An economic evaluation of fertilization of Montana winter wheat
by Craig Edgar Simons

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Applied Economics
Montana State University

Abstract:
Relationships between yield and protein response of Montana winter wheat to fertilizer application and various soil and climatic conditions were studied using data from 19 experiments conducted in southeastern Montana during the years 1976, 1977 and 1978. Relationships were estimated using a generalized non-linear algorithm. Explanatory variables were applied nitrogen, phosphorus and potassium, soil nitrate and soil water, both measured to a depth of four feet, soil phosphorus, measured to a depth of two feet, and April through July precipitation. The winter wheat variety used at all sites was Centurk.

Yield response was estimated using a second degree polynomial equation with an additive component error term. Variables important in explaining yield were applied phosphorus, nitrogen and potassium, and soil nitrate and phosphorus. Soil water and April through July precipitation were not statistically significant in explaining variations in yield and were combined into a total water variable. Results stemming from this combination were little different than considering soil water and precipitation separately. Consequently, water was eliminated from the analysis except through interaction variables with both applied nitrogen and phosphorus.

Variables important in explaining protein response were applied nitrogen, phosphorus, and potassium and soil nitrate. Water was only statistically significant as a component of the interaction term with applied nitrogen.

The estimated yield response equation was used to determine optimal rates of fertilizer application under varying fertilizer and wheat prices. Results indicated that potassium application was not economic, and should not be applied at its current price of 16 cents per pound unless the price of wheat was approximately $5.70. Phosphorus was not economic when soil phosphorus was at high levels of 20-25 pounds per acre measured in the top two feet of soil. Economic applications of phosphorus become much higher as water and applied nitrogen are increased. Nitrogen applications have the biggest effect on winter wheat yields and therefore, on profits. Economic applications of nitrogen depend heavily upon water and soil nitrate. The highest recommendation for nitrogen application occur when water is high and soil nitrate is at a relatively low level.

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Craig Simons

Date 11/24/80

AN ECONOMIC EVALUATION OF

FERTILIZATION OF MONTANA WINTER WHEAT

by

CRAIG EDGAR SIMONS

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Applied Economics

Approved:

Chairperson, Graduate Committee

Head, Major Department

Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

November 1980

ACKNOWLEDGMENTS

I wish to express my sincere appreciation and thanks to Dr. M.S. Stauber, chairman of my graduate committee, for his continued help and patience in the preparation of this thesis. I would also like to thank Drs. Oscar Burt, Paul Kresge, Myles Watts and Ed Ward for their help and advice. I am especially thankful for and indebted to Dr. Vince Haby for his data contribution as well as his expert advice. Special thanks are also extended to Mrs. Susan Wilson and Mrs. Evelyn Richard for typing the initial copies and to Ms. Angel Hochhalter who expertly typed the final draft.

Deserving of special note are my parents for their continued encouragement and support during my academic career.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Relationships between yield and protein response of Montana winter wheat to fertilizer application and various soil and climatic conditions were studied using data from 19 experiments conducted in southeastern Montana during the years 1976, 1977 and 1978. Relationships were estimated using a generalized non-linear algorithm. Explanatory variables were applied nitrogen, phosphorus and potassium, soil nitrate and soil water, both measured to a depth of four feet, soil phosphorus, measured to a depth of two feet, and April through July precipitation. The winter wheat variety used at all sites was Centurk.

Yield response was estimated using a second degree polynomial equation with an additive component error term. Variables important in explaining yield were applied phosphorus, nitrogen and potassium, and soil nitrate and phosphorus. Soil water and April through July precipitation were not statistically significant in explaining variations in yield and were combined into a total water variable. Results stemming from this combination were little different than considering soil water and precipitation separately. Consequently, water was eliminated from the analysis except through interaction variables with both applied nitrogen and phosphorus.

Variables important in explaining protein response were applied nitrogen, phosphorus, and potassium and soil nitrate. Water was only statistically significant as a component of the interaction term with applied nitrogen.

