A comprehensive nitrogen fertilizer management model for winter wheat (Triticum aestivum L.)
by Grant Dewayne Jackson

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crop and Soil Science
Montana State University

Abstract:
Winter wheat at 47 locations in Montana was topdressed with nitrogen (N) in the spring of 1970, 1971, 1972 and 1973.

A stepwise multiple regression technique was utilized to generate a comprehensive N fertilizer management model to predict potential grain yield, N fertilizer requirements, grain protein with additions of N fertilizer, grain yield and grain protein without spring N additions and residual soil NO3-N after harvest.

The data were organized into two groups based on soil NO3-N to 4 ft. Locations having soils which contained less than 120 lbs NOg-N/4 ' were designated as group I and remaining locations as group II. With group I data highly significant equations were generated for the entire N fertilizer management model. Independent variables for potential yield prediction were growing season rain-fall, evaporation rates during the first half of the growing season and soil organic matter. Soil NO3-N, potential yield, evaporation rate during the first half of the growing season and available soil water were the important factors for predicting N fertilizer requirement. The variables useful in predicting grain protein were potential yield, soil NO3-N, N fertilizer rate, soil organic matter and growing season rainfall. For comparison with potential yield, grain yield equations were generated from check plot data; the important independent variables were soil NO3-N, evaporation rate during the first half of the growing season, growing season rainfall and soil organic matter. Similarly grain protein was predicted; important factors were soil NO3-N, growing season rainfall, grain yield and soil temperature at 50 cm. Equations for the group II data were eractic because of insufficient data for analysis and response to added N was uncertain. Data from groups I and II were combined and equations developed similar to group I; only the protein functions were nonsignificant.

A modeling system to predict residual soil NO3-N after harvest was generated. The equations developed from the check plots were highly significant; the important variables include soil NO3-N, soil water, soil temperature at 50 cm, evaporation rate and grain protein. Equations generated from 80 to 180 - N treatments were nonsignificant.

The modeling system applies to winter wheat producing areas of Montana where excellent stands of recommended varieties are present, an alternate' crop-fallow management system is practiced and P fertilizer is drilled with the seed.

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Approved:

Kurt C Feltner
Head, Major Department

James R. Sims
Chairman, Examining Committee

Henry L Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
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ABSTRACT

Winter wheat at 47 locations in Montana was topdressed with nitrogen (N) in the spring of 1970, 1971, 1972 and 1973.

A stepwise multiple regression technique was utilized to generate a comprehensive N fertilizer management model to predict potential grain yield, N fertilizer requirements, grain protein with additions of N fertilizer, grain yield and grain protein without spring N additions and residual soil NO_3-N after harvest.

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A modeling system to predict residual soil NO_3-N after harvest was generated. The equations developed from the check plots were highly significant; the important variables include soil NO_3-N, soil water, soil temperature at 50 cm, evaporation rate and grain protein. Equations generated from 80 to 180 - N treatments were nonsignificant.

The modeling system applies to winter wheat producing areas of Montana where excellent stands of recommended varieties are present, an alternate crop-fallow management system is practiced and P fertilizer is drilled with the seed.

INTRODUCTION

A basic objective of any natural resource management scheme is to maximize sustained outputs, minimize inputs, and maintain a high quality product with a minimum pollution hazard. This idea is especially true of small grain production in which nitrogen (N) fertilization plays an important role as an input. In the past N fertilizer was applied haphazardly or according to single factor soil tests with little consideration of grain quality, potential yield and pollution potential. Furthermore in this day and age it is vitally important to manage N fertilizer additions intelligently since N is in limited supply, and our society has become more aware of food quality and environmental hazards.

Obviously, models to predict N fertilizer needs and the fate of applied N are necessary to produce optimum yields of high quality winter wheat while minimizing undesirable side effects. This dissertation is one attempt to develop such models.

LITERATURE REVIEW

Winter wheat production research has received considerable attention since the organization of agricultural experiment stations in the late 1800's and early 1900's. The data published are so immense that one could say "there is no such thing as a complete literature review of winter wheat research".

Certainly the conclusions of Collis-George and Davey (8) are pertinent to this study. They stated "until complete descriptions of experiments are available, the quantitative importance of environment and its interaction with fertilizer and cultivation practices cannot be determined". Their main criticism of recent field fertilizer experiments was the failure of investigators to include a sufficient number of soil properties and climatic factors as variables.

Thompson (50) and Schlehuber and Tucker (34) attribute recent increases in wheat production to increased nitrogen fertilization. However, the development of higher yielding varieties, phosphorus fertilization and more efficient summer fallowing techniques are also responsible for increased production (4).

Published models for predicting nitrogen fertilizer requirements of winter wheat are quite variable in their approach and in their utility. Simple linear regression analysis with soil nitrate nitrogen (NO_3-N) has been successful in some locals (36). However Smika et al. (42) reported no relationship whatsoever. Leggett (22) reported one of the first systems which included climatic variables to predict nitrogen fertilizer needs for winter wheat in Washington state. He used available soil water plus expected rainfall to determine maximum yield (Ym). Then the yield (Yn) one would expect from the initial soil NO_3-N content to the depth of six feet was calculated. The yield expected from nitrogen (N) mineralization (recrop yield) was added to Yn also. If Ym > Yn, then additional N was added at the rate of 3 lb N/bu ((Ym-Yn)/3 = additional N). In North Dakota, Young et al. (54), correlated (R=.70) available soil water at seeding to the depth of 122 cm, stored soil NO_3-N to 61 cm at seeding, precipitation from seeding to five days before harvest, and number of degree days above 21^{o}C from five to sixty days before harvest with response to spring wheat to N fertilizer. In Oklahoma Eck and Tucker (15) attempted, with little success, to correlate available soil water in the spring, growing season precipitation, soil organic matter and temperature at maturity with winter wheat response to N fertilizer. Currently in Montana (36) nomograms are used for N fertilizer recommendation. Available soil water and soil NO_3-N to four feet and expected rainfall are the variables that comprise the system. Kloster and Whittlesey (21) and Geist et al. (16) both published small grain yield predictions based on nitrogen fertilizer rates and other soil and climatic factors. Recently Read and Warder (32) utilized a stepwise multiple regression program to determine the soil and climatic variables important to response of spring wheat to fertilizer on stubble land. They concluded that an NH_4-N soil test was more important than NO_3-N; however, R^2 was increased only by 1 or 2% with the inclusion of either NH_4-N or NO_3-N. Growing season rainfall was more important than stored soil water on yield and protein content of unfertilized plots, but stored soil water had a greater influence than rainfall on the response of spring wheat to fertilizer.

Several attempts to quantify the relationships between winter wheat yield and several components of the environment are documented in the literature. Eck and Tucker (15) concluded that rainfall distribution was more important than total rainfall. Legget (22) used expected growing season rainfall as a factor in his fertilizer prediction equation. Lehane and Staple (23) correlated available soil water and rainfall received during the growing season with yield. In another paper (24) they recorded the relationship of spring wheat yield with rainfall and soil water. Based on research in Colorado, Nebraska and Montana, Smika et al. (42) reported grain yields to be positively correlated with stored soil water at seeding. Baier and Robertson (3) related yield components with available soil water.

Other researchers have shown (31, 44, 46) the effects of soil temperature, wind reduction, or shelter belts on the yields of wheat.

Grain protein content is a very important quality factor to be considered in the formulation of fertilizer management systems for wheat. This area has received considerable attention in recent times (16, 19, 37, 40) since the average protein level of Montana's wheat has declined considerably during the last 12 years.

McGuire et al. (28) and Sims and Jackson (41) published data that shows positive relationships between grain protein and N fertilizer and between grain protein and soil NO_3-N. They did not include least square analyses in their reports. In Australia Taylor and Gilmore (47) successfully predicted wheat grain protein from rainfall and air temperature variables. Alkier et al. (1) related protein content to soil NO_3-N and N fertilizer rate; however, no climatic variables were included. Johnson et al. (19) reported a positive relationship between grain protein and N fertilizer. Smika and Greb (43) used multiple linear regression analysis to relate grain protein with soil NO_3-N to 6 feet, available soil water to 6 feet and total precipitation 40-55 days before maturity. The relationship was positive with soil NO_3-N and negative with soil water and rainfall.

