AN ABSTRACT OF THE THESIS OF

Awadelkarim Hamid Ahmed for the degree of Doctor of Philosophy in Agricultural and Resource Economics presented on June 30, 1982

Title: AN ECONOMIC EVALUATION OF WHEAT FERTILIZATION
STRATEGIES IN NORTH CENTRAL OREGON

Abstract Approved:
Stanley F. Miller

Soft white winter wheat in the drylands of North Central Oregon is produced utilizing a summer-fallow production system. The practice of nitrogen fertilization of wheat has been established as an important cultural practice since the early 1950's. It is observed that current fertilization practice involves repeated applications of a fixed amount of nitrogen. This fertilization procedure is subject to two main criticisms. First, since this semi-arid area is characterized by a high degree of seasonal weather variability, accounting for short term weather conditions is necessary to attain maximum net revenues. Second, the fertilization system in practice provides no adjustment mechanism for fluctuating market conditions. Failure to adjust nitrogen application to market conditions may cause large economic losses.

The objectives of this thesis were: (1) to evaluate potential fertilization strategies, including the present practice, with reference to short-run weather conditions, and (2) to investigate the effect of risk on these strategies.

In order to meet the above objectives, an agronomic model was developed to predict grain yields using short term weather data. A second model was developed to evaluate potential fertilization strategies utilizing the results of the first model. Modifications were made in these two models to allow consideration of risk factors in the evaluation process.

Fertilizer application is possible in three periods in the production process, during fallow period, at seeding and to the growing crop. Thirteen potential strategies were evaluated. They consisted of combinations of fixed and calculated profit and utility maximizing nitrogen application. The results indicated that:

1. Calculated nitrogen application gives higher levels of expected profits than fixed application.
2. Calculated fertilizer application to the growing crop is the best profit maximizing strategy under critical market conditions.
3. Fertilizer use under profit maximization is consistent with the observed farmers' fertilization behavior.
4. All strategies give negative expected utility including neutral risk aversion.
5. Zero fertilizer application is the best utility maximizing strategy for higher levels of aversion to risk.
6. The calculated nitrogen quantity to be applied is inversely related to risk aversion level.

AN ECONOMIC EVALUATION OF WHEAT FERTILIZATION STRATEGIES IN NORTH CENTRAL OREGON

by

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The encouragement and sacrifice of my wife, Magda and my son, Husam, provided all the support and motivation throughout my graduate work.

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AN ECONOMIC EVALUATION OF WHEAT FERTILIZATION STRATEGIES IN NORTH CENTRAL OREGON

Introduction

A summer fallow system is used to produce soft white winter wheat in the drylands of North Central Oregon. Fallowing allows precipitation which falls in a given year to be stored in the soil so that it will be available for crop growth during the following year. It also provides an incubation period for the break down of soil organic matter by microorganisms and the release of nitrogen. Hence, this practice helps to stabilize yield and subsequently farmers' income. In these lands nitrogen has been identified as the most important nutrient limiting yield. Nitrogen available through natural processes is, however, insufficient. Accordingly, nitrogen fertilizer is commonly applied to improve yields and, to a degree, income.

A common fertilization practice in the area is repeated application of the same fertilizer quantity without adjustement for weather or soil mineralized nitrogen. This procedure is subject to two main criticisms. First, since this semi-arid area is characterized by a high degree of seasonal weather variability, accounting for short term weather conditions is necessary for attaining maximum revenue. Second, the fertilization system in practice is highly inflexible to fluctuating market conditions which may cause the production unit to incur large losses.

The objectives of this study are: (1) to evaluate potential fertilization strategies, including the present practice, and (2) to investigate the effect of risk on these strategies.

The thesis is presented in two papers: a manuscript detailing the evaluation of fertilization strategies in a profit maximization approach and a second manuscript detailing the effect of risk factors on these strategies.

MANUSCRIPT I

A STOCHASTIC PROFIT MAXIMIZATION APPROACH FOR EVALUATING WINTER WHEAT FERTILIZATION STRATEGIES IN NORTH CENTRAL OREGON

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Introduction

Nitrogen fertilization of soft white winter wheat in the drylands of the Pacific Northwest has been an important cultural practice for the past three decades following the realization that nitrogen was a limiting plant nutrient in the area [Stephens, et al., 1943]. Hunter, et al. [1957] and Isfan [1979] reported the importance of taking into account short-run weather conditions, for effective fertilizer use, in a summer fallow production system. However, the dominant observed practice in the semi arid zones of North Central Oregon involves application of yield maximizing fixed nitrogen quantities.

Continuous application of the same quantity of nitrogen fertilizer has often been critized. First, additional production costs (revenue) may be incurred (foregone) by over (under) fertilization [Dillon, 1977; Fuller, 1965]. Second, a high opportunity cost may exist if the production system does not adjust to changing market and/or weather conditions. Lastly, yield maximization is not a necessary nor a sufficient condition for profit maximization.

The primary objective of this study is to evaluate alternative winter wheat fertilization strategies, including the present strategy of a fixed nitrogen application, in North Central Oregon. A secondary objective is to determine the sensitivity of these potential strategies to price and cost changes.

To accomplish the above objectives, a simulation model was developed. The model first forecasts mineralized soil nitrogen, potential yields and the grain yield-nitrogen response function. Then an application strategy is invoked to give the amount of fertilizer to be applied given the forecast. Finally, the model evaluates the consequences of the strategy. Model validation and results are presented following the model's description. The conclusions and limitations of the study are discussed in the last section.

First-Stage Model

The first-stage model was designed to forecast soil mineralized nitrogen, potential yield and the parameters of a grain yield-nitrogen estimating equation for each of several time periods (fallow season, seeding time, crop season and harvest time) during a production cycle.[1/] The model utilizes actual information available up to each decision point and provides projections for mineralized nitrogen and potential yield using seasonal averages beyond that point.

The mathematical modeling was done in two stages. First, a conceptual model of the physical, biological and economic structures was expressed in mathematical terminology and, second, a specification

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[1/] A summer fallow system of production is utilized in which a cycle consists of two years: a fallow year and a crop year. The fallow season starts September of the first year and runs to August of the second year, while the production season goes from September of the second year to August of the third year.

of the mathematical equations was implemented in a form acceptable to the computer.[2/] A diagram of the components of the model is shown in Figure 1.

Predicted yield is assumed to be a function of nitrogen available to plants and expected potential yield. Predictions are made four times during the year, i) May 1st of the fallow season; ii) at seeding time; iii) March 30th of the crop season and, iv) at harvest time and depends upon farmer actions and prevailing precipitation and temperature.

Two sources of nitrogen are available to a plant, mineralized nitrogen and nitrogen fertilizer. These are assumed to be perfect substitutes. The quantity of nitorgen fertilizer is controlled by the farmer but the mineralization process is physically determined. The quantity of available mineralized nitrogen influences the producer's decisions of whether or not to apply additional nitrogen at a point in time.

Soil Mineralized Nitrogen

Mineralized nitrogen accumulates naturally through the decomposition of soil organic matter and residues. This biological process occurs throughout both the fallow and crop seasons.

The coefficients and their form were obtained from Dr. Michael Glenn. Previous work conducted by himself and Dr. F. Bolten provided

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[2/] The Flex modeling approach was used for the transition (White, 1977; White and Overton, 1977).

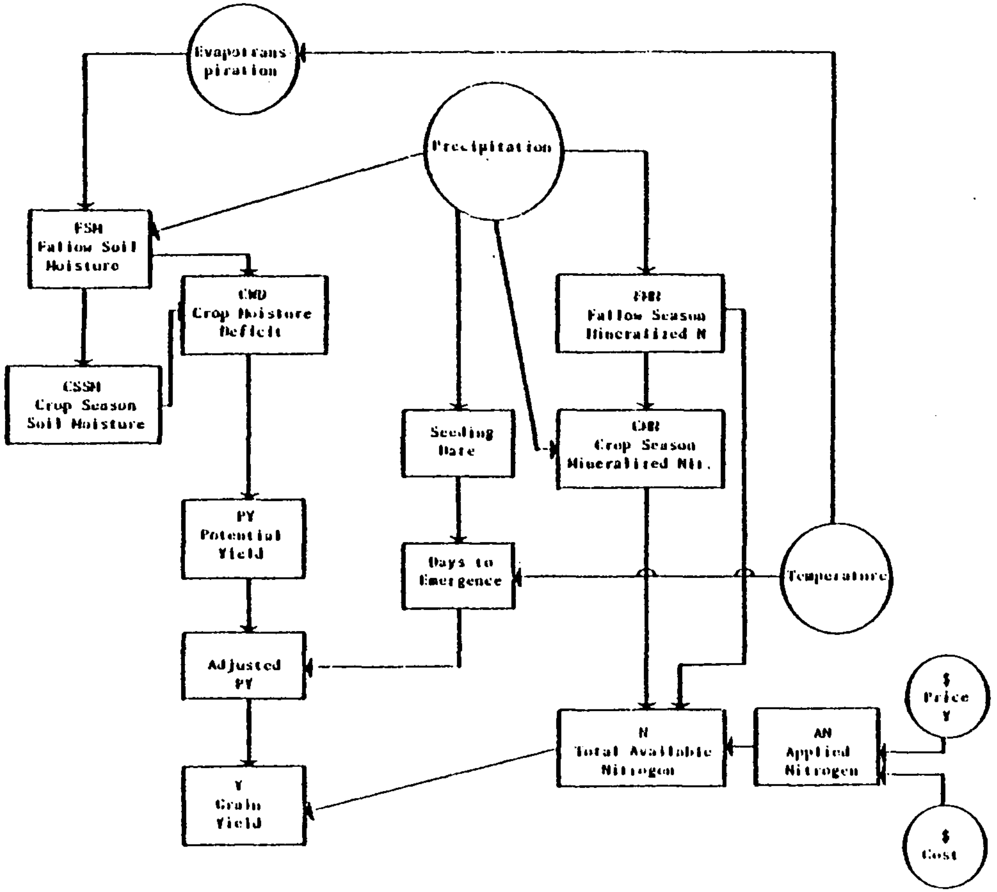


Figure I.1. Fractional Flow Diagram of Wheat Production all of the information needed for the estimation process. The functional forms of fallow and crop seasons mineralized nitrogen are given by equations [1] and [2] (D.M. Glenn, unpublished data).

$$FMN = 0 \quad , \text{ if } TFP \leq \beta_1 \tag{1a}$$

$$FMN = \beta_2[1.0 - e^{(\beta_3 + \beta_4 * TFP)}], \text{ if } TFP > \beta_1 \tag{1b}$$

where:

FMN = fallow season mineralized nitrogen in Kg/ha

TFP = total fallow season precipitation in millimeters (September to August)

β_1 = parameter for critical fallow season precipitation (= 163.5mm)

β_2 = asymptotic level of fallow season mineralization (= 30kg/ha)

β_3 = constant term (= 1.791)

β_4 = parameter for fallow season precipitation (= -.01095)

and

$$CMN = \beta_5 + \beta_6(FMN) + \beta_7(TFP) + \beta_8(TCP) \tag{2}$$

where:

CMN = crop season mineralized nitrogen in Kg/ha

β_5 = constant term (= 60 Kg/ha)

β_6 = parameter for fallow season mineralized nitrogen (= .187)

β_7 = parameter for fallow season total precipitation (= -.115)

β_8 = parameter for crop season total precipitation (= -.044)

TCP = total crop season precipitation in millimeters

FMN and TFP as in Equation (1).

(For estimation results, see Table A-1 of the appendix.)