The estimated yield response equation was used to determine optimal rates of fertilizer application under varying fertilizer and wheat prices. Results indicated that potassium application was not economic, and should not be applied at its current price of 16 cents per pound unless the price of wheat was approximately $5.70. Phosphorus was not economic when soil phosphorus was at high levels of 20-25 pounds per acre measured in the top two feet of soil. Economic applications of phosphorus become much higher as water and applied nitrogen are increased. Nitrogen applications have the biggest effect on winter wheat yields and therefore, on profits. Economic applications of nitrogen depend heavily upon water and soil nitrate. The highest recommendation for nitrogen application occur when water is high and soil nitrate is at a relatively low level.

Chapter 1

INTRODUCTION

PROBLEM STATEMENT

Nitrogen and phosphorus fertilizer use in Montana has increased substantially over the past several years. In 1970 Montana farmers used slightly less than seven pounds of actual nitrogen and phosphorus per acre. By 1976, this figure had more than doubled to over 14 pounds per acre.

During this same time period the prices of nitrogen and phosphorus fertilizer have fluctuated over a very wide range. Nitrogen varied from 10 to 30 cents per pound while the price of phosphorus was not as volatile, ranging from 21 to 53 cents per pound. Similiarly, the price that farmers received for their wheat varied considerably over the same period. The average price farmers received for their wheat in 1978 was more than double the 1970 price. However, the 1978 price was only about 65 percent of the price in 1973. (Prices are not adjusted for inflation.)

As a consequence of these rapidly changing input and output prices, determining an optimal fertilizer policy is at best precarious. An uneconomic application of fertilizer could mean a significant loss of profits for the winter wheat producer.

Farmers' decision criteria for fertilizer application vary considerably. This is not difficult to understand as the yield and protein response to nitrogen and phosphorus are not well defined, especially given variable soil and moisture conditions. In order for winter wheat producers to make economic applications of fertilizer, they must have two basic types of information. First, they must know the physical response of wheat to nitrogen and phosphorus at variable levels of application. This physical response must also be associated with variable soil and climatic conditions. Two types of physical response information are needed: (1) the producer needs good information about the incremental yields forthcoming from varying applications of nitrogen and phosphorus including marginal rates of technical substitution, and (2) marginal changes in the protein content associated with different levels of fertilizer application. In addition to physical response information, the producer also needs reliable estimates of fertilizer and winter wheat prices. Included in the winter wheat prices must be some reasonable estimate of the protein premium structure. Only when all this information is known can the producer expect to have a truly economically optimal fertilization program.

PURPOSE OF THE STUDY

The purpose of this study is to investigate and develop a decision criteria for profit maximization as related to fertilizer application on Montana winter wheat. Specifically, the objectives of this study are to:

1) Develop a winter wheat response (production) function for

yield and protein with respect to nitrogen and phosphorus fertilizer and other important soil and climatic conditions.

2) Determine optimal fertilizer application by considering the estimated production function, various winter wheat prices, fertilizer prices and protein premium structures.

3) Present the information from one and two above in a manner that helps winter wheat producers in Montana make economically rational decisions concerning their fertilizer programs.

Chapter 2

LITERATURE REVIEW

The ability to predict yield and protein response to fertilizer is necessary if the producer is to be able to determine optimal levels of fertilizer application. Research in this area is by no means a new or unique thing. Many factors thought to influence yield and/or protein content have been studied.

Increased yields and higher protein have often been attributed to nitrogen fertilizer (7, 9, 27). Other results indicate precipitation, soil moisture, phosphorus, potassium, soil type, temperature, varieties, row spacing and management practices influence yield and protein in grain (1, 4, 5, 26).

In very early work, Fisher (10) used a linear regression technique to examine the relationship between wheat yields and rainfall. Response functions were estimated by determining the change in yield resulting from an increase (or decrease) in average rainfall for a specific time of year. Similar work done in India (11) found that 75 percent of the total variation in yield was accounted for by variation in rainfall. The time of the growing season in which the rainfall was experienced was also important. More than normal rainfall one month before seeding time was found to be detrimental to wheat yields.