Nutrient losses in runoff, particularly N, have been studied for years. Daniel et al. (10) in 1938 evaluated NO_3-N losses from different cropping systems and concluded NO_3-N in rainfall was significantly larger than the NO_3-N lost via surface runoff from unfertilized plots. In 1945 Midgley and Dunklee (29) reported that volitalization and runoff are responsible for large losses of N when manure was spread on frozen soil. Some early data on nutrient losses from erosion was published by Massey et al. (27) also. So the problem is not new but was recognized many years ago when the Great Plains Program was legislated to reduce erosion and farm production.

During the last decade renewed interest in nutrient losses was created by continued use of high fertilizer rates in some areas of the United States, and the disposal of enormous quantities of animal and municipal wastes on land (25). Of course, attacks by Commoner (9) blaming agriculture and chemical fertilizers for pollution of lakes and streams certainly had their effect also.

Recent literature has placed nutrient losses from runoff in perspective. White and Williams (53) compared nutrient losses from prairie and cultivated soils and concluded that "losses of plant nutrients in soil eroded from cultivated land may be similar to average losses that would occur naturally if the area were in pristine prairie that was periodically subjected to fire". This conclusion agrees with the data of Timmons et al. (48); their vegetation leaching experiments indicate that vegetation is a potential source of nutrients.

Klausner et al. (20) reported with the exception of heavy fertilized, poorly managed soils, the total yearly accumulative N discharge in surface runoff did not exceed the amount of N received in rainfall measured in a 10 month period. Other researchers (33, 52) have shown no significant differences in total N loss from fertilized and unfertilized soils; however, NO_3-N was significantly higher in the sediment from fertilized soils. Thomas and Crutchfield (49) studied NO_3-N and P in streams that drain predominately cultivated and forested watersheds. Their data showed very little change in NO_3-N and P concentrations regardless of land use. Moe et al. (30) stated that erosion losses of organic N are much more severe than fertilizer loss from fallow soils.

Obviously nutrient losses via surface runoff are highly variable (52) and are related to soil conditions and plant cover (13, 14, 26). Furthermore, models to predict nutrient losses are lacking. Models to predict erosion losses from rainfall are available (51). However, modifications are apparently required before any erosion prediction equation can be adapted to predict erosion losses related to snow melt and spring runoff.[1]

Although many experiments on the response of wheat to N fertilizer have been conducted, only a few have resulted in useful predictive models. Furthermore, virtually none of the previous studies produced a comprehensive model for managing N fertilizer on small grain crops. Most published models relate grain yield response or protein response to N fertilizer with soil and climatic variables. To be of maximum utility a model should predict grain yield potential, grain yield and protein responses to N fertilization, and the fate of applied N as it related to a pollution potential. The primary objective of this study was to develop such a comprehensive model.

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1 Jerry Waller, U.S.D.A. Soil Conservation Service, Bozeman, Montana. Personal communication.

METHODS AND MATERIALS

Plot Location and Design

Data for this dissertation were gathered from winter wheat fertility plots which were located throughout Montana's winter wheat producing area. These data represent 19, 14, 8 and 6 locations for the growing season's of 1970, 1971, 1972 and 1973, respectively. Geographic locations, investigators and soils classification are included in the Appendix Table 1. The field plots were organized in randomized complete blocks with individual plots running across the rows. Individual plot sizes were uniform at a locations but ranged from 150 ft^2 to 300 ft^2. The following criteria were established for site location:

A. Field should have:

1. Received P fertilizer with the seed or prior to seeding and worked in.
2. Good stand.
3. Limited weed problem, particularly regarding cheat grass, wild oats and wild buckwheat.
4. Recommended variety of winter wheat.

B. Actual plot size should be:

1. Uniform in all visual aspects.
2. No less than 20 ft. from west side of strip.
3. No less than 150 ft. from end of strip.

C. Soil Should be:

1. Montana benchmark soil or a representative soil of an extensive dryland grain acreage for the particular area.

Climate Measurements

Open pan evaporation and rainfall were measured according to the methods described by Sims and Jackson (39). Pan evaporation was measured in this study to integrate humidity, wind velocity and air temperature variables. This approach was necessary because funds were unavailable for the equipment to continuously monitor the climatic variables.

Soil temperature was measured at 50 cm with a dial thermometer during the growing season's of 1970, 1971 and 1972. Indoor-outdoor thermometers were employed in 1973 by placing the outdoor sensor at a depth of 50 cm in a hole made with an oakfield tube and backfilling the hole with the soil cores. The soil depth of 50 cm was chosen so the diurnal effects would not be measured and cold soils can be delineated from warmer ones. Since the Soil Conservation Service (SCS) uses soil temperature at 50 cm in their soil classification system, then soil survey information can be utilized to estimate soil temperatures when the proposed model is applied. Climate measurements were taken at 7 to 14 day intervals throughout the growing season (1 May - 15 August).

Soil Analysis

Soil water was determined by conventional gravimetric analysis using a forced draft oven at 60-65°C for 48 hours. Available soil water was estimated by the method described by Cole and Mathews (7). Basically this method uses soil water content at harvest as the limit of available water rather than soil water at 15-bar tension. This proved to be more significantly related to winter wheat yield.

Soil nitrate-nitrogen (NO_3-N) was estimated by phenoldisulfonic acid procedure as described by Bremner (4).

Soil organic matter was measured by the colorimetric method published by Sims and Haby (38).

Grain Analysis

The grain was harvested from 80 ft^2 or more near the center of each plot. Sickle mowers and Vogel threshers were predominately utilized for cutting and threshing; however, at the Northern Research Center a combine was used in 1970 and 1971, and a Chain combine was employed on all 1973 plots.

Grain yields and test weights were determined at about 12% moisture with gravimetric and volumetric equipment. Grain protein was measured by the Udy dye method 46-16 (2).

Statistical Procedures

The multiple regression analysis was accomplished by a stepwise regression computer program developed at UCLA (12). Computations were made on a XDS Sigma 7 computer. The regression analysis and partial regression coefficients were tested by the methods of Steel and Torrie (45). The partial regression coefficients were tested using a single df F against error df; a standard F test was used for the regression equation.

Methods unique to specific analyses will be discussed in the Results and Discussion section.

RESULTS AND DISCUSSION

The following pages contain multiple regression models which deal with the major phases of N fertilizer management relative to winter wheat. Equations are proposed to predict potential yields based on soil properties and climatic factors. The predicted potential yields are then entered into N fertilizer requirement prediction models along with soil NO_3-N and other variables. These models generate the N fertilizer rates required to achieve the potential yields predicted by the first model. Following these, grain protein content models are presented which forecast protein contents based on soil NO_3-N, potential yields, N fertilizer rates and other variables. Next, models to forecast grain protein contents and yields without the use of spring applied N fertilizer are discussed. Finally, residual NO_3-N prediction models are presented that estimated NO_3-N in the surface foot of soil after harvest.

Before the equations are applied, the following criteria must be met: 1) adequate phosphorus fertilizer should be drilled with the seed; 2) good stands of recommended winter wheat varieties should exist; 3) weed control must be accomplished; and 4) equations apply only to the fallow system of farming.

To consummate the "best fit" of the data, the data were split into two groups based on soil NO_3-N content in 4 ft of soil. Soils which had less than 120 lbs of N were placed in one group (designated as Group I) while those with NO_3-N greater than 120 lbs of N comprise the other (designated as Group II). However equations based on all the data are included in the appendix tables 6-19. Group I contains 38 locations while group II contains 9.

Variable description

Variable designation, description, units, mean and standard deviation are listed in Table 1. These are the variables used in developing potential yield and nitrogen (N) fertilizer requirements of winter wheat. The data used in computing these statistics are summarized in Appendix Table 1. The data utilized in the potential yield, N fertilizer requirements and grain protein predictions are indicated by underscoring with a dotted line.

Nitrate-nitrogen and soil water were measured from soil samples collected at each location during the period 1-15 May. Potential yield is not necessarily the maximum yield measured at each location. It is a more conservative measurement of optimum yield obtained with an N fertilizer rate that will not create a high potential for N water pollution.

Changes in variables X1-X3 for check plot prediction equation are contained in Table 2. In other words Table 2 summarizes yield and protein data for the 0-N treatments in Appendix Table 1.

Variables were entered into the regression analysis based on a prescribed F value. In subsequent regression equations, the F was set

Table 1. Variables used in developing predictive equations for potential grain yield, N fertilizer requirements and grain protein content of winter wheat.