Expected Potential Yields

Potential grain yield is defined as the maximum attainable yield under a particular sequence of weather conditions. This yield potential is estimated through functional relationships between available water supply and storage efficiency [Glenn, 1981; Glenn and Bolton, 1982]. The following sequence of equations calculate the efficiency of storage and the actual water stored during the fallow and crop season.

$$FSE = [\beta_{12} + \beta_{13}(\sum_{\text{April}}^{\text{Sept.}} ET_{of})]\beta_{14} \tag{3}$$

where:

FSE = fallow storage efficiency (percentage)

β_{12} = constant term (= 147.91)

β_{13} = parameter for ET_{of} (= .108)

ET_{of} = fallow season evapotranspiration in millimeters

β_{14} = percentage (= .01)

$$FSM = (FSE)(\sum_{\text{Nov.}}^{\text{March}} P_f) \tag{4}$$

where:

FSM = fallow stored moisture in millimeters

P_f = fallow season precipitation in millimeters

FSE as in Equation (3)

$$CSSE = [\beta_{15} + \beta_{16}(\sum_{Nov.}^{March} P_c)(FSM)]\ \beta_{14} \qquad (5)$$

where:

CSSE = crop season storage efficiency (percentage)

β_{15} = constant term (= 73.4)

β_{16} = parameter for interaction term (= .0014)

P_c = crop season precipitation in millimeters

FSM and β_{14} as in Equation (4).

$$CSSM = (CSSE)(\sum_{Nov.}^{March} P_c) \qquad (6)$$

where:

CSSM = crop season stored moisture in millimeters

CSSE and P_c as in Equation (5)

The combination of stored moisture in the fallow and crop seasons less evapotranspiration constitutes crop water deficit as in the following eqaution.

$$CWD = (FSM + CSSM) - \sum_{April}^{July} ET_{ow} \qquad (7)$$

where:

CWD = crop water deficit in millimeters

ET_{ow} = growing season monthly evapotranspiration of the crop year adjusted for phenological sensitivity to water stress

Potential yield is then estimated as a linear function of crop water deficit. This relation is depicted by Equation (8).

$$PY = \beta_{17} + \beta_{18}(CWD) \qquad (8)$$

where:

PY = potential yield in Kg/ha

β_{17} = constant term (= 5.08)

β_{18} = parameter for water deficit (= .0186)

CWD as in Equation (7)

However, potential yield is also influenced by time of emergence. That is, late emergence is expected to have a negative effect on yield potential (Glenn, 1981; Glenn and Bolton 1982).

$$PYAF = 1.0 - \beta_{19}[1.0 - e^{(\beta_{20} + \beta_{21}*DE)}], \text{ if } DE > \beta_{22} \tag{9a}$$

$$PYAF = 1.0 \qquad , \text{ if } DE \leq \beta_{22} \tag{9b}$$

where:

$PYAF$ = potential yield adjustment factor

β_{19} = asymptotic proportional reduction in yield potential (= .40)

β_{20} = constant term (= .7269)

β_{21} = parameter for DE (= -8.1364)

DE = days to emergence

β_{22} = critical (maximum) number of days for normal emergence (= 15)

Seeding Date

Soft white winter wheat is assumed to be seeded on one of three possible dates depending on the sequence and amount of precipitation received. These *a priori* criteria were based on field experience of Glenn and Bolton. This relationship is estimated as follows:

SD = September 30th, if $G_1 > \beta_9$, or $Z_1 \geq \beta_{10}$ (10a)

SD = October 30th, if $G_1 \leq \beta_9$, and $Z_1 < \beta_{10}$, and $Z_2 \geq \beta_{11}$ (10b)

SD = November 30th, if $G_1 \leq \beta_9$, and $Z_1 < \beta_{10}$, and $Z_2 < \beta_{11}$ (10c)

where:

SD = seeding date

β_9 = parameter for fallow season minimum precipitation criteria for September seeding (= 260mm)

Z_1 = precipitation amount received in September of crop year

β_{10} = parameter for September minimum precipitation criteria for September seeding (= 15mm)

Z_2 = precipitation amount received in October of crop year

β_{11} = parameter for October minimum precipitation criteria for October seeding (= 15mm)

G_1 = total fallow season precipitation

Days to Emergence

Emergence is assumed to occur after the accumulation of 150° of soil temperature (Russelle and Bolton, 1980). The positive temperature of each day following seeding, called degree days, is calculated. The estimation process is carried out in two stages. First, total degree days available from October through January and during the first 15 days of February are calculated. Second, by an elimination process, the month in which the requirement is fulfilled is identified, day of emergence is pinpointed and the total days from seeding to emergence are calculated. If 150 degree days are not accumulated by February 15, February 15 is taken as the default emergence date.

Of basic concern in the calculation process is the constantly decreasing soil temperature from seeding to emergence.[3/] The functions used to depict this relation are:

$$H = Z + X \tag{11}$$

where:

H = beginning of the month soil temperature estimate (°c)

Z = average month soil temperature (°c)

X = 15 days * 0.24°/day (= 3.6)

24°c = negative temperature gradient

$$L = Z - X \tag{12}$$

where:

L = end of month soil temperature estimate

Z and X are as in Equation (11)

For calculating the positive degree days in a given month, two different cases were considered:

Case 1: When $L > 0$ $(H > 0)$; and is estimated by:

$$A = \beta_d * Z \tag{13}$$

where:

A = degree days available in the month (°c)

β_d = a parameter equal to 30 days/month

Z as in Equation (11)

[3/] The calculation process was based on simple algebra. All the algebraic equations used were developed by Dr. Thomas Nordblom.

Case 2: When $H > 0$ and $L \leq 0$ (see Figure 2a); and is estimated by:

$$D_o = \frac{H}{0.24} \tag{14a}$$

$$A = \frac{H^2}{.48} \tag{14b}$$

where:

D_o = the day of zero degree soil temperature

A and H are as in Equations (11) and (13)

Equations (11) to (14) apply to the months of October through January. As for February, it is the first 15 days for which degree days are considered. Figure 2 (b and c) is helpful in the following calculations:

For $Z > 0$:

$$A = (\frac{Z + H}{2})\ 15 \tag{15}$$

where:

A = degree days available in the first 15 days of February

Z and H are as before.

For $H > 0$ and $Z \leq 0$:

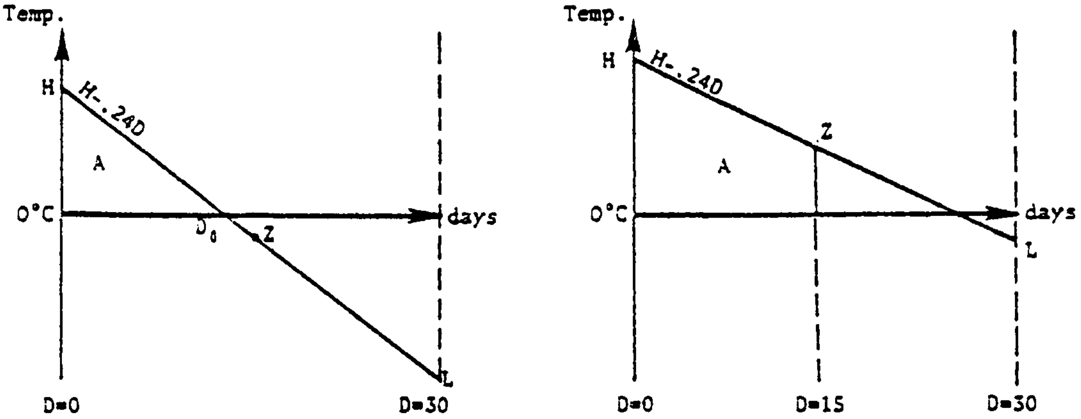
$$A = \frac{H^2}{.48} \tag{16}$$

where:

A as in Equation (15)

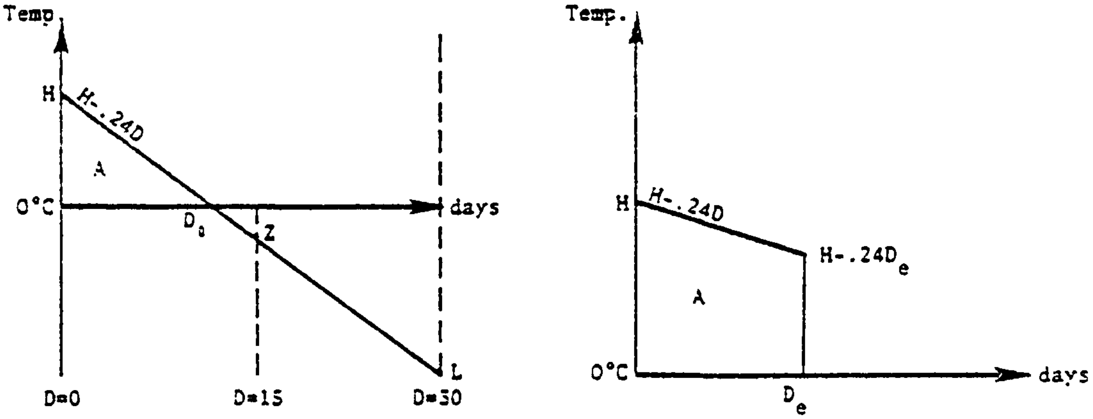
For $H \leq 0$: no degree days have accumulated in February

Given the three possible seeding dates, accumulation of degree days towards emergence requirement begins in the month immediately



a. Degree days (A) for $H > 0$ and $L < 0$

b. February degree days (A) for $Z > 0$



c. February degree days (A) for $H > 0$ and $Z < 0$.

d. Emergence day

Figure I.2. Estimation of Degree Days to Emergence following seeding. Using a stepwise process of elimination, the month in which emergence was expected is determined. Emergence day is determined by solving for D_e (see Figure 1d) in the following manner:

$$A = 2HD_e - .24D_e^2 \tag{17a}$$

$$D_e = \frac{2H - \sqrt{(2H)^2 - 1.92A}}{.48}^{\underline{4/}} \tag{17b}$$

Adding days from seeding to emergence gives the number of days to emergence.

Grain Yield - Nitrogen Response Function

Leggett [1959], Gardner et al. [1975] and Oregon State Fertilizer Guide [1976] reported that yield potential is attained only if nitrogen available to the crop is in the ratio of 50, 37 and 42 kg/ha/MT of potential yield, respectively. Other nitrogen quantities different than the specified optimum amount result in decreased grain yields. Considering varietal differences, Glenn [1981] found 40 kg/ha/MT of potential yield to be the optimum ratio in Eastern Oregon.

The above findings imply that realized grain yield is a function of potential yield and nitrogen available to the crop. Thus, for a given (weather-determined) potential yield, expected grain yield is specified as a quadratic function of nitrogen:

$$Y = aN^2 + bN + c \tag{18}$$

[4/] Choice of the negative sign when solving for the value of D_e was based on the following:

a) $.48\ D_e - 2H = \pm\sqrt{(2H)^2 - 1.92A} = X$; but b) $D_e \leq D_o = \frac{H}{.24}$ implying

c) $.48\ D_e \leq .48(H/.24) = 2H$; therefore d) $x \leq o$

where:

Y = predicted grain yield

N = total available nitrogen

a, b, and c are parameters whose equivalent values are determined next.

Following Glenn's results, grain yield is maximized, i.e., potential yield is attained, when N = 40PY. First order conditions for predicted grain yield (Y) maximization with respect to N give:

$$a = \frac{-b}{80PY} \tag{19}$$

Second order conditions ($\frac{\partial^2 Y}{\partial N^2} = 2a < 0$) imply a negative value for a and a positive b parameter since PY is, practically, positive.

Rewriting the yield equation for the maximizing level of N, the intercept, c, is solved for in terms of b and PY from the relation:

$$Y = PY = a(40PY)^2 + b(40PY) + c \tag{20}$$

and by substituting the value of a

$$c = PY(1 - 20b) \tag{21}$$

Hence, the predicted grain yield equation becomes:

$$Y = \frac{-b}{80PY} N^2 + bN + PY\ (1 - 20b) \tag{22}$$

The magnitude of the value of the slope, b, has implications on the curvature of the function through its effects on the values of the coefficient (a) and the intercept (c). Precisely, the smaller the value of b the smaller is the value of a and the larger is c which implies a lesser (flat) responsive function. Consequently, the value of b is directly related to the marginal product and, accordingly, its value. The estimated b values are .0108, .0337, .0287 and .0247 for fallow, seeding, crop and harvest times, respectively (see appendix for estimation procedure).

Second-Stage Model

The second stage of the model integrates all available information, whether from the first-stage model or exogenous sources, and includes it in the calculation process for a particular fertilization strategy. Specifically, given the available soil mineralized nitrogen, the model calculates optimum nitrogen levels to be applied and the corresponding net revenues.

Nitrogen Profit Function

The nitrogen profit function is defined as the total revenue from expected grain sales less the total cost attributed to applied quantity of nitrogen less expected revenue from grain sales given only soil mineralized nitrogen. This relationship is shown by:

$$\Pi = P_w\ (aN^2 + bN + c) - [F + U(N-MN)]I - P_w\ (a(MN)^2 + b(MN) + c) \qquad (23)$$

where:

Π = net profit from marginal nitrogen application ($/ha)

P_w = Wheat price ($/MT)

a = parameter in grain yield equation $(= \frac{-b}{80PY})$

b = slope of grain yield equation (constant)

c = intercept in grain yield equation (= PY(1 - 20b))

N = total nitrogen amount available to the crop (Kg/ha)

F = fixed application cost (\$/ha)

U = unit variable cost (\$/Kg)

MN = soil mineralized nitrogen (Kg/ha)

I = interest factor to compound application cost until harvest time [$I = (1.0 + r)^y$; r = interest rate and y = year fraction].

The above function assumes that all of the increases in profit is attributed to the quantity of the single factor nitrogen.

Maximizing the profit function with respect to N gives:

$$N^* = \frac{UI - P_w b}{2P_w a} \tag{24}$$

where N* equals optimum nitrogen level for maximum profit (Kg/ha). While the second order condition holds ($2P_w a < 0$ by definition of a), two additional conditions must be satisfied for application to take place. First, the optimum calculated amount should not be less than soil available amount (i.e., $N^* - MN > 0$). Second, expected profit given optimum nitrogen level must be positive (e.g., $E(\Pi/N^*) > 0$). The case where all conditions are satisfied is given by Figure 3.

Three time periods are specified for fertilizer application. These are (i) May 1st of fallow season, (ii) at seeding time, and (iii) March 30th of the crop season. No restriction is imposed against any combination of the three except that the amount applied to the growing crop (March 30th) could not exceed 40 KgN/ha.[5/]

[5/] 40 KgN/ha was assumed to be a safe upper limit to be applied to the growing crop. Exceeding this amount will result in reduced yield.

