Ultimately, the relevance of the source of the data base depends on the degree to which the statistical parameters generated are trusted or relied upon by farmers in their risk decision making.

6.5 Risk Decision Aids Needed

That individual farmers are expected to have different risk preferences and yield probabilities has created conceptual dilemmas for researchers modelling risk decisions in farm management. At the farm level, however, the ideal decision analysis should be sensitive to each decision maker (Dillon, 1979:34).

It seems apparent that Manitoba farmers could use a risk rating model incorporating uncertainty directly in making N rate decisions. A number of modelling approaches have been evaluated in Knight et al. (1987), of which the "Whole Farm Risk Rating Model" (see Anderson and Ikerd, 1985) may have application to Manitoba, in particular.

Some researchers have seized on the need for risk efficient analysis as opposed to risk optimal analysis, since the latter is complicated by risk preferences which, at present, cannot be reliably measured. In this vein, it is recognized that "... the most important challenge in risk management today involves assisting farmers and farm advisors to understand and measure the impact of their decisions in a probabilistic sense" (Jolly, 1982:113). There is also strong support for framing these risk probabilities in terms of the chance of bad events, concerns about the viability of the firm and the farmer's ability to withstand adverse outcomes (Patrick et al., 1985; Atwood et al., 1988).

6.6 Implications For Efficiency In N Allocation

One probable situation among highly leveraged farmers is that risk efficiency analysis could indicate the targeting of higher yields and N rates than the farmer is able or willing to finance.

The implication is that some of those farmers, due to capital rationing, are fertilizing below the risk efficient level, and making themselves more susceptible to adverse outcomes.

If risk increasing attributes of N fertilization are substantiated, there would appear to be a challenge and a benefit for government and industry to encourage production at risk efficient levels, thereby keeping the sector healthy, ensuring continued agricultural products demand and production supply. To this end, the potential mutual benefit of risk sharing, cost deferring, and cost sharing arrangements should be explained and promoted where farmers are under perceived economic inducement to act in an opposite manner.

Similarly, if creditors make decisions which force farmers to produce at inefficient N rates, identification of the risk attributes of fertilization could help them to be more discriminating in terms of where they ask those farmers to make their budgetary cuts. More efficient risk management in relation to N fertilization should increase the probability that creditors recover their loans.

Under the assumption of N as yield CV increasing, high equity farmers are indicated to be acting in risk efficient manners by selecting zero N rate. However, information on the large increases in profit potential that are possible with only small increases in risk, at higher N rates, should be available to farmers to assist their decision making.

At the very least, farmers should be aware of the magnitudes of risk which are involved in comparing these N options and the expected trade-offs in profit and risk which these fertilization decisions imply. Ideally, farmers should choose optimal N rate plans from a set of profitable options with acceptable levels of whole farm risk. The analysis presented here illustrates one way in which this information need may be addressed.

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