Variable Designation	Variable Description	Units	Mean			Standard Deviation		
			All Loc.	Group I	Group II	All Loc.	Group I	Group II
X1	Grain protein content	%	12.46	12.33	13.00	1.39	1.36	1.44
X2	Maximum grain yield	Bu/A	37.04	36.71	38.39	8.83	8.24	11.46
X3	N fertilizer rate	# N/A	28.51	31.58	15.56	24.49	24.33	21.86
X4	Soil NO_3-N in 1' of soil	# N/A	30.07	24.60	53.19	23.41	18.96	27.32
X5	Soil NO_3-N in 2' of soil	# N/A	52.92	42.60	96.51	36.99	24.97	48.37
X6	Soil NO_3-N in 3' of soil	# N/A	66.98	52.92	126.31	44.43	29.62	48.91
X7	Soil NO_3-N in 4' of soil	# N/A	77.44	59.01	155.26	51.34	32.49	42.99
X8	Soil NO_3-N in 5' of soil	# N/A	82.11	58.75	180.74	65.50	42.14	53.99
X9	Soil NO_3-N in 6' of soil	# N/A	89.17	65.46	189.30	77.40	51.11	91.70
X10	Available soil water in 1' of soil	inches	1.64	1.60	1.84	0.86	0.67	1.45
X11	Available soil water in 2' of soil	inches	3.43	3.37	3.64	1.36	1.19	2.01
X12	Available soil water in 3' of soil	inches	4.81	4.73	5.13	1.67	1.61	1.98
X13	Available soil water in 4' of soil	inches	5.84	5.71	6.39	2.03	1.97	2.33
X14	Available soil water in 5' of soil	inches	5.97	5.71	7.11	3.22	3.39	2.20
X15	Available soil water in 6' of soil	inches	6.13	6.06	6.42	3.90	4.08	3.24
X16	Growing season rainfall (1-15May-1-15 Aug)	inches	4.47	4.46	4.51	1.60	1.65	1.31
X17	Ave. soil temp @ 50 cm (1-15May-15-30June)	C°	13.86	13.51	15.33	2.53	2.47	2.36
X18	Ave. soil temp @ 50 cm (15-30June-1-15Aug)	C°	18.71	18.51	19.56	2.14	2.24	1.45
X19	Evaporation rate (1-15May-15-30June)	Cm/day	0.57	0.56	0.62	0.16	0.14	0.22
X20	Evaporation rate (15-30June-1-15Aug)	Cm/day	0.65	0.65	0.65	0.14	0.16	0.09
X21	Soil organic matter	%	2.42	2.31	2.89	0.88	0.91	0.54

Table 2. Variables used in developing predictive equations for grain yield and grain protein content of winter wheat without spring applied N fertilizer.

Variable			Mean			Standard Deviation		
Designation	Variable Description	Units	All Loc.	Group I	Group II	All Loc.	Group I	Group II
X1	Grain protein content	%	11.40	11.13	12.56	1.97	2.03	1.16
X2	Grain yield	Bu/A	32.11	31.36	35.30	8.01	7.44	9.99
X3 thru X21 are identical to Table 1								

at .05 consequently variables were chosen and regression analysis performed when in fact the variable may have contributed significantly or very little to regression mean square. The data were entered into a second multiple regression program (18) as a cross-check on the primary program used.

Potential grain yield models

Multiple regression equations for potential yield are summarized in Tables 3 and 4. Variables X10-X21 were designated as independent.

In Table 3, growing season rainfall (X16) appears to be the most important and significant variable of the entire list. Available soil water variables (X11 and X13) were not included until the final steps and they were both nonsignificant. This phenomenon appears confusing at first; however, remember the equations were developed with data from fallow management systems and adequate water should have been stored prior to seeding. This is reflected in the low standard deviations for the soil water variables given in Table 1. Evaporation rate (X19) during the early part of the growing season was included at the second step and raised R^2 about 12%. Soil organic matter and early season soil temperature (X21 and X17) variables were included in equations 3 and 4; however, only X21 was significant when it was included in equation 4. Equation three (3) appears to be the most useful for predicting potential yield, it will predict potential yield within about 7 bu/A 66% of the time assuming at least

Table 3. Multiple linear regression equation expressing potential grain yield of winter wheat as a function of soil and climatic data (group I data).

	Equation	F 1/	SE 2/	R
1.	Y = 25.38 + 2.54** x16	12.63**	7.19	.510
2.	Y = 36.19 + 2.55** x16 - 19.28* x19	10.14**	6.75	.606
3.	Y = 32.87 + 2.38** x16 - 19.72* x19 + 1.86x21	7.83**	6.61	.639
4.	Y = 26.30 + 2.27** x16 + 0.54x17 - 21.12* x19 + 2.12# x21	6.30**	6.57	.658
5.	Y = 27.46 - 0.25x13 + 2.35** x16 + 0.52x17 - 21.39* x19 + 2.25# x21	4.95**	6.65	.660
6.	Y = 27.52 - 0.39x11 + 2.34** x16 + 0.53x17 - 21.43* x19 + 2.16# x21	4.95**	6.66	.660

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

3-5 inches of available water is present in 4-6 feet of soil and plant nutrients are not limiting. However variables X16 and X19 are intangible and cannot be precisely known at the outset of spring growth. It is proposed that long term averages from official weather station records be used for these variables. By using rainfall probability publications (17) and Caprio's information on evaporation (5) one could calculate the odds for harvesting a certain yield providing the required plant nutrients are supplied. Then the N fertilizer recommendation equation can be employed to predict the actual N fertilizer necessary to achieve the estimated yield potential.

Equation 3 is limited because it accounts for about 41% of the total variation. Obviously the other climatic factors measured did not increase the regression mean square, and only equation 4 produced a lower standard error of estimate. Perhaps measurements in total radiation, net radiation or more frequent measurements of the variables already discussed would increase the R^2 of the potential yield equation.

The equations for Group II locations appear a little erratic, probably due to the low df. Rainfall (X16) was not included until equation 4 and was non-significant when it was entered. However it did become significant when X18 and X10 were also entered in equation 5 and 6. Caution should be exercised in attaching significance to equation 5 and 6 because the number of variables included are only slightly less than the total df. Since soil NO_3-N was uniformily high in these 9 locations and variation in rainfall was not great, these variables would not be expected to contribute significantly to prediction of potential yields. Thus, factors such as soil temperature, pan evaporation and organic matter content should be responsible for some of the variation in yield observed at these locations. Equations 3-6 in Table 4 substantiate this argument. Considering total df involved, standard error of estimate and R, equation 3 is proposed as the most reliable predictive model for potential yield of Group II locations.

Nitrogen fertilizer requirement model

Tables 5-12 contain the equation which predict N fertilizer requirements of winter wheat for both groups of data; Tables 5-8 represent Group I and Tables 9-12 Group II. Equations were generated in this analysis by regressing N fertilizer rate (X3) at optimum yield against potential yield (X2), soil NO_3-N and water at a given depth, plus all the other variables listed in Table 1.

In the equations representing Group I data, 64% of the variation was accounted for by the inclusion of all the variables at a given soil depth. This is a considerably high amount of the varation in view of the fact that factors such as variety, seeding rate, drill type and phosphorus fertilizer material are not included as variables.

Table 4. Multiple linear regression equations expressing potential grain yield of winter wheat as a function of soil and climatic variables (group II data).

Equation	F 1/	SE 2/	R
1. Y = - 3.32 + 14.44x21*	6.11*	8.95	.683
2. Y = - 44.54 + 2.03x17 + 17.91x21*	4.77#	8.22	.784
3. Y = - 133.54 + 6.36x17* + 56.53x19* + 13.69x21*	7.70*	6.11	.907
4. Y = - 134.14 + 2.44x16 + 6.07x17* + 63.42x19* + 10.15x21	6.48*	5.92	.931
5. Y = 35.84 + 6.62x16* + 5.14x17* - 6.30x18* + 75.14x19** - 10.17x21	11.71*	4.13	.975
6. Y = 52.17 - 1.23x10 + 6.72x16* + 5.52x17* - 7.13x18 + 80.94x19** - 12.85x21	11.18#	3.90	.985

1/ F ratio due to regression; total df = 8

2/ SE = Standard error of the estimate

sign. p = .10; * sign, p = .05; ** sign. p = .005

Table 5. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (1' soil samples; group I data).