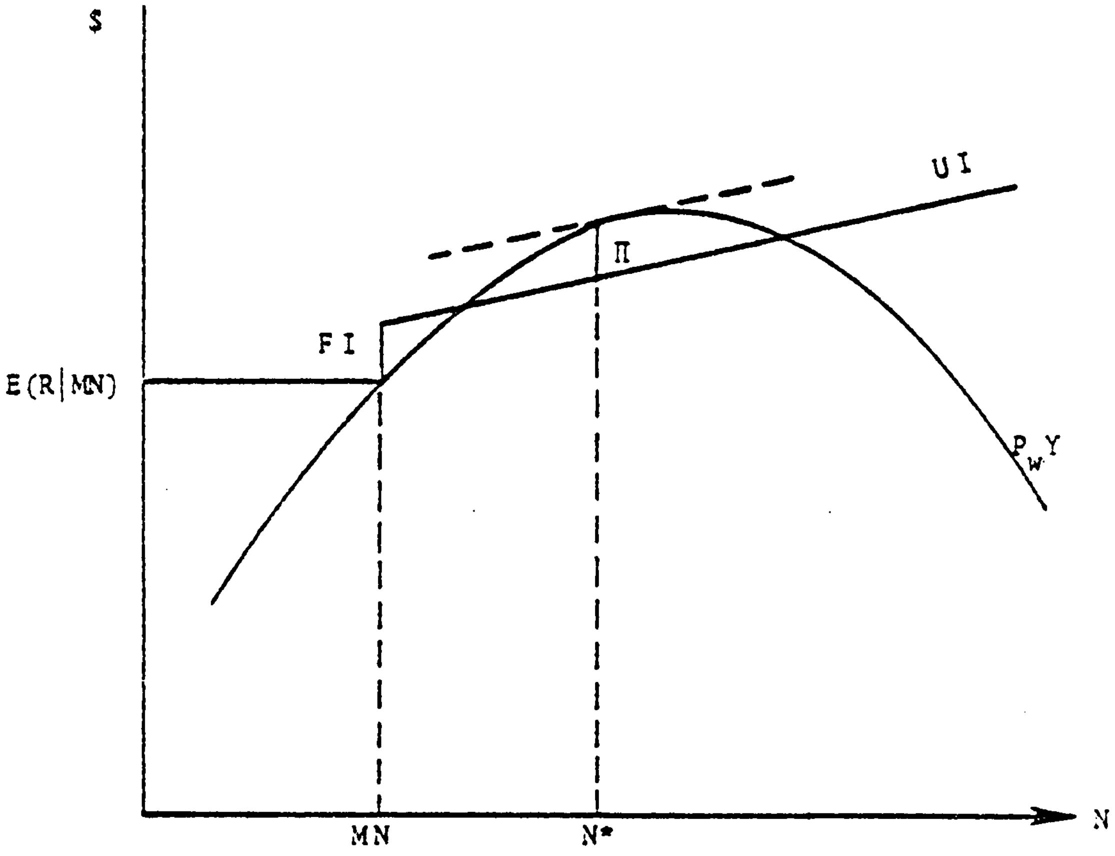


Figure I.3. Net Profit From Nitrogen Application

August 30th is taken as the harvest date and the crop is assumed to be marketed directly after harvest.

As described earlier, mineralized soil nitrogen and potential yield are predicted for the four time periods by utilizing the actual weather data up to that particular point in time beyond which seasonal averages are used.

Accordingly, the calculation procedure is directed to reflect the sequential nature of the decision-making process. Fallow time decisions are considered first. Then, the results of the fallow decisions are taken as input to seeding time decisions. Subsequently, the results of both fallow and seeding time decisions are fixed at crop season decision time. Finally, the net revenue is determined at harvest time given the results of all decisions. This relationship is represented by the flow chart in Figure 4.

Model Validation

The model was tested to see how well it predicted actual yields. This was done with goodness of fit tests. First, the agronimic (first-stage) model was tested for consistency by comparing forecasted potential to actual yields for the period 1918 to 1976. The coefficients of determination (R^2) where found to have the values of .008, .035, .093 and .155 for fallow, seeding, crop and harvest time periods, respectively. This result indicates an increasing value for the coefficient as the estimation process approaches harvest time. Mean potential yield at harvest time was 2.5 compared to the actual mean yield of 2.1 MT/ha.[6/] This relationship is consistent with the

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[6/] Mean potential yields for fallow, seeding and crop times were 2.32, 2.48 and 2.44 MT/ha, respectively (see Table A-1 in the appendix).

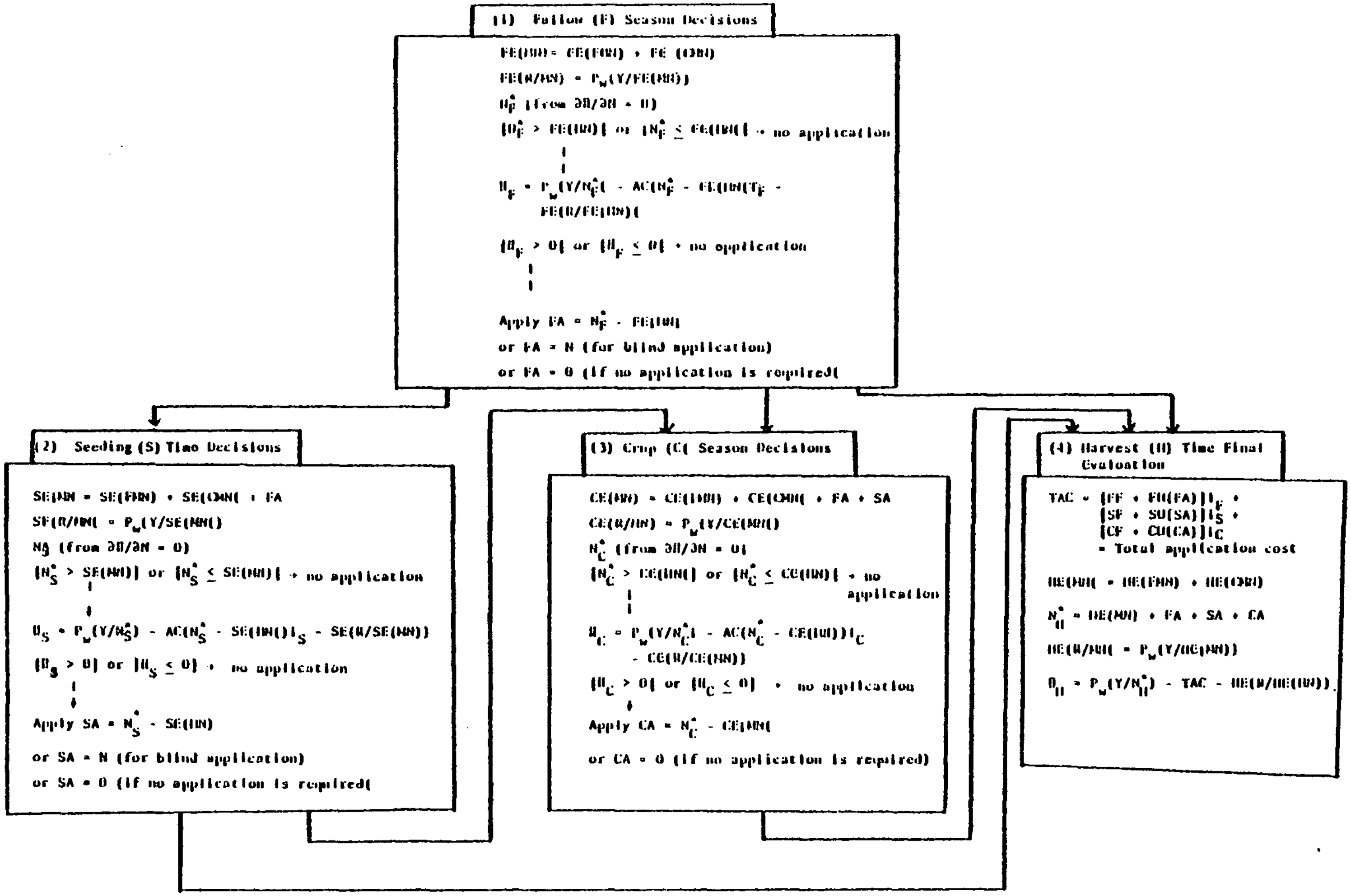

Figure I.4. Functional Flow Chart of Application Decisions and Net Revenue Calculation expectation that yield potential is equal or greater than realized yield.

Johnson and Rausser [1977] and Kost [1980] reported Thiel's inequality coefficient and the decomposition of Root Mean Square Error as two acceptable validation tests. Also, chi square is referenced as a reliable test for goodness of fit [see Johnson and Rausser, 1977; Ott, 1977]. Consequently, these methods are used for the second test.

The time period 1951 to 1976, for which input data (nitrogen fertilizer) was available for the commercial plot at the Sherman Branch Experiment Station (Moro) was considered for the second test. A summary of test results is presented in Table 1.

Table 1a shows statistically equal estimated and actual mean yields. Also, the value of Thiel's inequality coefficient is relatively low and the values for the bias and variation coefficients of the decomposed mean square error are almost zero. The results in Table 1b indicate that the predicted yield follows the same distribution as the actual (see Figure 5). These results imply a high degree of model predictability and reliability.

Potential Fertilization Strategies and Evaluation Procedure

The fertilization strategies considered for evaluation consisted of combinations of blind application (a fixed amount applied each year) and calculated optimum profit maximizing quantities. Potentially, there were twenty seven combinations which were reduced to thirteen.[7/]

[7/] There were three application periods (fallow season, seeding time, and crop season) and three alternative actions (no application, a blind application, or a calculated application).

Table I.1a. Test Results of Comparing Predicted to Actual Yields

Mean Actual Yield	Mean Predicted Yield	Thiel's Inequality Coefficient	Decomposed Mean Square Error		
			U-Bias	U-Variation	U-Covariation
2.44331	2.44415	0.104	0.000	0.002	0.998
(t = .0044)*					

* Fail to reject the null hypothesis that mean predicted yield equals mean actual yeild.

Table I.1b. Frequency Distribution of Predicted and Actual Yields

Time Period	Frequency Distribution										X^2
	Cell 1		Cell 2		Cell 3		Cell 4		Cell 5		
	Act.	Pred.	Act.	Pred.	Act.	Pred.	Act.	Pred.	Act.	Pred.	
1951-1976 4 cells	2	2	9	9	11	11	4	4	--	--	0.00[a]
1951-1976 5 cells	2	2	4	3	9	10	8	8	3	3	0.36[b]

[a] and [b] Fail to reject the null hypothesis that the distribution of predicted yield is identical to that of the actual.

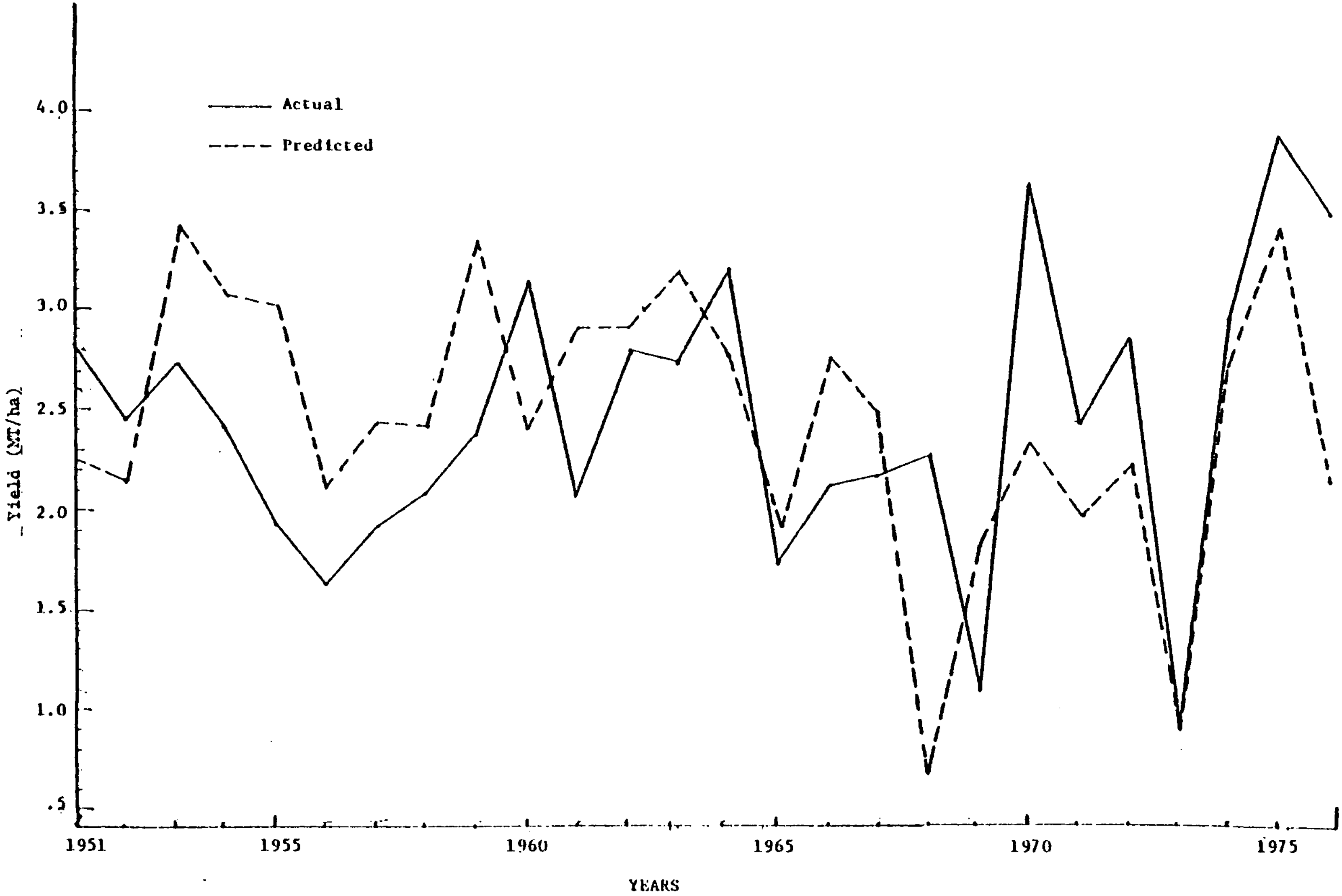

Figure I.5. Comparing Actual and Predicted Yield

The underlying assumptions were that: i) blind application is done only once a year, ii) no blind application is made to the growing crop and, iii) no blind application follows a calculated optimum application amount in the previous decision period.