Research done on winter wheat in Kansas (30) indicated that the influence of soil moisture at planting time and growing season precipitation affected yield and yield response to fertilizer to about the same degree. This, according to the study, differs from summer grown crops where soil moisture largely determines yield and yield response to fertilizer. Yield increases in this study were noted more often for nitrogen (58 percent) than for any other element. Phosphorus caused yield increases in 33 percent of the sites (most of which were very low in soil phosphorus). Potassium and sulfur had little effect on winter wheat yields.

The same study included analysis of protein response to fertilizer. Results showed almost no response to phosphorus. Nitrogen, however, increased protein .3 to .6 percent for each 20 pound increment.

In Australia (29), researchers found rainfall to be the major source of variation in yield. In this study, pre-sowing rainfall was found to be detrimental to yields. In all, rainfall accounted for about 80 percent of the variation in yield. Published research by Bauer, et al. (3) on yield experiments done on spring wheat and barley found water was the cause of 40 percent of the variation. Phosphorus was found to be of little use in predicting yields. Eck and Tucker (8) found soil moisture and precipitation to be critical in explaining variations in yield. Growing season temperature and organic matter were also found important in explaining variation in yield. Unfortunately, the relationships did not yield satisfactory prediction equations. In a similar study (2), researchers found soil moisture was the best estimator of yield followed by minimum and maximum temperature. Rainfall was completely unsuitable for yield estimation in this research project.

Nebraska researchers (30) found a highly significant inverse protein-yield relationship for applied nitrogen. Nitrogen was found to increase yields on irrigated crops. At the same time, wheat had little yield response to nitrogen on dryland, but showed significant increases in protein content.

Results published by Smika, et al. (28) found grain yields positively correlated with soil water at seeding time. When soil water was included in the analysis, the largest yields were found with the lowest levels of soil nitrate. The exclusion of soil water from the analysis found no apparent relationship between soil nitrate and yield. Results also showed that yields were higher on mulched soil than bare soil (where NO_3-N was available in sufficient quantities in both), but yield response to nitrogen fertilizer was greater on bare soil than mulched soil.

Jackson (16) used a stepwise multiple regression technique to predict grain yield and protein with and without nitrogen fertilizer additions. Estimations were also made of residual soil nitrate levels after harvest. In the first step, potential yield was estimated. Independent variables used were soil organic matter, growing season precipitation, and evaporation rates. Soil nitrate, evaporation rates, potential yield, and available soil water were the variables then used to predict nitrogen fertilizer requirements. Variables used in predicting grain protein were potential yield, growing season rainfall, organic matter and soil nitrate.

When soil nitrate was higher than 120 kilograms per hectare, Olson, et al. (24) found little or no yield response to applied nitrogen. An additional 50 to 60 kilograms per hectare of applied nitrogen would, however, be needed to obtain maximum protein.

Researchers in Illinois (14) studied the effects of applied nitrogen on both hard and soft winter wheat. Results indicated increases in yield and protein percentage in all experiments. The favorable results from these experiments indicated that despite increased costs, split application of nitrogen fertilizer made late in the spring has merit in the interests of minimizing pollution.

Researchers in Montana (22), using five spring wheat varieties and five nitrogen treatments, found no difference in yield response due to variety. However, due to increasing nitrogen application rates, grain protein percent decreased as the grain to straw ratio increased for all varieties. Pendleton and Dungan (25) found that different varieties showed different yield response to nitrogen as well as different response to seeding rates. Similar research (19, 32) also showed varying yield response to different varieties.