	Equation	F 1/	SE 2/	R
1.	Y = - 16.33 + 1.30x2*	8.75*	22.12	.442
2.	Y = - 8.57 + 1.44x2** - 0.52x4*	9.74**	20.05	.598
3.	Y = - 2.57 + 1.60x2** - 0.45x4* - 5.81x21	7.52**	19.68	.632
4.	Y = - 27.16 + 1.80x2** - 0.43x4* + 32.97x19 - 6.61x21#	6.23**	19.45	.656
5.	Y = 9.74 + 1.90x2** - 0.39x4* - 2.39x18 + 42.81x19 - 8.05x21*	5.76**	18.98	.688
6.	Y = 12.32 + 2.00x2** - 0.46x4* - 3.69x18* + 45.26x19# + 33.21x20 - 9.26x21*	5.14**	18.82	.706
7.	Y = 9.50 + 1.96x20** - 0.54x4* + 5.36x10 - 3.85x18* + 43.75x19# + 36.73x20 - 9.68x21*	4.57**	18.80	.718
8.	Y = 12.24 + 1.93x2 - 0.57x4 + 5.79x10 + 0.81x17 - 4.57x18 + 42.68x19 + 38.28x20 - 9.51x21	3.90**	19.08	.720

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign, p = .05; ** sign. p = .005

Table 6. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (2' soil samples; group I data).

Equation	1/ F	2/ SE	R
1. Y = - 16.33 + 1.30x2*	8.75*	22.12	.442
2. Y = - 5.02 + 1.61x2** - 0.53x5**	16.17**	18.03	.693
3. Y = - 15.53 + 1.59x2** - 0.63x5** + 4.67x11#	12.31**	17.56	.722
4. Y = - 45.46 + 1.80x2** - 0.65x5** + 5.09x11# + 38.10x19#	10.63**	17.03	.750
5. Y = - 43.96 + 1.88x2** - 0.61x5** + 4.86x11# + 40.31x19# - 2.95x21	8.57**	17.11	.757
6. Y = - 25.93 + 1.93x2** - 0.56x5** + 4.73x11# - 1.14x18 + 44.72x19# - 3.96x21	7.17**	17.20	.762
7. Y = - 25.62 + 2.02x2** - 0.61x5** + 4.86x11# - 2.32x18 + 47.69x19* + 31.60x20 - 4.99x21	6.57**	16.98	.778
8. Y = - 23.16 + 1.92x2** - 0.70x5** + 6.23x11* + 2.58x17 - 4.40x18# + 45.52x19* + 35.20x20 - 3.77x21	6.04**	16.84	.790
9. Y = - 21.09 + 1.77x2 - 0.71x5 + 5.89x11 + 1.40x16 + 2.60x17 - 4.54x18 + 42.40x19 + 39.57x20 - 3.76x21	5.30**	17.01	.794

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign, p = .05; ** sign. p = .005

Table 7. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (3' soil samples; group I data).

Equation	F 1/	SE 2/	R
1. Y = 51.35 - 0.37x6**	9.39**	21.96	.455
2. Y = - 3.51 + 1.62x2** - 0.46x6**	17.26**	17.75	.705
3. Y = - 32.86 + 1.84x2** - 0.47x6** + 38.88x19#	13.36**	17.20	.736
4. Y = - 44.41 + 1.82x2** - 0.57x6** + 3.35x12 + 41.48x19#	11.22**	16.77	.759
5. Y = - 43.32 + 1.91x2** - 0.53x6** + 3.36x12 + 43.83x19# - 3.35x21	9.15**	16.78	.767
6. Y = - 52.03 + 1.93x2** - 0.56x6** + 3.50x12 + 43.41x19# + 14.52x20 - 3.39x21	7.61**	16.90	.772
7. Y = - 31.82 + 2.01x2** - 0.53x6** + 3.18x12 - 1.67x18 + 48.83x19# + 26.57x20 - 4.90x21	6.67**	16.90	.780
8. Y = - 29.34 + 1.84x2** - 0.54x6** + 2.87x12 + 1.71x16 - 1.83x18 + 45.30x19# + 31.81x20 - 4.84x21	5.84**	17.01	.785
9. Y = - 28.15 + 1.77x2** - 0.58x6** + 3.48x12 + 1.72x16 + 1.55x17 - 3.02x18 + 44.01x19# + 33.17x20 - 4.26x21	5.17**	17.14	.790

2/ SE = Standard error of the estimate
sign. p = .10; * sign, p = .05; ** sign. p = .005

Table 8. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (4' soil samples; group I data).

Equation	F 1/	SE 2/	R
1. Y = 51.88 - 0.34x7**	9.63**	21.91	.459
2. Y = - 3.26 + 1.63x2** - 0.42x7**	17.87**	17.60	.711
3. Y = - 32.50 + 1.87x2** - 0.44x7 + 38.73x19	13.82**	17.04	.741
4. Y = - 43.26 + 1.86x2** - 0.54x7** + 2.74x13 + 41.63x19#	11.44**	16.68	.762
5. Y = - 42.53 + 1.92x2** - 0.50x7** + 2.84x13 + 44.13x19# - 3.42x21	9.34**	16.68	.770
6. Y = - 53.19 + 1.95x2** - 0.54x7** + 3.09x13# + 43.77x19* + 17.07x20 - 3.49x21	7.85**	16.74	.777
7. Y = - 52.67 + 1.75x2** - 0.56x7** + 2.84x13 + 1.87x16 + 39.26x19# + 21.57x20 - 3.18x21	6.79**	16.81	.783
8. Y = - 35.45 + 1.80x2** - 0.53x7** + 2.56x13 + 2.04x16 - 1.39x18 + 43.30x19# + 31.50x20 - 4.46x21	5.96**	16.91	.788
9. Y = - 28.16 + 1.75x2** - 0.57x7** + 2.95x13 + 2.05x16 + 1.44x17 - 2.26x18 + 42.37x19# + 32.56x20 - 4.09x21	5.17**	17.14	.791

2/ SE = Standard error of the estimate
sign. p = .10; * sign, p = .05; ** sign. p = .005

Also R^2 tend to increase with sampling depth, in other words, the best correlations come from the deeper soil samples.

The equations in Tables 6-8 for soil depths 2-4 ft appear to be almost identical with respect to the order of variable inclusion. The values of the partial coefficients are almost the same for comparable equations; of course, the coefficients for soil, water and NO_3-N are smaller with increasing soil depth indicating a decrease in efficiency of extraction of water and NO_3-N by wheat. Equation 4 of all three tables appears to be the best model since SE's tended to increase with the inclusion of more variables. The soil water variables were almost significant (p=.10) in Tables 7 & 8 and they were significant (p=.10) in table 6. This conclusion was documented with another multiple regression program called Mini-Rex (18). The program calculates all possible regression equations and sorts out the best model based on the lowest error mean square (EMS). Equation 4 was picked by the Mini-Rex program also. Apparently lowest EMS corresponds to the lowest SE predicted by the stepwise program. It was interesting to note that evaporation rate (X19) was positively correlated with N fertilizer rate while in the potential yield prediction, the correlation was negative. The same value in one instance would reduce the N fertilizer prediction via a lower potential yield, and in the other instance show an increased prediction for N fertilizer. Both relationships probably can be explained. In the case of the potential yield equation, the negative relationship observed is consistent with the literature (31) (ie., a high evaporative demand, thus a low yield). On the other hand, the positive correlation with N fertilizer requirement would indicate a greater plant dependence upon stored soil NO_3-N and N fertilizer rather than NO_3-N mineralized from soil organic matter. The high evaporation rate would appear to dictate a low soil water content in the surface soil and thus a decrease in organic matter decomposition.

The equations in Table 5 differ from the others; organic matter was entered much sooner and soil water at a later step. The greater dependence on organic matter probably resulted because the shallow soil sampling does not allow for the influence of deep soil NO_3-N. In this set, equation 7 appears to be the best model and is suggested for use when only surface soil samples are available. However the models generated by deeper samples account for 10-15% more variation at any given step. Consequently the models of Tables 6-8 and preferably those in Table 8 should be used if deep soil samples are available.

The equations developed from the Group II data (tables 9-12) are much like those which predict potential yield - the models are difficult to interpret due to the small number of data points (N=9).

Table 9. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (1' soil samples; group II data).