The procedure followed for determining optimum nitrogen quantities for blind application strategies involved two steps. First, the relevant interval was located through repreated model runs with randomly chosen quantities (see Figure 3). Second, the optimum quantity was approximated by narrowing the interval by trying more appropriate nitrogen quantities. For strategies involving calculated application, profit maximizing quantities were determined by the model in one step in the profit maximization context described earlier. Optimum quantities to be blindly applied in a combined blind and calculated application strategies were approximated by repeated runs. The technical relationships of evaluations are given in Figure 4.

Results

Profit maximizing nitrogen quantities to be applied, given average mineralized nitrogen, average potential yield and 1980 prices and costs, were calculated as 25.72, 41.08 and 46.73 KgN/ha for fallow, seeding and crop decision times, respectively. The corresponding net revenues were -.06, 48.97 and 41.22 $/ha, respectively. These results indicate that, on average, the more information is obtained, the more fertilizer is required. This is not necessarily true for maximum net revenues as they are also a function of application costs at a particular decision period.

Three simulation runs were made for each of the thirteen strategies for the time period 1918 to 1976 in an attempt to determine the sensitivity of the strategies to alternative costs and prices. In the first run, 1980 prices and costs were used. Average wheat price for the last ten years and 1980 costs were used for the second run. The last run was made with average wheat prices and a 20 percent inflated 1980 costs. The results are given in Table 2.

The calculated combined application strategy at fallow and crop seasons dominates all other strategies with respect to expected net profits given 1980 prices ($4.00/bu) and costs. Calculated application to the growing crop ranked second. The strategies of blind fallow application combined with calculated application to the growing crop and blind application at seeding time combined with calculated crop season application ranked third and fourth, respectively. It should be noted that all of these "better" strategies involve a complete or partial calculated application of nitrogen fertilizer to the growing crop.

While the expected profits from these "better" strategies do not significantly differ from one another, the distribution of profit is different, however. All distributions are skewed to the right (Figure 6) with a non-negative profit percentage years of 86.4, 86.4, 81.4 and 78.0 for the first, second, third and fourth ranked strategies, respectively.8/

8/ These results could be further analyzed through stochastic dominance procedures to detect the dominant set.

Table I.2. Expected Profits and Optimal Nitrogen Levels for Application Strategies

		BF[a]	BF+CS[b]	BF+CS+CC[c]	BF+CC	BS[d]	BS+CC	CF[e]	CF+CS	CF+CS+CC	CF+CC	CS	CS+CC	CC
1980 Wheat Price and Application Costs	$E(\pi)$[f]	20.07	19.27	20.13	26.33	14.82	24.99	4.19	16.51	18.41	27.30	16.34	18.24	26.58
	$\sigma\pi$[g]	36.71	41.62	43.18	33.93	29.18	31.74	13.00	39.05	42.00	30.25	39.02	41.98	29.27
	E(AN)[h]	36.00	47.57[j]$_{34}$	52.93$_{31}$	41.00$_{20}$	30.00	39.12$_{15}$	3.14	44.77	51.24	35.44	44.66	51.13	33.62
	σAN	00.00	21.68	23.28	16.97	00.00	17.07	9.36	24.92	24.80	12.99	25.00	24.91	10.26
	Rank[i]	6th	7th	5th	3rd	12th	4th	13th	10th	8th	1st	11th	9th	2nd
Average Wheat Price and 1980 Application Costs	$E(\pi)$	13.43	12.41	13.01	17.75	8.83	16.54	00.00	9.56	11.11	19.26	9.56	11.11	19.26
	$\sigma\pi$	27.95	32.69	33.92	25.97	21.79	25.37	00.00	30.20	32.34	23.76	30.20	32.34	23.76
	E(AN)	33.00	45.04$_{33}$	49.69$_{31}$	38.32$_{17}$	27.00	36.13$_{10}$	00.00	42.05	47.26	33.03	42.05	47.26	33.03
	σAN	00.00	20.73	22.70	17.13	00.00	16.56	00.00	24.05	24.64	10.62	24.19	24.64	10.62
	Rank	4th	6th	5th	2nd	9th	3rd	10th	--[k]	--	--	8th	7th	1st
Average Wheat Price and Inflated 1980 Costs	$E(\pi)$	8.86	7.19	7.94	12.01	4.38	12.08	00.00	4.22	5.75	15.05	4.22	5.75	15.05
	$\sigma\pi$	25.85	27.38	29.55	25.50	17.03	21.10	00.00	26.48	28.37	22.13	26.48	28.37	22.13
	E(AN)	31.00	40.17$_{28}$	44.58$_{29}$	37.16$_{21}$	22.00	32.94$_{9}$	00.00	38.41	42.94	31.06	38.41	42.94	31.06
	σAN	00.00	20.61	22.28	16.57	00.00	17.72	00.00	23.34	23.99	13.26	23.34	23.99	13.26
	Rank	4th	6th	5th	3rd	8th	2nd	10th	--	--	--	9th	7th	1st

[a] BF = Blind application at fallow season.
[b] CS = Calculated application at seeding time.
[c] CC = Calculated application to growing crop.
[d] BS = Blind application at seeding time.
[e] CF = Calculated application at fallow season.
[f] $E(\pi)$ = Expected net profit ($/ha).
[g] σ = Standard deviation.
[h] E(AN) = Expected applied Nitrogen amount (Kg/ha).
[i] Ranking is based on expected profits.
[j] Number in corners indicate optimal amounts to be blindly applied.
[k] -- Indicates that strategies including combinations of CF are excluded from ranking as zero profits are expected from CF alone.

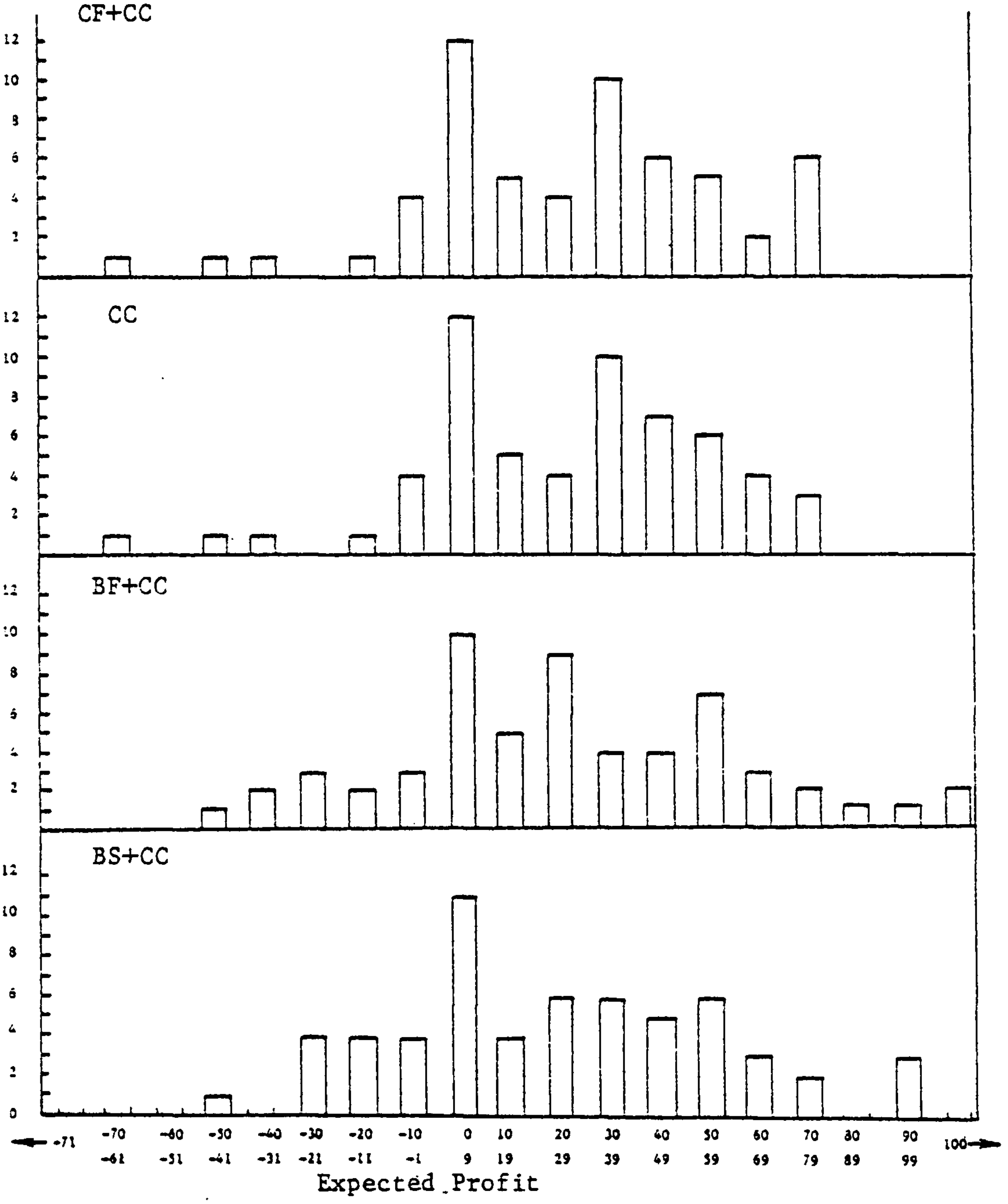

Figure I.6. Distribution of Expected Profits

In reference to the demand for fertilizer, calculated application to the growing crop requires the least average amount. This is also associated with a least application variability.

Blind application at fallow season ranked sixth given 1980 prices and costs which suggests that it is a good strategy if no information is available for the calculation process. The optimum fertilizer quantity suggested by the model is 36 KgN/ha. Discussion with knowledgeable agronomists confirmed that the common fertilization strategy is a blind application of 40 KgN/ha at fallow time or in a split application at fallow and crop seasons. This is consistent with the nitrogen amount determined by the model for the strategies involving blind fallow application alone or in combination with calculated crop season application.

When the average wheat price ($3.4/bu) and 1980 costs were used the results indicate that calculated application at crop season gives the highest expected profits. Naturally, the profits are smaller since the price of wheat has decreased while the costs remained unchanged. Again, this strategy requires the smallest fertilizer application and it has the smallest associated variance. Likewise, this strategy ranks first when costs are increased by 20 percent and the average wheat price is maintained. On the other hand, calculated application at fallow time, in all cases, is the least profitable.

In the three simulation runs, if one compares the strategies involving fixed application only, blind application at fallow season always dominates blind seeding time application. In the case of strategies involving only calculated application, application to the growing crop gives the best results followed by application at seeding time. Calculated fallow application gives the least profits. This result implies that delayed application is favorable and also consistent with the hypothesis that calls for the consideration of short term weather conditions when making fertilization decisions.

Finally, a simulation run was made with a six percent rate of interest (seven percent less than the 1980 prevailing rate)[9/] given 1980 prices and costs. The results showed no significant change in expected profits and hence, ranking of strategies was not affected.

Conclusions and Limitations

The model developed for the purpose of this study appears to have acceptable predictive ability. It determined 36 KgN/ha to be applied at fallow time and 41 KgN/ha for a split fallow-crop season application. This is consistent with the observed fixed application of 40 Kg/ha.