Garnick, et al. (12), using data from 43 winter wheat experiments in Montana, estimated yield response using third degree polynomial equations. Explanatory variables included April through July precipitation, applied phosphorus, applied nitrogen and available soil nitrate and available soil water measured in the top four feet of the soil in early spring. Unfortunately, because of statistical insignificance, probably partially caused by measurement problems and variation across sites, soil water and applied phosphorus were excluded from the yield analysis. Results show that nitrogen and soil nitrate as well as precipitation increased yields while the nitrogen variables and applied phosphorus increased protein. Precipitation had a negative influence on protein.

In many of these studies there are conflicting results; Smika et al. (28) found soil nitrate important in explaining yield. Similarly, Bair and Robertson (2) found rainfall unsuitable for explaining yield, while others (11, 29) found it very significant. Variability in results from these studies in predicting protein and yield response may be attributable to variation in soil characteristics, management practices, distribution of nitrogen and phosphorus in the soil as well as many other factors.

It is hoped that the following research will contribute to a better understanding of the factors which influence yield and protein response in Montana winter wheat.

Chapter 3

ESTIMATION OF YIELD AND PROTEIN FUNCTIONS

SOURCE OF DATA

Data used in this research were collected from a series of yield/protein response experiments conducted under the auspices of Dr. Vincent A. Haby, assistant professor of soils, Montana State University at the Southern Agricultural Research Center, Huntley. Nineteen sets of data representing ten different sites are used in the final analysis. For each set of data there are 23 treatments, seven which are replicated twice for a total of 30 observations for each site, or 570 total data points. Site location and year are presented in Appendix A.

Data for the analysis were selected according to their ability to meet certain predetermined criteria. Experimental plots were located on summer fallow, with efforts made to insure each site was uniform in soil type, free of insects and weeds as well as any other damaging factors. A uniform stand of Centurk hard red winter wheat was seeded at all sites. As a result of these criteria, one site from the original data base of 21 sites was excluded because of hail damage and another was disqualified due to high soil salt content.

Independent variables recorded were soil nitrate (NO_3-N) and soil water, both measured to a depth of four feet in early spring, April through July precipitation, and soil phosphorus measured to a depth of two feet. Observations were also collected on the dependent variables, yield and protein content, at harvest time.

Each fertilizer nutrient was applied at five different rates. Nitrogen was broadcast at rates ranging from 0 to 89 pounds in increments of 22.25 pounds per acre. Phosphorus was banded with the seed at rates varying from 0 to 35.6 pounds per acre of elemental phosphorus in increments of 8.9 pounds per acre. Potassium application rates ranged from 0 to 85.6 pounds of elemental K, in increments of 21.4 pounds per acre.

ALGEBRAIC SPECIFICATION OF THE RESPONSE FUNCTION

Selection of the algebraic specification of the protein and yield response function warrants careful consideration. The function must be able to describe the characteristics of the phenomenon being studied. No functional form will be an exact 'fit', but care must be taken to select a function with the most desirable characteristics.

In this study of the economic application of fertilizer, polynomial equations were selected for several major reasons. Consider a simple polynomial of the form

$$Y = \alpha + \beta_1 X + \beta_2 X^2$$

where:

Y = total output;

α = the value of the equation when the independent variable is zero;

X = the units of the independent variable; and

β_1 and β_2 = the parameters of the equation.

Because we expect total output to reach a maximum and decline, we hypothesize that the parameter β_1 will be positive while β_2 is negative. Thus the equation lends itself to both positive and negative marginal products.

Extensions of the previous equation allow substantial flexibility to the production function being estimated. In the quadratic equation, the marginal product curve is linear. This restriction is easily overcome by the introduction of a cubic term.

It is also often true that influence of one explanatory variable depends upon the level of the other variables. Hence it may be necessary to incorporate interaction terms between two variables in the response function.

Previous studies (12, 16) indicate that polynomial equations have been quite useful in the study of yield and protein response to fertilizer application.