Equation	1/ F	2/ SE	R
1. Y = - 22.87 + 8.52x16	2.45	20.11	.509
2. Y = 37.29 + 8.79x16 - 95.07x20	2.05	19.45	.638
3. Y = 83.30 - 6.26x10 + 7.17x16 - 137.16x20	1.96	18.75	.735
4. Y = 137.26 - 0.36x4 - 7.53x10 + 5.94x16 - 179.20x20#	2.46	16.62	.843
5. Y = 239.56 - 0.61x4# - 8.97x10# + 7.53x16# - 222.80x20* - 22.30x21#	5.81#	10.92	.952
6. Y = 228.49 + 0.30x2 - 0.57x4 - 8.87x10 + 6.71x16 - 209.95x20# - 25.02x21	3.57	12.78	.956
7. Y = 38.73 + 0.66x2 - 0.44x4 - 7.84x10 + 3.63x16 + 6.69x18 - 198.49x20 - 10.22x21	2.30	14.95	.970

1/ F ratio due to regression; total df = 8
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05

Table 10. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (2' soil samples; group II data).

Equation	1/ F	2/ SE	R
1. Y = 85.61 - 0.21x5 + 9.48x16 - 142.86x20	2.42	17.67	.769
2. Y = - 29.36 - 0.32x5* + 9.32x16# + 8.26x18# - 197.92x20*	4.78#	12.86	.909
3. Y = 23.36 - 0.29x5* - 4.37x11 + 6.42x16 + 7.84x18* - 226.16x20*	8.37#	9.23	.966
4. Y = - 53.40 + 0.63x2 - 0.23x5 - 4.37x11 + 3.43x16 + 10.06x18# - 200.48x20#	7.80	8.85	.979
5. Y = - 132.39 + 0.60x2 - 0.22x5 - 4.31x11 + 2.17x16 + 13.07x18 - 205.82x20 + 10.08x21	5.09	10.22	.986

1/ F ratio due to regression; total df = 8
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05

Table 11. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (3' soil samples; group II data).

Equation	1/ F	2/ SE	R
1. Y = 124.04 - 6.36x12 + 3.57x16 - 142.41x20	2.51	17.48	.775
2. Y = 135.90 - 9.42x12 + 3.56x16 + 40.58x19 - 175.27x20#	2.32	16.96	.836
3. Y = - 62.66 - 9.61x12# + 1.81x16 + 9.21x17 + 124.98x19# - 153.33x20#	4.63	12.09	.941
4. Y = - 181.21 - 1.17x2 - 10.33x12* + 7.05x16 + 16.07x17# + 221.63x19# - 186.46x20*	9.40#	8.09	.983
5. Y = - 225.22 - 1.53x2 - 10.75x12# + 6.90x16 + 18.16x17 + 238.94x19# - 191.87x20# + 7.41x21	5.40	9.93	9.87

2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05

Table 12. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (4' soil samples; group II data).

Equation	1/ F	2/ SE	R
1. Y = 97.07 - 4.12x13 + 5.82x16 - 126.17x20	2.03	18.56	.741
2. Y = 124.03 - 9.66x13# + 6.32x16 + 72.76x19 - 186.145x20#	3.02	15.42	.867
3. Y = - 45.53 - 8.96x13# + 5.17x16 + 7.49x17 + 135.54x19# - 160.35x20#	4.11	12.74	.934
4. Y = - 135.51 - 0.84x2 - 9.00x13 + 9.23x16 + 12.40x17 + 202.95x19 - 180.15x20	3.60	12.73	.957
5. Y = - 252.19 - 1.95x2 - 11.57x13 + 8.68x16 + 18.38x17 + 264.39x19 - 210.61x20 + 23.57x21	7.94	8.22	.991

2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05

In other words, increased reliability would be gained if data were gathered from more locations that have soil NO_3-N contents greater than 120 lbs of N in 4' of soil.

These equations show that soil NO_3-N and potential yield data are of less value for predicting fertilizer response when soil NO_3-N is high as compared to when it is low (<120 # N/ac). Soil NO_3-N variables were not entered in the deeper sampling depths (tables 11-12). Note that soil water factors are negatively related to fertilizer requirements rather than the expected positive relationship. One possible explanation is that increased mineralization of organic nitrogen could have resulted from the higher soil water content. If this negative relationship is related to mineralization of organic N and to nitrification it probably reflects microbial activities during the previous fallow period as well as during the cropping period.

The Group II N fertilizer rate prediction equations and potential yield equations are less reliable than those of Group I due to the low number of observations involved. However, the equations with 4 or less variables which were statistically significant should be useful in predicting N fertilizer rates for these higher producing soils. The equations should be viewed as tools for use in achieving that increment of yield which will increase yields from near optimum to the optimum as opposed to the Group I equations which should be viewed as tools for use in achieving major yield increases on soils producing mediocre yields thereby moving their yields to optimum levels.

Protein prediction models

These models will enable a producer to estimate protein content if the wheat is fertilized according to the scheme proposed in the previous pages. Then late applications of N to boost grain protein could be applied, according to the methods of Sims and Jackson (40).

The protein prediction equations were developed from the data in Table 1 by regressing grain protein (X3) on potential yield, N fertilizer rate, soil NO_3-N, the water variables and the remaining climatic and soil factors (X16 - X21).

Tables 13-16 contain the equations for Group I data. The signs of the regression coefficients of all the factors in these equations are consistent with previously reported data (6, 28, 40, 41). A decrease in protein with increasing water is evident. Also it was interesting to note that soil NO_3-N and N from fertilizer are practically equivalent in terms of producing grain protein (ie., witness the similarity in magnitude of the coefficients of X3 to X7). Again the equations based on the deeper samples produce the best correlations.

Table 13. Multiple linear regression equations expressing grain protein as a function of potential yield, N fertilizer, soil and climatic variables (1' soil samples; group I data).

Equation	F [1/]	SE [2/]	R
1. Y = 15.24 - 0.08x2**	10.67**	1.21	.478
2. Y = 14.75 - 0.09x2** + 0.41x21#	7.38**	1.18	.545
3. Y = 14.63 - 0.09x2** + 0.01x4 + 0.34x21	5.55**	1.17	.573
4. Y = 14.66 - 0.11x2** + 0.01x3 + 0.02x4 + 0.40x21#	4.51**	1.16	.595
5. Y = 13.36 - 0.12x2** + 0.01x3 + 0.02x4 + 0.07x18 + 0.45x21#	3.69*	1.17	.604
6. Y = 12.93 - 0.11x2** + 0.01x3 + 0.02x4# - 0.14x17 + 0.19x18 + 0.41x21#	3.27*	1.17	.622
7. Y = 12.90 - 0.11x2** + 0.01x3 + 0.02x4 + 0.12x10 - 0.13x17 + 0.18x18 + 0.40x21	2.74*	1.18	.625
8. Y = 12.88 - 0.10x2** + 0.01x3 + 0.02x4 + 0.16x10 - 0.06x16 - 0.12x17 + 0.17x8 + 0.41x21	2.36*	1.20	.628

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 14. Multiple linear regression equations expressing grain protein as a function of potential yield, N fertilizer, soil and climatic variables (2' soil samples; group I data).

	Equation	F 1/	SE 2/	R
1.	$Y = 14.67 - 0.09x2^{**} + 0.01x5 + 0.29x21$	5.48^{**}	1.17	.571
2.	$Y = 14.70 - 0.12x2^{**} + 0.02x3 + 0.02x5^{\#} + 0.33x21$	4.71^{**}	1.15	.603
3.	$Y = 14.77 - 0.11x2^{**} + 0.02x3 + 0.02x5^{\#} - 0.11x16 + 0.33x21$	3.85^{*}	1.16	.613
4.	$Y = 15.26 - 0.11x2^{**} + 0.02x3 + 0.02x5^{*} - 0.11x16 - 0.04x17 + 0.29x21$	3.16^{*}	1.17	.616
5.	$Y = 13.67 - 0.11x2^{**} + 0.02x3 + 0.02x5^{\#} - 0.12x16 - 0.16x17 + 0.17x18 + 0.31x21$	2.95^{*}	1.17	.638
6.	$Y = 13.86 - 0.11x2^{*} + 0.02x3 + 0.02x5^{\#} - 0.11x16 - 0.16x17 + 0.17x18 - 0.42x19 + 0.32x21$	2.51^{*}	1.18	.639

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 15. Multiple linear regression equations expressing grain protein as a function of potential yield, N fertilizer, soil and climatic variables (3' soil samples; group I data).