When blind fertilization practices were compared to calculated strategies that utilize short-term weather conditions, net profits were found to increase considerably. Although the calculated strategies did not maintain consistent rankings for alternative market conditions, the strategy of applying calculated optimum nitrogen quantities to the growing crop generates the highest expected net profits particularly under the expectations of increased

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[9/] The interest rate for operating capital in 1980 was 13% (Oregon State University Extension Service, 1979-80).

costs and/or decreasing gross margins. Adopting this strategy is expected to result in less fertilizer usage.

Although this study is oriented to provide information that could be important to wheat producers in North Central Oregon, the methodology used has other advantages considering different regions or countries. One advantage is that this methodology could serve as a guide to policy making in reference to the explicit way in which factor use is presented. Also, it is beneficial in supplying useful information that could be helpful in credit policy improvement.

The profit maximization approach adopted in this study implicitly assumes, among other things, neutral risk effects. This assumption, however, is unrealistic if risk has a significant effect on the decision making process. The incorporation of risk factors will be considered in the second manuscript.

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MANUSCRIPT II

RISK AND FERTILIZATION STRATEGIES: DRYLAND WHEAT IN NORTH CENTRAL OREGON

RISK AND FERTILIZATION STRATEGIES:
DRYLAND WHEAT IN NORTH CENTRAL OREGON

Introduction

The inclusion of risk considerations in practical agricultural decision making has been the subject of many theoretical and empirical investigations over the past two decades. Most, if not all, of the studies recommend that risk be explicitly considered in decision models.

Output variability related to technological innovations is one area that has received considerable attention. The stochastic nature of fertilizer response functions have been recognized in many studies (e.g., Fuller, Day, de Janvry, and Anderson). However, when estimating the effect of inputs on risk many common functional forms possess an *a apriori* restriction on the nature of the effect of inputs [Just and Pope, 1978, 1979]. Just and Pope report an estimation procedure to relax such restraints.

Accounting for producer's risk attitudes in the decision making process is also important. Empirical measurements of behavioral adjustments in the face of risky options is documented in the literature. The primary objective of this study is to investigate the effect of wheat yield variability and risk attitude on decision making with regard to fertilization strategies.

To achieve this objective, a risk-avoiding utility maximizing simulation model is developed. The model is developed using historic weather information for North Central Oregon in estimating the results of potential fertilization strategies on both yield and yield variability.

The model is then utilized to study the effect of risk neutral and risk averse decision making.

This essay provides a description of the model and the results of the study. Conclusions are represented in the last section.

Incorporating Risk in a Fertilizer Application Model

The incorporation of risk into a fertilizer application model required three sets of considerations. First, the question of risk estimation is addressed. Second, a framework for risk in decision making is proposed and the risk estimation entered within this framework. Third, the specific implementation including the timing aspects of the fertilization decision making is formulated.

Variability of Yield

The basic methodology used for determining wheat yields involves the estimation of a production function. Since the focus involved risk, the production function includes estimates of both mean yield and yield variability as related to input use. This was done following the approach developed by Just and Pope. The basic requirement for the estimation process is the use of a function in the form:

$$Y = f(x) + h^{\frac{1}{2}}(x)\varepsilon \ , \ E(\varepsilon) = 0 \ , \ V(\varepsilon) > 0 \qquad (1)$$

where f(x) is the expectation of yield (Y), h(x) is its variance and the ε is unexplained variation. Just and Pope suggest a three stage estimation procedure to estimate this functional form. First, initial parameter estimates are developed for f(x) by applying ordinary least square (OLS) regression to $Y_t = f(x_t) + \varepsilon_t^*$, where ε_t^* is a stochastic term. The parameters of $h^{\frac{1}{2}}(x)$ are estimated in the second stage by regressing $\varepsilon_t^* = h^{\frac{1}{2}}(x_t)$. Finally, given the estimated parameters from the second stage, an OLS regression is done on f(x) using the relationship $Y_t\ h^{-\frac{1}{2}}(x_t) = f(x_t)\ h^{-\frac{1}{2}}(x_t) + \varepsilon_t$.

Following the Just and Pope approach, a nitrogen response function was developed (see Ahmed for a detailed description) with modification to estimate yield variable in wheat. The conceptual form of the function incorporates stochastic weather conditions and weather determined mineralized soil nitrogen. The function is given as:

$$Y = (aN^2 + bN + c) + \alpha_0\ N^{\alpha_1}(PY)^{\alpha_2}\ \varepsilon \qquad (2)$$

where:

Y = wheat grain yield (MT/ha)

a = parameter in expected yield function established so that maximum yield occurs at a level of 40 Kg of nitrogen per metric ton of potential yield. Thus, $a = \frac{-b}{80PY}$.

N = total available nitrogen (soil mineralized plus applied) Kg/ha

b = slope of expected yield function

c = intercept of expected yield function established so that expected grain yield is maximum, i.e., equal to potential yield. Thus, $c = (1 - 20b)PY$.

PY = potential yield

α_0 = constant term in yield variability component

α_1 = parameter for total available nitrogen in yield variability component

α_2 = parameter for potential yield in yield variability component

ε = stochastic term

Accordingly, the mean yield was estimated by OLS regression of the form:

$$Y_t = \left(\frac{-N_t^2}{80PY_t} + N_t - 20PY_t\right)b + PY_t + \varepsilon_t^* \qquad (3a)$$

or equivalently

$$Y_t - PY_t = \left(\frac{-N_t^2}{80PY_t} + N_t - 20PY_t\right)b + \varepsilon_t^* \qquad (3b)$$

where b is the parameter to be estimated. The yield variability component is estimated by OLS regression of the form:

$$\operatorname{Ln}|\varepsilon_t^*| = A + \alpha_1 \operatorname{Ln}(N_t) + \alpha_2 \operatorname{Ln}(PY_t) + U_t^* \qquad (4)$$

where:

$$\varepsilon_t^* = Y_t - PY_t - \left(\frac{-N_t^2}{80PY_t} + N_t - 20PY_t\right)\hat{b}$$

$A = \operatorname{Ln}(\alpha_0)$

α_1 and α_2 are the coefficients of total available nitrogen and potential yield, respectively.

Using the absolute value of ε_t^* was shown to give consistent OLS estimated coefficients except for the constant term α_0 (Just and Pope, 1978). Also, use of absolute value guarantees that variance ε_t^* will not be negative (Just and Pope, 1979).[1/] The estimated coefficient A, however, is found to be biased downwards. This bias is removed by adding .6352 to the estimated coefficient A following Just and Pope, and Harvey.

[1/] Note that natural logarithms are undefined for negative values of ε_t^*.

In the third step, the slope, b, is re-estimated by applying OLS to the relation:

$$\frac{Y_t - PY_t}{\hat{\alpha}_0 N_t^{\hat{\alpha}_1} (PY_t)^{\hat{\alpha}_2}} = \left(\frac{\frac{-N_t^2}{80PY_t} + N_t - 20\ PY_t}{\hat{\alpha}_0 N_t^{\hat{\alpha}_1} (PY_t)^{\hat{\alpha}_2}} \right) b + \varepsilon_t \qquad (5)$$

Finally, variance ε is obtained from the results of equation (5).

The Utility Function

A potentially important consideration in fertilizer application strategies is the farmer's response to risk. Risk is considered in this study utilizing the Bernoullian expected utility framework. This was done by explicitly intorducint the following objective function [Freund; Hazell and Scandizzo; and Bussey]:

$$\text{Max } EU(\Pi) - \phi\ \sigma^2_\pi \qquad (6)$$

where:

EU = expected utility

Π = profit or net revenue

ϕ = risk aversion coefficient

σ^2_π = variance of profit

Now, given the production function in (1), equation (6) becomes:

$$\text{Max } EU(\Pi) = Pf(x) - c(x) - \phi\ P^2 h(x)\ \sigma^2_\varepsilon \qquad (7)$$

where P, c(x) and σ^2_ε are price, activity cost and variance of the stochastic term, respectively. Competitive markets are assumed. Maximizing equation (7) with respect to the decision variable X, the optimum activity level can be determined for a specified value of the risk aversion coefficient ϕ.

Empirically, the risk aversion coefficient (λ) was linearly estimated following McCarl. The MOTAD model and its variants have been used extensively [see Brink and McCarl for a review]. This model is of the form:

$$\text{Max } E(\Pi) - \lambda\, h^{\frac{1}{2}}(x)\, \sigma_{\varepsilon} \qquad (8)$$

where λ is the risk aversion coefficient and found to be ranging between zero and two. Assuming equal marginal effects of risk implies that $\phi = \frac{\lambda}{2\sigma\Pi}$ which completes the definition of all the terms in the utility function to be maximized (for the derivation of the relationship between ϕ and λ, see the appendix).

Now, given the estimated function in equation (2), expected profit from nitrogen application was defined as:

$$E(\Pi) = P_w(aN^2 + \hat{b}N + c) - [F + U(N-MN)]I - E(R/MN)$$

where:

P_w = wheat market price

F = fixed cost of nitrogen application (\$/ha)

U = unit variable cost of nitrogen application (\$/kg)

N = total nitrogen available to the crop (Kg/ha)

MN = soil mineralized nitrogen (Kg/ha)

I = interest factor to compound application cost

$E(R/MN)$ = expected revenue given soil mineralized nitrogen ($= P_w\,(a(MN)^2 + \hat{b}(MN) + c)$) (\$/ha)

Substituting $\frac{\lambda}{2h^{\frac{1}{2}}(x)\sigma\varepsilon}$ for ϕ, the utility maximizing objective function was specified as:

$$\begin{aligned}\text{Max } EU(\Pi) = {} & P_w\,(aN^2 + bN + c) - [F + U(N-MN)]I \\ & - E(R/MN) - \lambda/_2\, P_w\, \hat{\alpha}_0\, N^{\hat{\alpha}_1}(PY)^{\hat{\alpha}_2}\sigma\varepsilon \qquad (9)\end{aligned}$$

Equation (9) can then be maximized with respect to N through root finding procedures such as the Newton-Raphson Method (Britton et al.; and Kohenberger et al.) to determine the optimal utility maximizing quantity of nitrogen to be available to the crop.[2/]

Risk and Timing

The fertilizer decision problem in reality involves fertilization at many times during the year. The model allows fertilizer application at three time periods (1) May 1st of fallow season, (2) at seeding time, and (3) March 30th of the crop season. No restriction was imposed on when and how much fertilizer is used except that the amount to be applied to the growing crop could not exceed 40 Kg/ha. August 30th was taken as the harvest date and the crop was assumed to be marketed directly after harvest.

The time period at which the fertilizer is applied has implications for both the mean and variance of the response function. Consequently, Just and Pope production functions were estimated for each of the three time periods as well as harvest time for evaluation purposes.

In turn, the model was designed so that fallow time decisions were made first, while seeding time decisions were made in light of what was decided upon at fallow season. Ultimately, crop season decisions take into account all the previous time period decisions. The final results of the decisions were evaluated at harvest time. The decision making and evaluation procedure is described by the flow chart

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[2/] Three conditions must hold equally for fertilizer application: a) $2P_w a - (\hat{\alpha}_1 - 1)\, \hat{\alpha}_1\, \lambda/_2\, P_w\, \hat{\alpha}_0\, N^{\hat{\alpha}_1 - 2}\, (PY)^{\hat{\alpha}_2} \sigma\varepsilon < o$, b) optimal N should not be less than the soil mineralized nitrogen (MN), and c) $E(\Pi) > 0$.

chart in Figure 1.

Estimation Results

The production function in equation (2) was estimated for each of the three time periods. The data used included yields and weather statistics obtained from the Sherman Branch Experiment Station (see Ahmed). Estimation results are given in Table 1.[3/]

The results in Table 1 show, in general, an increasing value for the coefficient of determination (R^2), for all three stages, as the estimation process approaches harvest time. However, the value of R^2 at seeding time is greater than that at crop season but less than that at harvest time in the first estimation stage. The ordering is also slightly off in the thrid stage. Obtaining more efficient b estimates is the purpose of the third stage, however. The low R^2 values (maximum of .154 at harvest) are of concern to the author although they are not materially different from those reported by Just and Pope (1979). They reported .219 and .22 for R^2 when they estimated Cobb-Douglas fertilizer response functions.

All harvest time estimated coefficients are significant compared to other time periods.[4/] These results are consistent with the expectations that the more information obtained the more reliable are the results. In other words, more knowledge is obtained about weather conditions approaching harvest time.

[3/] A problem of serial correlation was encountered in all three stages. This problem was corrected through a maximum likelihood iterative technique.

[4/] Minimum significance level is .10 (for α_1) at harvest time while at least one coefficient has a lower level of significance in each of fallow, seeding and crop time periods.