ADDITIVE ERROR MODEL

The first model used in the estimating yield and protein response was the following form:

$$(2.1) \quad Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 = \beta_7X_7$$

$$+ \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{11} X_{11} + \beta_{12} X_{12} + \beta_{13} X_{13}$$
$$+ \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16} + \beta_{17} X_{17} + \beta_{18} X_{18} + \beta_{19} X_{19}$$
$$+ \beta_{20} X_{20} + \beta_{21} X_{21} + \beta_{22} X_{22} + W_{iLt} + U_L + V_t$$

where:

Y = estimated yield or protein;

β_i ($i = 0$ to 22) = unknown parameters to be estimated;

X_1 = applied nitrogen;

X_2 = applied nitrogen squared;

X_3 = applied phosphorus;

X_4 = applied phosphorus squared;

X_5 = precipitation;

X_6 = precipitation squared;

X_7 = soil water;

X_8 = soil water squared;

X_9 = soil nitrogen;

X_{10} = soil nitrogen squared;

X_{11} = soil phosphorus;

X_{12} = soil phosphorus squared;

X_{13} = applied nitrogen x applied phosphorus;

X_{14} = N x precipitation;

X_{15} = N x soil nitrogen;

X_{16} = precipitation x soil water;

X_{17} = precipitation x soil nitrogen;

X_{18} = soil water x soil nitrogen;

X_{19} = applied phosphorus x soil phosphorus;

X_{20} = applied phosphorus x precipitation;

X_{21} = potassium;

X_{22} = potassium squared;

W_{iLt} = the random variation due to experimental error associated with location L, time t, and treatment i;

U_L = the random variation associated with location L; and

V_t = the random variation associated with year t.

Although the components of the error term cannot actually be separated in estimation, their distinction is vitally important statistically.

Define

$$\varepsilon_{iLt} = W_{iLt} + U_L = V_t$$

where:

$$W_{iLt} \simeq N(0,\sigma_w^2)$$
$$U_L \simeq N(0,\sigma_u^2)$$
$$V_t \simeq N(0,\sigma_v^2).$$

The assumption of homoskedasticity implies that

$$\mathrm{Var}(\varepsilon_{iLt}) = E(\varepsilon_{iLt} - E(\varepsilon_{iLt}))^2 = \sigma^2 = \sigma_u^2 + \sigma_w^2 + \sigma_v^2.$$

Further assumptions concerning the components include

1) $E(U_L V_t) = E(U_L W_{iLt}) = E(V_t W_{iLt}) = 0$

2) $E(U_L U_{L'}) = 0 \qquad L \neq L'$

3) $E(V_t V_{t'}) = 0 \qquad t \neq t'$

4) $E(W_{iLt} W_{i'Lt}) = E(W_{iLt} W_{iL't}) = E(W_{iLt} W_{iLt'})$

$= E(W_{iLt} W_{i'L't'}) = 0$ for $i \neq i'$, $L \neq L'$, $t \neq t'$.

The first assumption means statistical independence between the components. Assumptions 2, 3, 4 mean that there is an absence of serial correlation, and 4 also implies no correlation among treatments or across locations.

The coefficient of correlation between the disturbance at two different points in time, i.e., between ε_{iLt} and $\varepsilon_{iLt'}$, $t \neq t'$ is

$$\frac{COV(\varepsilon_{iLt}, \varepsilon_{iLt'})}{\left[Var(\varepsilon_{iLt}) Var(\varepsilon_{iLt'})\right]^{\frac{1}{2}}} = \frac{E(\varepsilon_{iLt}, \varepsilon_{iLt'})}{\left[E(\varepsilon_{iLt}^2)\ E(\varepsilon_{iLt'}^2)\right]^{\frac{1}{2}}} = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2 + \sigma_w^2} =$$

$$\frac{\sigma_u^2}{\sigma_\varepsilon^2},$$

because of the assumptions of independence among components and independence within components over location, time, and treatment.

The coefficient of correlation between the disturbances of different cross-sectional units, i.e., between ε_{iLt} and $\varepsilon_{iL't}$ $(L \neq L')$ is