	Equation	F 1/	SE 2/	R
1.	Y = 14.87 - 0.09x2** + 0.01x6#	7.81**	1.17	.556
2.	Y = 14.92 - 0.11x2** + 0.02x3 + 0.02x6#	6.03**	1.15	.589
3.	Y = 14.65 - 0.12x2** + 0.02x3 + 0.02x6# + 0.32x21	5.10**	1.14	.618
4.	Y = 14.72 - 0.11x2** + 0.02x3# + 0.02x6* - 0.13x16 + 0.31x21	4.26**	1.14	.632
5.	Y = 15.27 - 0.11x2** + 0.02x3# + 0.02x6* - 0.13x16 - 0.04x17 + 0.27x21	3.51*	1.15	.636
6.	Y = 13.92 - 0.11x2** + 0.02x3# + 0.02x6* - 0.14x16 - 0.14x17 + 0.14x18 + 0.29x21	3.15*	1.15	.651
7.	Y = 14.21 - 0.12x2** + 0.02x3# + 0.02x6* - 0.13x16 - 0.14x17 + 0.15x18 - 0.63x19 + 0.31x21	2.70*	1.17	.653
8.	Y = 14.47 - 0.12x2** + 0.02x3# + 0.02x6# - 0.06x12 - 0.12x16 - 0.15x17 + 0.15x18 - 0.70x19 + 0.31x21	2.34*	1.18	.665

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 16. Multiple linear regression equations expressing grain protein as a function of potential yield, N fertilizer, soil and climatic variables (4' soil samples; group I data).

	Equation	F 1/	SE 2/	R
1.	Y = 14.86 - 0.09x2** + 0.01x7*	7.90**	1.16	.558
2.	Y = 14.91 - 0.12x2** + 0.02x3 + 0.02x7*	6.18**	1.14	.594
3.	Y = 14.65 - 0.12x2** + 0.02x3 + 0.02x7* + 0.31x21	5.19**	1.13	.621
4.	Y = 14.73 - 0.11x2** + 0.02x3# + 0.02x7* - 0.15x16 + 0.30x21	4.41**	1.13	.639
5.	Y = 15.34 - 0.11x2** + 0.02x3# + 0.02x7* - 0.15x16 - 0.05x17 + 0.25x21	3.65*	1.14	.643
6.	Y = 14.20 - 0.11x2** + 0.02x3# + 0.02x7* - 0.15x16 - 0.13x17 + 0.11x18 + 0.27x21	3.19*	1.15	.653
7.	Y = 14.66 - 0.11x2** + 0.02x3# + 0.02x7* - 0.08x13 - 0.15x16 - 0.16x17 + 0.12x18 + 0.26x21	2.78*	1.16	.659
8.	Y = 15.02 - 0.12x2** + 0.02x3# + 0.02x7* - 0.09x13 - 0.13x16 - 0.15x17 + 0.13x18 - 0.70x19 + 0.29x21	2.42*	1.18	.662

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Apparently potential yield is the most important factor of the entire lot; it was entered first on all four tables. This was expected from the classical yield-protein content relationships verified many times in the literature and recently reemphasized for Montana by Sims and Jackson (40, 41). However, soil NO_3-N, organic matter, and N fertilizer are also important. This fact is reflected by their appearance with potential yield in equivalent equations for all four depths of soil sampling.

Probably the best model is equation 4 for the 3 ft or 4 ft depth (tables 15 and 16). These equations contain rainfall (X16) in addition to the factors mentioned in the preceeding paragraph. But only about 41% of the variation in protein is accounted for although the equations will predict protein within 1.2 percentage points 66% of the time. Precision was lost by the inclusion of soil water and the other climatic factors (ie., SE was actually increased).

Appendix Tables 2-5 contain the protein prediction equations for the Group II locations. None of the equations were significant even at the 10% level. These results were neither surprising nor alarming. These soils produced grain of rather high protein content by winter wheat standards (table 1) and thus acceptable protein levels (although not optimum) are automatically predicted by placing a soil in Group II. Furthermore, the protein prediction models based on all locations in the study (Appendix Tables 11-13) can suffice until data are collected from more locations having high soil NO_3-N contents.

Grain yield models

Data from 0-N treatments, summarized in Table 2, were used in generating the models in tables 17-21; all soil and climatic variables were included. By comparing the wheat yields predicted by these equations with those in table 3, one can estimate the response due to N fertilizer to predict a net return (if any) from N fertilization.

By looking at equations generated from Group I locations (tables 17-20), again it is evident that deep soil samples produce the best correlations, and the equations in Tables 18-20 are practically the same with respect to variable inclusion. Equation 4 of Tables 18-20 appears to be the best model, because inclusion of more variables tends to dilute the effect of the four factors already included. This is evident as the standard error of estimate goes through a minimum at equation 4 in all cases. Furthermore, the signs of these models are consistent with classical theory. It is interesting to note, after close examination of equation 4 of Tables 18-20, that an inch of rainfall predicts about 1.25 bu. of wheat/A and that one hundred lbs of NO_3-N in 4' will predict only 5 or 6 bu. Also a hot, dry spring will tend to lower the yield (witness the magnitude and sign of X19). The negative relationship of the soil water

Table 17. Multiple linear regression equations expressing grain yield as a function of soil and climatic variables (1' soil samples, group I data).

Equation	F 1/	SE 2/	R
1. Y = 24.06 + 3.16x21*	6.34*	6.95	.387
2. Y = 35.60 - 21.01x19* + 3.28x21*	7.72**	6.40	.553
3. Y = 30.49 + 1.35x16* - 20.97x19* + 2.87x21*	7.37**	6.04	.628
4. Y = 24.46 + 1.26x16* + 0.49x17 - 22.26x19** + 2.09x21*	5.96**	6.00	.648
5. Y = 24.72 + 0.04x4 + 1.29x16* + 0.40x17 - 21.47x19* + 2.81x21*	4.81**	6.04	.655
6. Y = 26.29 + 0.05x4 + 1.18x16# + 0.54x17 - 21.29x19* - 5.82x20 + 2.99x21*	4.05**	6.08	.663
7. Y = 24.44 + 0.06x4 + 1.15x16# + 0.39x17 + 0.26x18 - 21.51x19# - 7.16x20 + 3.05x21*	3.38*	6.17	.664

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 18. Multiple linear regression equations expressing grain yield as a function of soil and climatic variables (2' soil samples, group I data).

Equation	F [1/]	SE [2/]	R
1. $Y = 26.37 + 0.12^{*}x5$	6.59^{*}	6.93	.393
2. $Y = 37.60 + 0.11^{*}x5 - 19.80^{*}x19$	7.28^{**}	6.43	.542
3. $Y = 32.83 + 0.09^{*}x5 + 1.28^{\#}x16 - 19.93^{*}x19$	6.65^{**}	6.16	.608
4. $Y = 29.89 + 0.06x5 + 1.19^{\#}x16 - 20.57^{*}x19 + 2.19^{\#}x21$	6.19^{**}	5.95	.655
5. $Y = 32.08 + 0.08x5 - 0.85x11 + 1.30^{\#}x16 - 21.16^{*}x19 + 2.08^{\#}x21$	5.07^{**}	5.97	.665
6. $Y = 34.58 + 0.09^{\#}x5 - 0.86x11 + 1.20^{\#}x16 - 20.79^{*}x19 - 4.31x20 + 2.08^{\#}x21$	4.20^{**}	6.03	.670
7. $Y = 29.24 + 0.09x5 - 0.81x11 + 1.10x16 + 0.43x18 - 21.83^{*}x19 - 7.72^{\#}x20 + 2.42x21$	3.62^{*}	6.08	.677

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 19. Multiple linear regression equations expressing grain yield as a function of soil and climatic variables (3' soil samples, group I data).

Equation	F [1/]	SE [2/]	R
1. Y = 26.04 + 0.10x6*	6.88*	6.91	.400
2. Y = 37.53 + 0.10x6* - 20.59x19*	7.89**	6.35	.557
3. Y = 33.01 + 0.08x6* + 1.22x16# - 20.58x19*	6.93**	6.11	.616
4. Y = 30.04 + 0.06x6 + 1.15x16# - 20.99x19* + 2.13x21#	6.36**	5.92	.660
5. Y = 31.72 + 0.07x6# - 0.53x12 + 1.23x16# - 21.46x19** + 2.13x21#	5.12**	5.96	.667
6. Y = 34.50 + 0.08x6# - 0.55x12 + 1.13x16# - 21.18x19* - 4.62x20 + 2.14x21#	4.26**	6.02	.672
7. Y = 30.83 + 0.07x6 - 0.36x12 + 1.03x16 + 0.34x17 - 21.77x19* - 6.40x20 + 2.47x21#	3.64*	6.07	.678

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 20. Multiple linear regression equations expressing grain yield as a function of soil and climatic variables (4' soil samples, group I data).