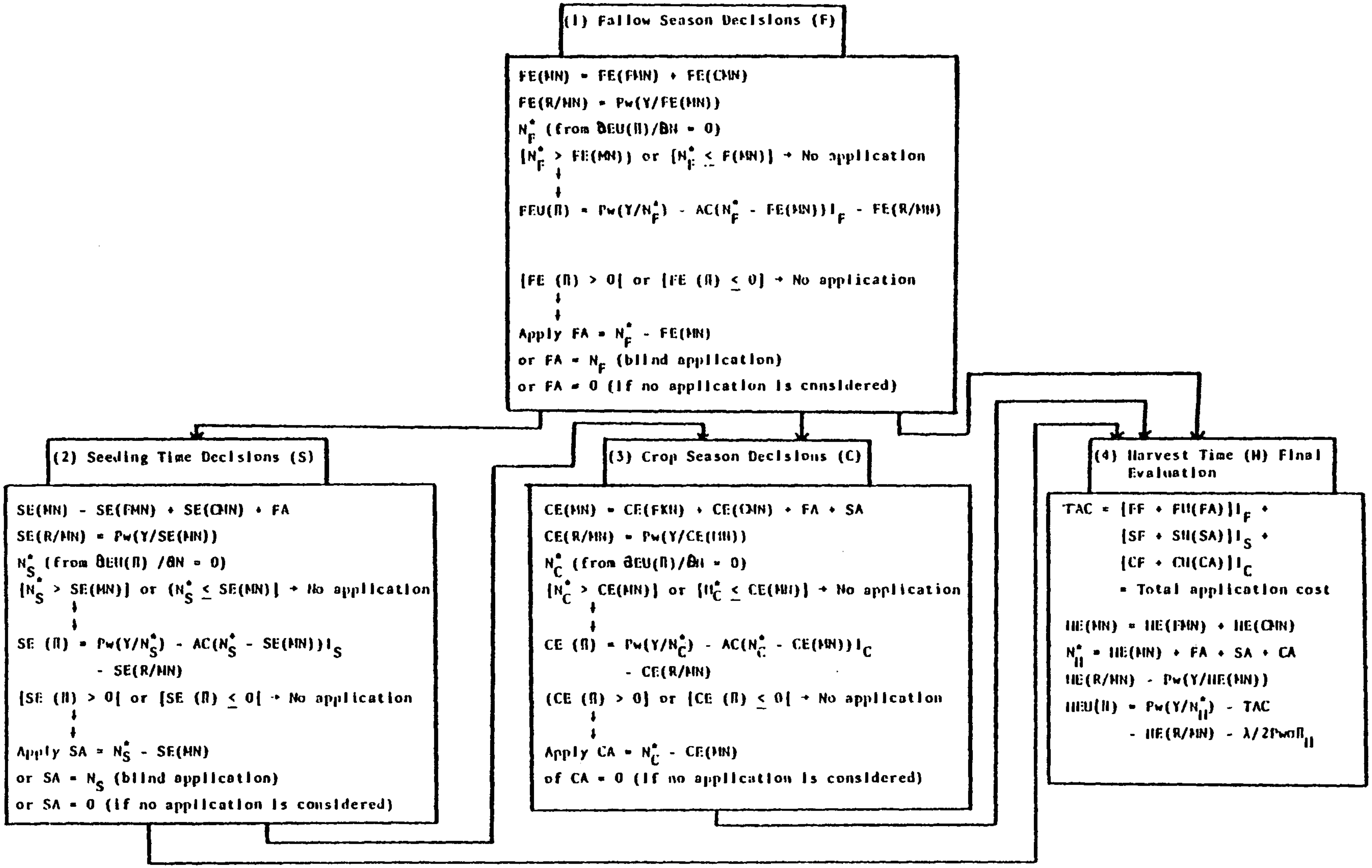

Figure II.1. Functional Flow Chart of Fertilization Decision Making and Expected Utility Calculation

Table II.1. Estimates of Fertilizer Response Functions

Time Period	First Stage		Second Stage					Third Stage		σ_ϵ^2
	$\hat{b}$	R^2	$\hat{A}$	$A^{*a/}$	$\hat{\alpha}_1$	$\hat{\alpha}_2$	R^2	$\hat{b}$	R^2	
Fallow	.0108 (.0086)	.059	2.268 (2.725)	2.903	.0287 (.1829)	-3.713 (2.999)	.033	.0116 (.0078)	.059	0.587
Seeding	.0337 (.0049)	.136	-2.57 (1.264)	-1.935	.202 (.260)	.962 (.444)	.054	.030 (.006)	.127	0.711
Crop	.0287 (.0063)	.098	-4.422 (1.14)	-3.787	.685 (.226)	.785 (.551)	.116	.0277 (.0048)	.097	0.694
Harvest	.0247 (.0049)	.154	-3.170 (1.011)	-2.534	.351 (.211)	1.131 (.343)	.131	.0099 (.0051)	.122	0.618

Note: Figures in parenthesis are OLS Standard errors.

a/ A* is the corrected natural log of the constant (α_0).

Except for fallow season, the (b) values become smaller when they are re-estimated through the various stages. The (b) values at harvest time was substantially decreased. This decreasing magnitude of b has implications on the shape of the estimated function. That is, by definition of the parameter a and the intercept c, the deterministic component will be less responsive (flatter) to nitrogen the smaller the value of b. Hence, the value of the slope is directly related to the marginal product and, accordingly, its value. Consequently, optimum utility maximizing nitrogen quantities are expected to be a function of the slope b and yield variability. Thus, the amount of fertilizer to be applied is expected to be the smallest at fallow time, largest at seeding time and somewhere in between at crop season.

Consistent with the findings of Fuller, and Just and Pope (1979), the estimated coefficients for available nitrogen indicate a positive marginal effect on yield variability for all time periods. Given average soil mineralized nitrogen and average potential yields, the variance in yield is found to be .465, .375, .220 and .403 for fallow, seeding, crop and harvest times, respectively. These results are consistent with respect to the expectations regarding the magnitude of the variance for the three decision periods (fallow, seeding and crop times), i.e., the largest variance is expected to be at fallow time where the least information about the short-run weather is available. However, the variance at harvest time, as seen above, is unexpectedly larger than the ones at seeding and crop time periods. Apparently, there are two opposite forces governing the magnitude of the variance. The first one is related to the expectations about the role of increased weather information in reducing the variance. The other is related to the reliability of the estimation process in reflecting the actual variability in the estimated variables.[5] While the first force seemed to work in the decision periods, the second appeared to be the dominant at harvest time.

Utility Maximizing Results

The models estimated above provide the basis for investigation of fertilizer decision making under risk. Thirteen potential strategies were evaluated. They included combinations of a fixed and calculated-utility maximizing-amounts of nitrogen. Three values were specified for the risk coefficient (λ). These values were zero, one and two. The prices and costs in 1980 were used in the evaluation process.

Evaluation of strategies required two steps. The first step involved the determination of the optimal (fixed or calculated) nitrogen amount to be applied at a certain decision period(s) as specified by a particular strategy. Second, the expected utility calculation was done at harvest time given the decision(s) in the previous periods (see Figure 1).[6] The results of evaluation are given in Table 2.

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[5] Soil mineralized nitrogen and potential yield are weather determined variables. They were estimated for each of the four time periods utilizing actual weather information up to a decision point and then seasonal averages are used beyond that point (see Ahmed). The larger the period for which season averages are used, the smaller will be the variance of the predicted yield.

[6] Optimum quantities for strategies involving fixed applications were approximated by repeated trials in which the quantity to be applied is varied each time. Calculated applications are done in one step as explained earlier in the text.

Table II.2. Evaluation of Fertilization Strategies Under Different Levels of Risk Aversion

		BF[a]	BF+CS[b]	BF+CS+CC[c]	BF+CC	BS[d]	BS+CC	CF[e]	CF+CS	CF+CS+CC	CF+CC	CS	CS+CC	CC
λ = 0	EU(Π)[f]	- 3.89	- 12.43	- 14.22	- 8.02	- 3.62	- 3.59	- .08	- 13.91	- 16.47	- 4.97	- 14.71	- 17.26	- 3.59
	σμ[g]	5.95	15.34	15.39	9.29	0.92	10.12	5.79	13.50	12.35	9.55	14.49	13.29	10.12
	E(AN)[h]	17.00	46.05[j] 34	51.89 37	39.00 16	3.00	33.50 0	8.90	42.67	50.33	38.34	42.83	50.50	33.50
	σAN	00.00	20.80	22.15	17.27	00.00	10.33	13.54	24.48	24.54	16.30	24.43	24.44	10.33
	Rank[i]	4th	7th	9th	6th	3rd	--[k]	1st	8th	11th	5th	10th	12th	2nd
λ = 1	EU(Π)	-47.18	- 73.54	- 75.34	- 65.88	- 47.18	- 60.74	- 51.04	- 73.69	- 76.04	- 63.07	- 74.31	- 76.66	- 60.74
	σμ	17.87	24.53	24.82	21.00	17.87	18.68	19.52	25.51	25.86	21.01	25.47	25.76	18.68
	E(AN)	00.00	42.06 28	45.02 30	31.39 12	00.00	29.42 0	8.54	39.79	43.22	32.34	39.89	43.32	29.42
	σAN	00.00	20.86	20.57	14.86	00.00	11.92	12.99	23.40	22.49	15.32	23.39	22.45	11.92
	Rank	--	5th	8th	4th	--	--	1st	6th	9th	3rd	7th	10th	2nd
λ = 2	EU(Π)	-94.35	-132.33	-132.98	-117.29	-94.35	-112.15	-100.60	-132.02	-132.89	-111.67	-132.19	-133.06	-112.15
	σμ	35.75	50.67	50.77	45.71	35.75	44.55	40.43	50.83	50.95	44.81	50.87	50.98	44.55
	E(AN)	00.00	37.65 22	38.19 22	20.37 8	00.00	19.56 0	7.35	36.83	37.74	20.85	36.75	37.67	19.56
	σAN	00.00	20.88	20.62	11.51	00.00	11.97	12.15	22.20	21.62	12.14	22.65	21.68	11.97
	Rank	--	7th	9th	4th	--	--	1st	5th	8th	3rd	6th	10th	2nd

[a] BF = Blind application at fallow season.
[b] CS = Calculated application at seeding time.
[c] CC = Calculated application to growing crop.
[d] BS = Blind application at seeding time.
[e] CF = Calculated application at fallow season.
[f] EU(Π) = Expected utility of profit /ha.
[g] σ = Standard deviation.
[h] E(AN) = Expected applied nitrogen Kg/ha.
[i] Ranking is based on expected utility.
[j] Numbers in corners indicate optimal amounts to be blindly applied.
[k] -- indicates that no blind application should take place.

The results for neutral aversion to risk ($\lambda = 0$) indicate negative expected utility (or equivalently expected profit) for all evaluated strategies. This result could be justified according to two relationships. First, the final estimates of the slope (b) imply more nitrogen responsive functions at the decision periods than at harvest time. Consequently, fertilization decisions based on such functions are expected to call for relatively higher levels of applied nitrogen. Second, calculation of expected tuility is done at harvest time and accounts for the decisions in the previous time periods. Hence, considering the nature of the function at harvest time, returns to the quantities decided upon are decreased.

The strategy of calculated application at fallow time give the highest expected utility for the risk neutral case. This is consistent, in terms of time of application, with the observed farmers' application behavior. No blind application, at any time period, is found to be the best strategy for higher levels of risk aversion with respect to expected utility. Calculated application to the growing crop ranks second in all cases (excluding zero application). However, the strategy of calculated application at seeding time combined with calculated application at crop season constantly ranks last. In summary, there is a consistency in rankings of strategies that recommend application of positive nitrogen quantities, at least for the first four spots.

Despite the consistency in the ranks of the four "better" strategies in reference to expected utility, this consistency does not apply to the associated variances. While the mean and variance give a general idea about the performance of the strategies, the distribution (skewness) of expected utility is important in determining the dominant one(s). Such distribution is shown for the first three "better" strategies in Figure 2 (also see Tables A-1 to A-3 in the appendix). From Figure 2, it could be observed that expected utility follows a narrow distribution for the risk neutral case. The distribution becomes broader with increase in the level of risk aversion, however. This suggests a wider interval of confidence for expected utility for increased risk aversion.

Fertilizer use is found to be inversely related to risk aversion level for all evaluated strategies. It is the least for calculated application at fallow time, except for the risk neutral case. Calculated crop season application and the combined fallow-crop season calculated application are second and third, respectively, with respect to the required amounts of fertilizer to be applied. The variance of the fertilizer quantity demanded does not follow the same pattern, however.

Comparing the results in this study with the profit maximization results obtained in the first manuscript, one finds that in both studies, calculated application always give better results than the blind application practice. Also, the strategy of calculated application to the growing crop is consistent, in all considerations, in the two essays. Other strategies differ in ranks and fertilizer use particularly for the first and third ranked strategies where very small fertilizer quantities are required in the expected utility case.