	Equation	1/ F	2/ SE	R
1.	Y = 25.79 + 0.09x7*	7.38*	6.87	.413
2.	Y = 37.25 + 0.10x7* - 20.51x19*	8.21**	6.31	.565
3.	Y = 33.02 + 0.08x7* + 1.17x16# - 20.50x19*	7.00**	6.10	.618
4.	Y = 30.09 + 0.05x7 + 1.12x16# - 20.93x19* + 2.11x21#	6.37**	5.91	.660
5.	Y = 32.73 + 0.06x7 + 1.01x16 - 20.63x19* - 4.49x20 + 2.11x21#	5.09**	5.97	.665
6.	Y = 29.00 + 0.05x7 + 0.93x16 + 0.43x17 - 21.59x19* - 6.80x20 + 2.52x21#	4.34**	5.99	.676
7.	Y = 30.34 + 0.06x7 - 0.20x13 + 0.97x16 + 0.37x17 - 21.69x19* - 6.75x20 + 2.49x21#	3.62*	6.08	6.77

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

variables is confusing, but their effect is insignificant even at the 10% level. Placing physical significance on the variable coefficients should be exercised with caution since the equations do not include all the factors which contribute to yield.

Equations for Group II locations are in Table 21. The utility of these models beyond equation 2 is questionable; witness the positive correlation of evaporation rate (X19) and the negative relationship of organic matter (X21). Soil NO_3-N variables were nonsignificant as expected, and soil water variables were not entered in any of the equations. In addition, deep sampling did not add further significance to soil NO_3-N or soil water. However soil temperature during the latter half of the growing season (X18) was the first variable entered, and it predicts lower yields with warmer soils. These are the only models where soil temperature variables were entered in the first steps of the analysis. More locations with high soil NO_3-N contents need to be monitored and then analyzed to produce reliable equations.

Grain protein prediction models

Tables 22-29 contain the equations developed from 0-N treatment data for Groups I and II. These equations were generated from Table 2 data by regressing grain protein versus soil and environmental variables.

Table 21. Multiple linear regression equations expressing grain yield as a function of soil and climatic variables (group II data).

Equation	F 1/	SE 2/	R
1. Y = 143.24 - 5.52x18*	12.34*	6.43	.799
2. Y = 134.61 + 2.58x16 - 5.67x18*	9.06*	5.75	.867
3. Y = 113.85 + 3.24x16 - 5.19x18* + 11.55x19	6.72*	5.64	.895
4. Y = 246.96 + 7.50x16* - 10.55x18* + 35.17x19# - 21.08x21#	9.98*	4.26	.953
5. Y = 162.99 + 6.29x16* + 2.55x17# - 9.19x18* + 54.82x19* - 17.04x21#	23.24*	2.59	.987
6. Y = 162.05 + 6.34x16* + 2.70x17# - 9.60x18* + 56.02x19* + 12.13x20 - 17.81x21#	21.56*	2.47	.992
7. Y = - 24.82 + 0.18x4 + 3.95x16# + 6.14x17# - 6.23x18# + 81.34x19* + 32.36x20# - 3.64x21	338.28*	0.59	1.000
8. Y = 82.47 + 0.05x5 + 4.80x16 + 4.52x17 - 8.56x18 + 67.22x19 + 27.79x20 - 12.13x21	13.66	2.87	.995

Table 21. Continued.

Equation	1/ F	2/ SE	R
9. Y = 129.47 + 0.03x6 + 5.76x16 + 3.83x17 - 9.68x18 + 63.06x19 + 20.90x20 - 16.01x21	15.17	2.73	.995
10. Y = 173.22 - 0.48x7 + 6.23x16 + 2.59x17 - 9.83x18 + 58.17x19 + 8.29x20 - 17.92x21	11.82	3.09	.994

1/ F ratio due to regression; total df = 8
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05

Table 22. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables (1' soil samples; group I data).

Equation	F 1/	SE 2/	R
1. Y = 10.37 + 0.03x4#	3.24#	1.98	.287
2. Y = 11.85 + 0.03x4# - 0.33x16#	3.23#	1.92	.395
3. Y = 11.07 + 0.03x4 - 0.38x16# + 0.49x21	2.82#	1.90	.447
4. Y = 12.42 - 0.08x2 + 0.03x4# - 0.27x16 + 0.67x21#	2.82#	1.86	.505
5. Y = 9.85 - 0.08x2 + 0.03x4 - 0.29x16 + 0.14x18 + 0.73x21#	2.45#	1.86	.526
6. Y = 9.10 - 0.07x2 + 0.03x4# - 0.27x16 - 0.28x17 + 0.37x18 + 0.66x21#	2.39#	1.84	.562
7. Y = 8.84 - 0.07x2 + 0.04x4* - 0.31x16 - 0.30x17 + 0.48x18# - 2.36x20 + 0.75x21#	2.14#	1.85	.577
8. Y = 8.75 - 0.07x2 + 0.04x4 + 0.22x11 - 0.33x16 - 0.28x17 + 0.47x18# - 2.24x20 + 0.74x21#	1.84	1.87	.580

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05

Table 23. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables (2' soil samples; group I data).

	Equation	F 1/	SE 2/	R
1.	Y = 9.74 + 0.03x5*	6.33*	1.90	.387
2.	Y = 11.56 + 0.04x5** - 0.47x16*	7.02**	1.77	.535
3.	Y = 13.21 - 0.08x2# + 0.05x5** - 0.37x16#	6.01**	1.72	.589
4.	Y = 15.18 - 0.08x2# + 0.05x5** - 0.36x16# - 0.16x17	5.03**	1.70	.616
5.	Y = 12.30 - 0.07x2# + 0.05x5** - 0.36x16# - 0.37x17# + 0.30x18	4.65**	1.66	.649
6.	Y = 12.44 - 0.08x2# + 0.06x5** - 0.42x16* - 0.41x17* + 0.41x18# - 2.56x20	4.10**	1.66	.665
7.	Y = 11.46 - 0.09x2* + 0.05x5** - 0.43x16* - 0.37x17# + 0.44x18# - 3.10x20 + 0.43x21	3.74*	1.65	.683
8.	Y = 12.05 - 0.09x2 + 0.06x5 - 0.21x11 - 0.40x16 - 0.43x17 + 0.48x18 - 3.16x20 + 0.38x21	3.29*	1.66	.690

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 24. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables (3' soil samples; group I data).

	Equation	F 1/	SE 2/	R
1.	Y = 9.53 + 0.03x6*	8.55*	1.85	.438
2.	Y = 11.40 + 0.04x6** - 0.50x16*	9.35**	1.69	.590
3.	Y = 13.20 - 0.08x2* + 0.04x6** - 0.40x16*	8.22**	1.62	.648
4.	Y = 15.24 - 0.09x2* + 0.05x6** - 0.39x16* - 0.16x17	6.92**	1.59	.675
5.	Y = 13.02 - 0.08x2# + 0.05x6** - 0.39x16* - 0.33x17# + 0.23x18	5.92**	1.58	.693
6.	Y = 13.16 - 0.08x2* + 0.05x6** - 0.44x16* - 0.35x17# + 0.32x18 - 2.33x20	5.14**	1.57	.706
7.	Y = 12.27 - 0.09x2* + 0.05x6** - 0.45x16* - 0.32x17# + 0.36x18# - 2.84x20 + 0.37x21	4.58**	1.57	.719
8.	Y = 13.14 - 0.10x2* + 0.05x6** - 0.18x12 - 0.42x16* - 0.38x17# + 0.38x18# - 2.79x20 + 0.34x21	4.07**	1.58	.727

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 25. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables (4' soil samples; group I data).

	Equation	F 1/	SE 2/	R
1.	Y = 9.48 + 0.03x7*	8.88*	1.85	.445
2.	Y = 11.39 + 0.04x7** - 0.53x16**	10.19**	1.66	.607
3.	Y = 13.27 - 0.09x2* + 0.04x7** - 0.42x16*	9.12**	1.58	.668
4.	Y = 15.41 - 0.09x2* + 0.05x7** - 0.42x16* - 0.17x17	7.76**	1.55	.696
5.	Y = 13.73 - 0.09x2* + 0.05x7** - 0.42x16* - 0.29x17# + 0.17x18	6.35**	1.55	.706
6.	Y = 13.90 - 0.09x2* + 0.05x7** - 0.47x16* - 0.31x17# + 0.26x18 - 2.18x20	5.47**	1.55	.717
7.	Y = 13.04 - 0.10x2* + 0.05x7** - 0.47x16* - 0.29x17 + 0.29x18 - 2.62x20 + 0.33x21	4.79**	1.55	.727
8.	Y = 13.94 - 0.10x2* + 0.05x7** - 0.16x13 - 0.44x16* - 0.34x17# + 0.31x18 - 2.68x20 + 0.31x21	4.25**	1.56	.735

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 26. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables (1' soil samples; group II data).