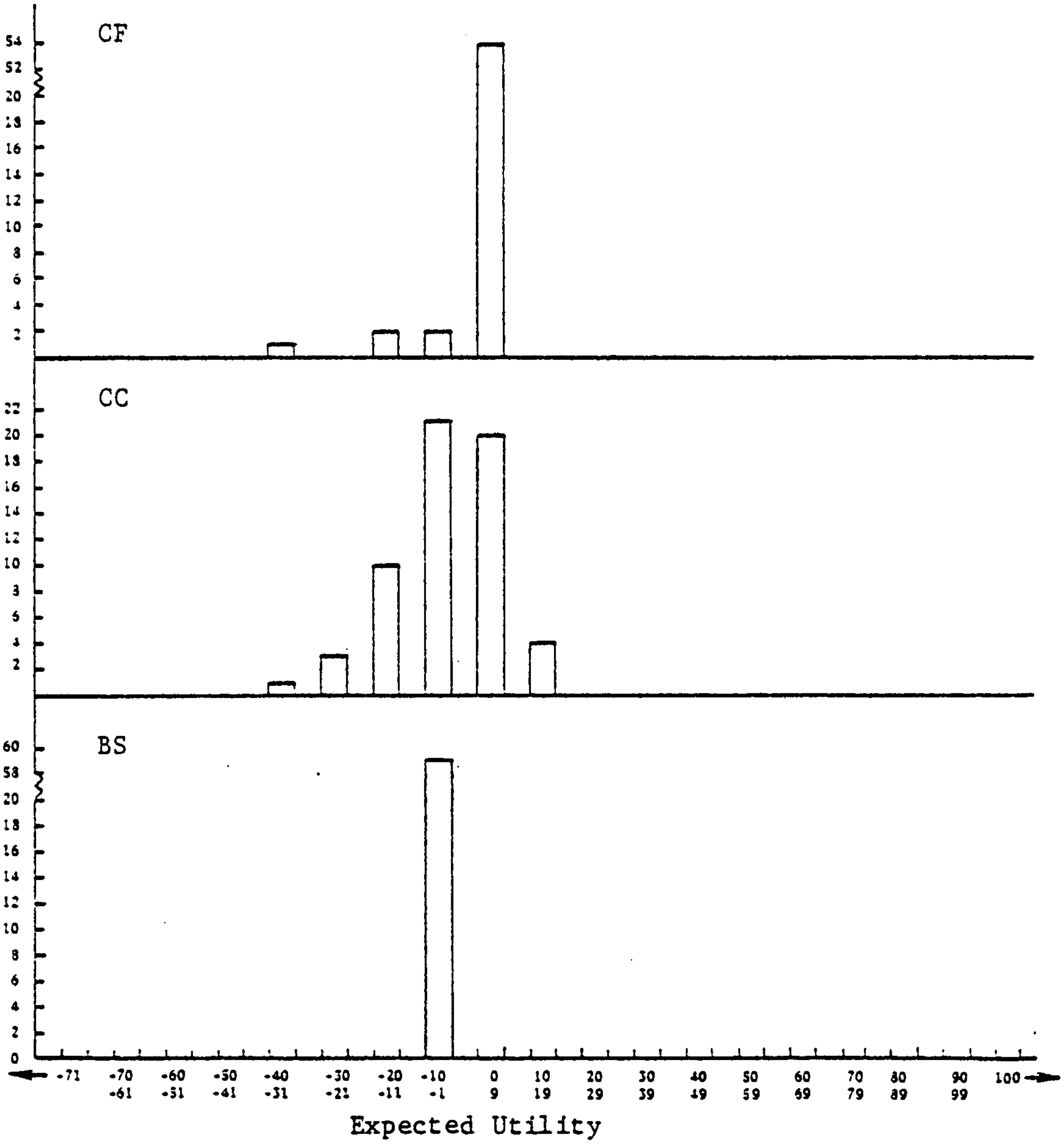

Figure II.2a. Expected Utility Distribution for λ = 0

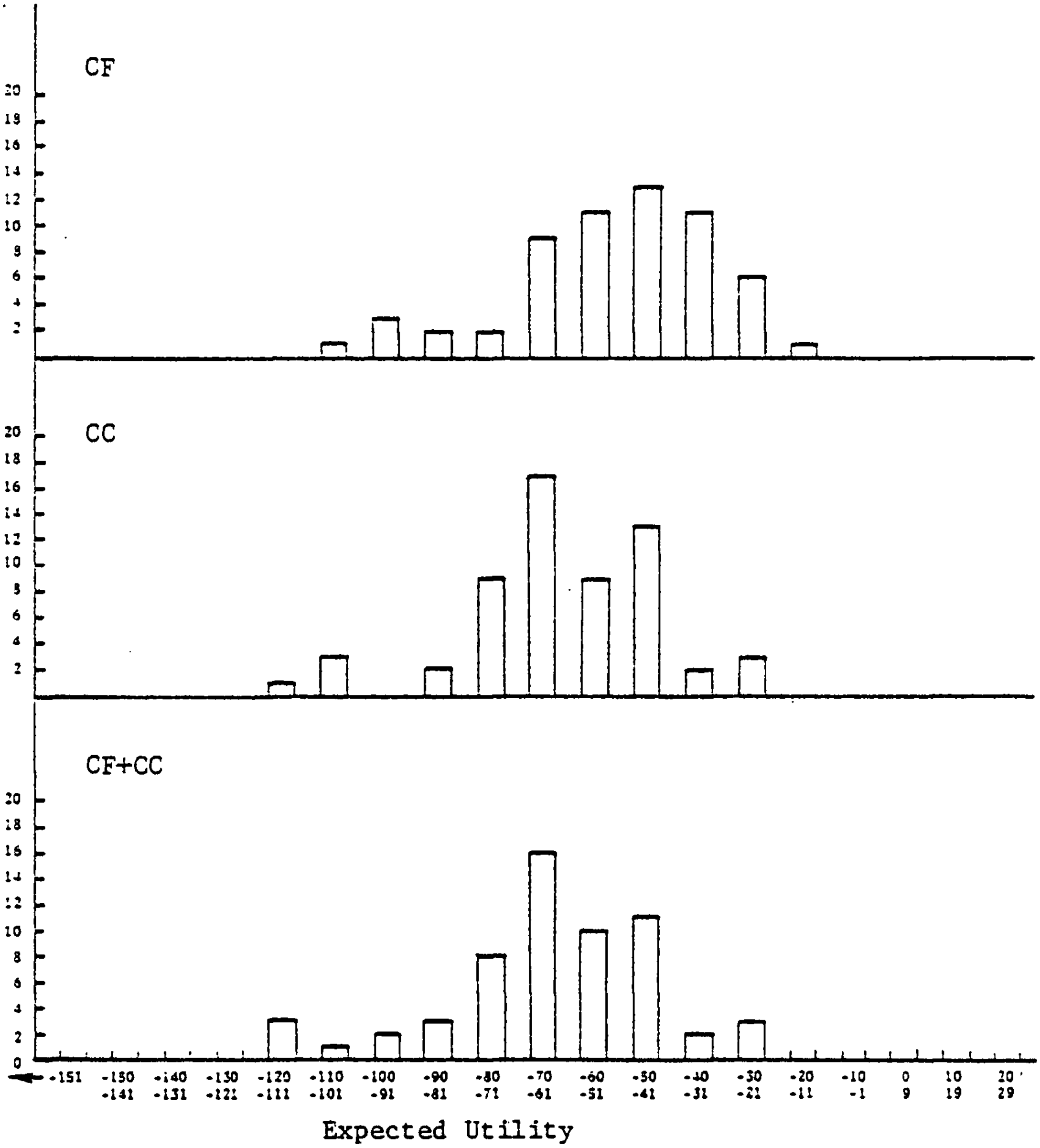

Figure II.2b. Expected Utility Distribution for λ = 1

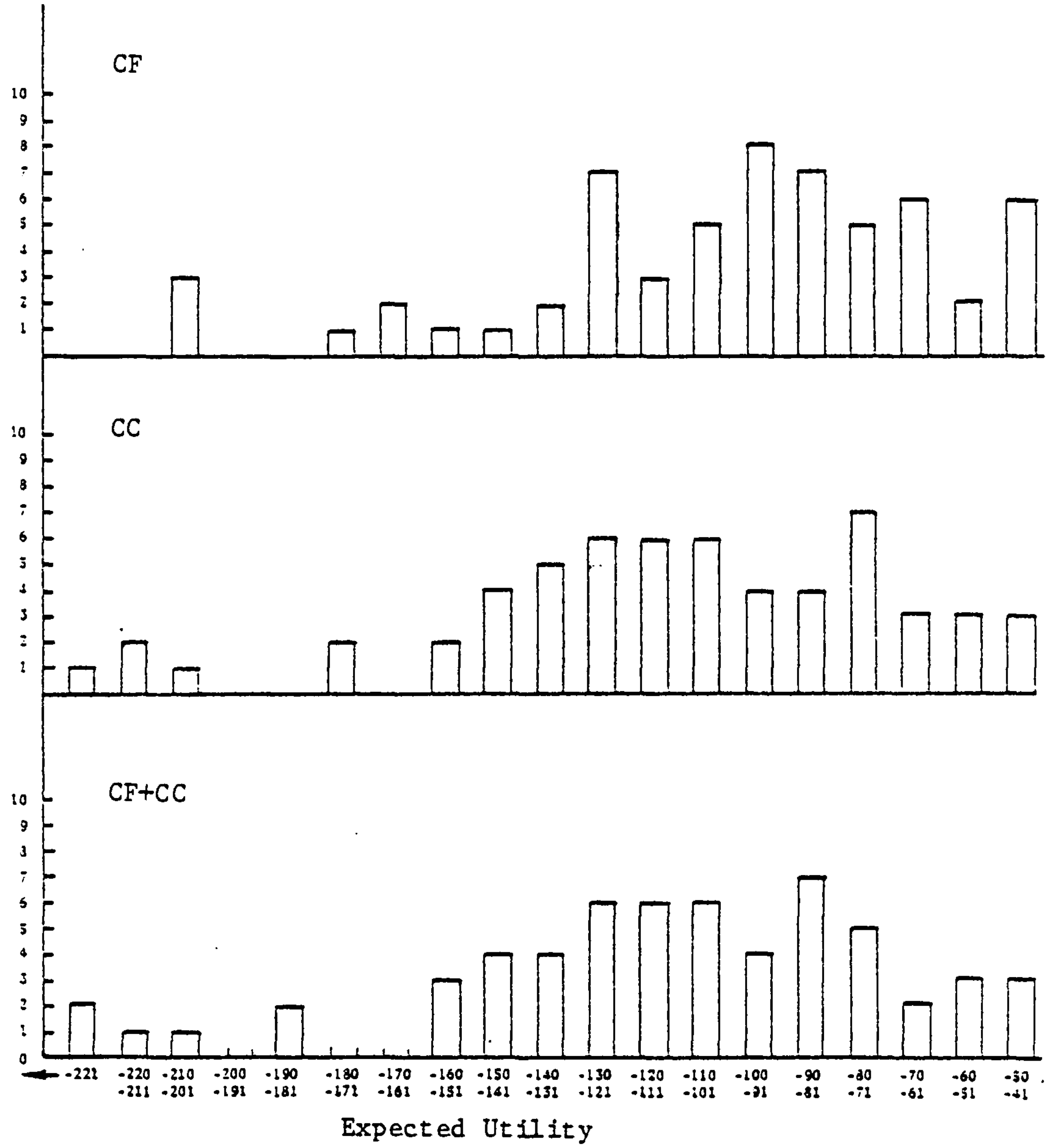

Figure II.2c. Expected Utility Distribution for λ = 2

Conclusions

A wheat grain yield-nitrogen response function was developed in which both expected yield and yield variability were estimated. These estimates were then incorporated in a risk-avoiding utility maximizing model for the purpose of evaluating fertilization strategies. The results indicated that:

a. Nitrogen has a positive marginal effect on yield variability.

b. The functions reveal that yield variance decreases, on average, as application approaches harvest period (i.e., later in the production season). However, harvest time yield variance was still relatively high.

c. The strategy of calculated application at fallow time constantly gives the largest expected utility and the smallest fertilizer use excluding zero fertilization.

d. Although some major differences exist between the results of the expected utility approach used in this study and the profit maximization results in the first manuscript, both studies report that calculated application is better than blind application. Consistent with the findings of Isfan, this result suggests the consideration of short-term weather conditions in fertilization decision making. Specific recommendations to farmers require further estimation with a more refined data set, however.

The Just and Pope approach adopted in this study did not work as expected. This may have occured because of the nature of data used for response functions estimation.[7] Given this limitation, the methodology developed in this study has not been proven to be advantageous to decision making analysis under risk for this particular problem.

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[7] The data used for the analysis included time series and cross sectional observations for different varieties.

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APPENDIX

APPENDIX I

Table I.A-1. Estimated Soil Mineralized Nitrogen and Potential Yield

Year	Soil Mineralized Nitrogen				Potential Yield			
	Fallow	Seeding	Crop	Harvest	Fallow	Seeding	Crop	Harvest
1918	39.811	40.194	38.060	39.375	2.387	3.262	3.253	2.531
19	38.849	39.391	39.290	40.584	2.215	2.344	2.029	1.671
1920	41.038	39.409	41.486	41.293	2.265	2.058	1.327	1.311
21	38.698	40.271	39.917	40.029	2.302	1.991	2.526	2.565
22	41.247	39.556	34.482	41.378	2.318	2.392	2.716	2.012
23	39.361	41.638	41.480	39.931	2.351	1.852	1.765	1.937
24	41.525	37.955	39.653	41.889	2.291	2.203	1.989	1.013
25	40.704	39.346	39.108	38.347	2.208	1.304	1.654	1.560
26	41.638	40.382	42.151	42.798	2.254	2.284	2.714	1.729
27	35.048	41.180	37.057	30.008	2.265	1.603	3.338	3.327
28	37.194	33.626	32.003	33.186	2.235	3.111	2.672	2.263
29	41.092	39.789	42.002	43.190	2.341	2.083	2.728	2.729
1930	41.365	41.010	40.037	42.049	2.319	2.457	1.820	1.568
31	41.563	38.559	40.575	40.363	2.313	2.036	2.459	2.383
32	40.334	41.575	40.801	40.022	2.313	1.875	1.891	1.719
33	41.473	40.866	41.622	42.142	2.309	2.252	2.059	1.862
34	41.215	41.278	42.277	43.901	2.194	1.945	1.873	1.110
35	41.478	41.638	43.148	43.926	2.214	1.472	1.523	1.153
36	41.397	41.760	41.642	41.219	2.290	1.723	1.876	1.868
37	41.518	41.612	44.181	41.686	2.215	2.275	2.307	2.707
38	38.244	41.519	39.319	39.781	2.324	2.036	2.550	2.654
39	40.614	39.910	41.745	43.333	2.323	2.626	1.772	1.708
1940	38.645	40.297	36.967	36.298	2.298	2.249	2.107	2.321
41	39.969	39.958	39.514	38.933	2.364	2.531	1.920	2.071
42	39.116	38.803	37.866	36.647	2.338	2.608	2.405	3.205
43	31.936	38.375	32.897	32.651	2.411	2.944	2.529	4.616
44	41.509	33.170	34.609	34.472	2.397	4.498	2.830	3.302
45	41.539	42.213	42.988	42.729	2.401	2.886	1.805	1.916
46	40.807	41.638	41.128	41.264	2.344	2.203	2.611	3.183
47	40.934	40.934	44.295	43.693	2.368	2.956	1.959	1.791
48	32.530	41.575	37.945	36.159	2.324	1.738	2.207	2.768
49	40.358	47.182	26.949	28.815	2.415	3.197	2.962	3.037
1950	41.200	41.632	41.245	41.183	2.282	2.510	2.690	3.224

Table I.A-1. (continued)

Year	Soil Mineralized Nitrogen				Potential Yield			
	Fallow	Seeding	Crop	Harvest	Fallow	Seeding	Crop	Harvest
51	31.669	41.533	34.867	34.779	2.337	2.951	2.492	2.983
52	41.535	31.955	31.902	31.220	2.303	3.728	2.347	2.907
53	37.503	41.138	38.823	37.147	2.329	2.959	3.667	5.125
54	38.341	35.747	33.296	33.727	2.424	4.359	3.464	4.557
55	41.638	38.894	40.997	40.654	2.372	4.030	3.008	4.230
56	34.988	41.551	36.768	35.492	2.460	2.882	2.224	2.767
57	41.584	31.304	32.540	32.320	2.335	4.075	2.466	2.600
58	36.348	41.412	39.248	37.932	2.314	2.316	2.321	2.502
59	40.978	35.833	34.962	36.559	2.406	2.829	3.573	3.698
1960	40.700	41.584	45.184	44.779	2.270	2.892	2.168	2.416
61	38.209	40.000	37.762	36.948	2.361	2.022	2.799	2.975
62	40.411	38.450	41.253	40.892	2.319	2.627	2.706	2.939
63	37.458	40.116	40.671	39.654	2.271	2.294	2.775	3.339
64	41.257	35.767	39.436	40.413	2.418	2.684	2.503	2.800
65	37.562	40.448	37.056	37.773	2.293	2.023	2.359	1.941
66	41.599	38.362	39.972	41.002	2.278	2.504	3.080	2.802
67	41.297	41.407	42.225	42.520	2.242	2.065	2.479	2.488
68	34.340	41.647	45.735	47.249	2.422	1.916	1.629	1.248
69	38.313	35.177	34.557	33.188	2.249	1.750	1.856	1.851
1970	40.131	36.994	35.591	37.276	2.333	2.496	2.550	2.325
71	41.637	41.628	42.605	42.227	2.319	2.243	2.217	2.039
72	41.504	41.394	42.754	42.552	2.273	2.062	2.537	2.227
73	39.317	41.031	44.877	46.698	2.302	2.059	2.110	1.347
74	32.492	35.848	31.435	31.937	2.222	1.598	2.589	2.739
75	41.617	36.540	37.261	37.496	2.359	2.915	3.389	3.676
1976	41.250	41.000	43.027	43.462	2.351	2.537	1.997	2.125
Means	39.50	39.25	39.12	39.27	2.318	2.480	2.437	2.499

An Estimation Procedure for the Slope of Wheat Grain Yield-Nitrogen Function

The slope of the predicted grain yield function was estimated through regression analysis using the functional form:

$$Y = (\frac{-1}{80PY} N^2 + N - 20PY)\ b + PY$$

or equivalently,

$$Y - PY = (\frac{-1}{80PY} N^2 + N - 20PY)\ b$$

where b is the regression (through origin) coefficient.

The data used in the estimation process consisted of a pooled cross-sectional and time series observations obtained from the Sherman Branch Experiment Station. The cross-sectional data comprised different nitrogen treatments for the period 1954 to 1969 while the time series data included observations from the station's commercial plot for the years 1951 to 1976. These observations are given in Tables A-2 and A-3.

A problem of autocorrelation was encountered in the estimation process. It was corrected for by transforming the data, in an iterative technique (maximum likelihood) (see TSP, 1980). Using the appropriate time period values for potential yield and mineralized nitrogen, the final estimates of the slope, b, are given in Table A-4.

Table I.A-2. Nitrogen Experimental Treatments and the Corresponding Wheat Yield (MT/ha) at the Sherman Branch Experiment Station

	89.6 KgN/ha	67.2 KgN/ha	44.82 KgN/ha	33.6 KgN/ha	22.41 KgN/ha	00.00 KgN/ha
1954	NR	2.60	2.46	NR	2.26	1.91
1955	2.53	2.62	2.58	NR	2.44	2.08
1956	NR	1.94	1.94	NR	1.90	1.77
1957	NR	NR	2.17	NR	2.01	1.90
1958	NR	NR	2.88	NR	2.72	2.57
1959	NR	NR	2.06	NR	1.92	1.72
1960	NR	NR	2.79	NR	2.36	1.83
1961	NR	1.73	1.68	NR	1.68	1.53
1962	NR	1.46	NR	1.46	NR	1.56
1963	NR	3.08	3.24	NR	3.08	3.04
1964	3.20	3.22	3.29	NR	3.26	3.26
1965	NR	1.46	NR	1.37	NR	1.56
1966	NR	1.26	NR	1.30	NR	1.25
1967	NR	1.89	NR	1.39	NR	1.40
1968	NR	1.68	NR	1.56	NR	1.76
1969	NR	1.07	NR	0.79	NR	0.93

Table I.A-3. Nitrogen Fertilization and the Corresponding Wheat Yield from the Commercial Plot at the Sherman Branch Experiment Station

Year	Yield (MT/ha)	Applied N (MT/ha)	Year	Yield (MT/ha)	Applied N (MT/ha)
1951	2.825	None	1964	3.188	50.42
1952	2.468	None	1965	1.722	50.42
1953	2.724	None	1966	2.105	50.42
1954	2.408	None	1967	2.172	50.42
1955	1.924	None	1968	2.260	50.42
1956	1.628	None	1969	1.117	50.42
1957	1.910	33.61	1970	3.598	70.58
1958	2.085	33.61	1971	2.408	62.74
1959	2.354	50.42	1972	2.832	50.42
1960	3.134	50.42	1973	0.908	50.42
1961	2.078	50.42	1974	2.939	50.42
1962	2.758	50.42	1975	3.841	50.42
1963	2.690	50.42	1976	3.450	50.42

Table I.A-4. Estimated Slope Results

Time Period	$\hat{b}$	R^2	Durbin-Watson Statistics
Fallow	.0108 (.0086)*	.059	2.09
Seeding	.0337 (.0049)**	.136	2.168
Crop	.0287 (.0063)**	.098	2.03
Harvest	.0247 (.0049)**	.154	2.00

Note that figures in parenthesis are OLS Standard errors.

* Significant at .25 level.

** Significant at .01 level.

APPENDIX II

Specifying a Value for ϕ

Given the E - V objective function

$$\max \quad cx - \phi\sigma^2 \qquad [1]$$

and the modified MOTAD model

$$\max \quad cx - \lambda\sigma \qquad [2]$$

the marginal risk effect is obtained, by assigning the first derivative, a zero value, as

$$c = 2\phi\sigma \frac{\partial\sigma}{\partial x} \qquad [3]$$

and

$$c = \lambda \frac{\partial\sigma}{\partial x} \qquad [4]$$

Thus, equating the right hand sides of Equations (3) and (4) the relationship $\phi = \frac{\lambda}{2\sigma}$ is verified.

However, in reference to the total risk effect in Equations (1) and (2) the relationship $\phi = \frac{\lambda}{\sigma}$ also exists. This consanguinity is not considered for the purpose of this study.

Table II.A-1. Distribution of Expected Utility ($\lambda = 0$)

	<-70	-70 -61	-60 -51	-50 -41	-40 -31	-30 -21	-20 -11	-10 -1	0 9	10 19	≥20
CF	0	0	0	0	1	0	2	2	54	0	0
CC	0	0	0	0	1	3	10	21	20	4	0
BS	0	0	0	0	0	0	0	59	0	0	0
BF	0	0	0	0	0	1	6	34	18	0	0
CF+CC	0	0	0	0	1	3	12	23	17	3	0
BF+CC	0	0	0	1	1	1	18	30	5	3	0
BF+CS	0	0	1	3	5	6	12	20	10	2	0
CF+CS	0	0	1	1	6	10	10	26	5	0	0
BF+CS+CC	0	0	2	4	4	7	13	22	6	1	0
CS	0	0	2	2	4	11	9	27	4	0	0
CF+CS+CC	0	0	1	1	6	13	15	20	3	0	0
CS+CC	0	0	2	2	4	14	14	20	3	0	0
BS+CC	-	-	-	-	-	-	-	-	-	-	-

Table II.A-2. Distribution of Expected Utility (λ = 1)

	<-150	-150 -141	-140 -131	-130 -121	-120 -111	-110 -101	-100 - 91	- 90 - 81	- 80 - 71	- 70 - 61	- 60 - 51	- 50 - 41	- 40 - 31	- 30 - 21	- 20 - 11
CF	0	0	0	0	0	1	3	2	2	9	11	13	11	6	1
CC	0	0	0	0	1	3	0	2	9	17	9	13	2	3	0
CF+CC	0	0	0	0	3	1	2	3	8	16	10	11	2	3	0
BF+CC	0	0	0	1	2	1	2	6	10	14	5	10	8	0	0
BF+CS	0	1	3	1	1	1	4	8	7	10	18	5	0	0	0
CF+CS	0	1	3	1	1	1	4	9	6	14	10	7	0	2	0
CS	0	1	3	1	1	1	4	9	7	15	9	6	0	2	0
BF+CS+CC	0	2	2	2	0	2	4	8	7	11	19	2	0	0	0
CF+CS+CC	0	2	2	2	1	1	3	12	8	12	7	7	1	1	0
CS+CC	0	2	2	2	1	1	3	12	9	13	6	6	1	1	
BS+CC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table II.A-3. Distribution of Expected Utility ($\lambda = 2$)

	<-220	-220 -211	-210 -201	-200 -191	-190 -181	-180 -171	-170 -161	-160 -151	-150 -141	-140 -131	-130 -121	-120 -111	-110 -101	-100 - 91	- 90 - 81	- 80 - 71	- 70 - 61	- 60 - 51	- 50 - 41	- 40 - 31
CF	0	0	3	0	0	1	2	1	1	2	7	3	5	8	7	5	6	2	6	0
CC	1	2	1	0	0	2	0	2	4	5	6	6	6	4	4	7	3	3	3	0
CF+CC	2	1	1	0	2	0	0	3	4	4	6	6	6	4	7	5	2	3	3	0
BF+CC	3	0	1	0	2	0	1	4	4	6	5	6	5	3	4	7	3	4	1	0
CF+CS	5	0	0	2	2	1	3	5	3	5	4	9	4	4	6	3	1	1	1	0
CS	5	0	0	2	2	1	3	5	3	5	4	9	4	5	5	3	1	1	1	0
BF+CS	5	0	0	3	1	1	3	4	5	2	6	8	4	3	7	6	1	0	0	0
CF+CS+CC	5	0	0	2	2	1	4	5	4	3	5	8	4	4	6	3	1	1	1	0
BF+CS+CC	5	0	0	3	1	1	4	4	5	1	7	7	4	3	7	6	1	0	0	0
CS+CC	5	0	0	2	2	1	4	5	4	3	5	8	4	5	5	3	1	1	1	0
BS+CC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BF	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-