Equation	F 1/	SE 2/	R
1. Y = 11.53 + 0.02x4	1.81	1.11	.454
2. Y = 12.09 + 0.02x4 - 0.31x10	1.65	1.08	.596
3. Y = 10.78 + 0.03x2 + 0.02x4 - 0.33x10	1.19	1.12	.645
4. Y = 12.43 + 0.06x2 + 0.02x4 - 0.38x10 - 0.85x21	0.90	1.19	.689
5. Y = 19.84 + 0.05x2 + 0.02x4 - 0.42x10 - 0.27x18 - 1.31x21	0.59	1.34	.704
6. Y = 28.72 + 0.01x2 + 0.01x4 - 0.40x10 + 0.28x16 - 0.63x18 - 1.95x21	0.39	1.58	.734
7. Y = 146.44 - 0.34x2* - 0.03x4# - 0.56x10* + 3.58x16* - 5.40x18* + 16.08x19* - 13.87x21*	116.74#	0.11	.999

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate
\# sign. p = .10; * sign. p = .05; ** sign. p = .005

Table 27. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables (2' soil samples; group II data).

Equation	F [1]	SE [2]	R
1. Y = 13.22 - 0.18x11	.78	1.18	.317
2. Y = 12.64 + 0.01x5 - 0.22x11	.74	1.20	.444
3. Y = 14.96 + 0.01x5 - 0.24x11 - 0.12x18	.46	1.30	.466
4. Y = 30.22 + 0.01x5 - 0.33x11 - 0.63x18 - 1.68x21	.68	1.27	.636
5. Y = 32.71 + 0.01x5 - 0.29x11 + 0.21x16 - 0.75x18 - 2.09x21	.46	1.42	.660
6. Y = 72.20 - 0.01x5 - 0.22x11 + 1.34x16 - 0.64x17 - 1.81x18 - 6.59x21	.92	1.20	.857
7. Y = 100.91 - 0.10x2 - 0.02x5 - 0.14x11 + 2.10x16 - 0.89x17 - 2.77x18 - 8.49x21	.72	1.33	.914

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate

Table 28. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables (3' soil samples; group II data).

Equation	F 1/	SE 2/	R
1. Y = 13.51 - 0.19x12	.79	1.18	.318
2. Y = 15.91 - 0.22x12 - 0.11x18	.40	1.26	.344
3. Y = 29.79 - 0.27x12 - 0.59x18 - 1.49x21	.65	1.24	.530
4. Y = 40.93 - 0.43x12 - 0.23x17 - 0.83x18 - 2.27x21	.66	1.27	.630
5. Y = 65.07 - 0.33x12 + 0.97x16 - 0.56x17 - 1.61x18 - 5.24x21	1.39	1.04	.836
6. Y = 73.47 - 0.01x6 - 0.23x12 + 1.35x16 - 0.77x17 - 1.72x18 - 6.53x21	1.44	1.00	.901
7. Y = 93.01 - 0.09x2 - 0.02x6 - 0.11x12 + 1.95x16 - 0.94 - 2.37x18 - 7.63x21	1.69	0.92	.960

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate

Table 29. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables (4' soil samples; group II data).

Equation	F [1]	SE [2]	R
1. Y = 13.60 - 0.16x13	.84	1.17	.327
2. Y = 17.86 - 0.23x13 - 0.20x18	.53	1.23	.387
3. Y = 26.50 - 0.21x13 - 0.49x18 - 1.03x21	.50	1.29	.480
4. Y = 37.84 - 0.40x13 - 0.26x17 - 0.73x18 - 1.59x21	.56	1.31	.598
5. Y = 62.80 - 0.30x13 + 0.98x16 - 0.59x17 - 1.53x18 - 4.75x21	1.21	1.09	.818
6. Y = 63.00 - 0.01x7 - 0.19x13 + 1.18x16 - 0.71x17 - 1.38x18 - 5.13x21	.90	1.20	.855
7. Y = 91.10 - 0.18x2 - 0.04x7 + 0.12x13 + 2.26x16 - 1.05x17 - 2.16x18 - 6.63x21	3.60	.64	.981

1/ F ratio due to regression; total df = 37
2/ SE = Standard error of the estimate

The models can be utilized to estimate protein without spring N topdressing.

Again the Group I equations show the value of deep soil samples compared to surface soil samples. The variables expected to be the most important (yield, soil NO_3-N and rainfall) were entered in the analysis during the first three steps of Tables 23 through 25. Equation 5 of these tables appears to be the most useful.

It is noteworthy that 10 lbs of NO_3-N will predict an increase of about 0.4 of a percent of protein while a 10 bu/A increase in wheat yield will predict a decrease in protein content of about 0.1% and one inch of rain will predict a decrease in protein content of approximately 0.5%. The Group II equations in Tables 26-29 are of considerably less value for protein prediction for the same reasons as given for the Group II equations resulting from the data from fertilized plots. Only equation 7 in Table 26 was statistically significant and it is not reliable as the number of factors is only one less than total df. Furthermore it would not lend itself to practical application. In view of these results, protein prediction for Group II soils not receiving spring N topdressing, would best be accomplished using equations based on all locations (Appendix Tables 16-19).

Residual NO_3-N models

Equations for predicting residual NO_3-N in 1' of soil were generated for fertilizer treatments of 80 lbs of N in 1972, 180 lbs of N in 1970 and 1971 and 0 lbs of N from 1970, 71 and 72. These equations coupled with some means of predicting erosion such as the universal soil loss equation could be used to estimate what additional amounts of NO_3-N would enter a water-way via surface runoff.

Such a model should predict residual NO_3-N in 0-1' of soil without the use of N fertilizer and then predict in a similar manner, a value for residual NO_3-N when N fertilizer is incorporated into the management system. The difference between the two predictions would be the amount of NO_3-N directly attributable to N fertilization which would be available for water pollution via surface runoff.

Carry-over NO_3-N or NO_3-N that would be available for the next crop could be estimated also; however, NO_3-N that would be mineralized could not be estimated with these models.

Data for analysis are indicated in Appendix Table 1 where soil NO_3-N after harvest is reported for the 0-N treatment and the 180 or 80 - N treatment. Not all locations were included because soil samples were not available. Independent variables included X16 through X21, X13, X4 and X7 from Table 1. In addition yield and protein data from the 0 and high - N treatments were included as independent variables. Of these additional variables, protein of 0-N plots and yield of the 80-N plots were the only ones entered in the stepwise analysis. These are designated X22 and X23, respectively.

Table 30 contains 5 equations which predict residual NO_3-N after a crop of winter wheat without spring application of N fertilizer. These equations are based on soil NO_3-N contents in one foot of soil. Any of these equations will predict residual NO_3-N with acceptable SE's; however, equation 4 appears to be the best model. If information to estimate soil temperature and evaporation is available, then equations 3 and 4 would give the best prediction. It is apparent that soil NO_3-N in 4' is not as useful in predicting residual NO_3-N as soil NO_3-N in 1' (see table 31); this relationship is probably due to decreasing activity of wheat roots in the 4 ft zone. The models in Table 31 do not have readily measurable parameters in the first two steps (ie., soil temperature and evaporation rates would have to be estimated). Equations 4 and 5 do contain soil water and soil NO_3-N variables however.

One thing that may be a little confusing is the positive relationship between soil water (X13) and residual NO_3-N. A negative relationship was expected (ie. more water therefore greater yield thus more NO_3-N uptake by wheat). However, the positive relationship may indicate more NO_3-N being mineralized.

Table 30. Multiple regression equations expressing residual NO_3-N in 1' of soil as a function of soil and climatic variables (1' soil samples) without N topdressing.

	Equation	F 2/	SE 1/	R
1.	$Y = 10.73 - 0.17x4^{*}$	8.52^{*}	5.54	.528
2.	$Y = 3.01 - 0.20x4^{**} + 1.41x13^{*}$	8.10^{**}	5.02	.660
3.	$Y = 21.08 - 0.17x4^{**} + 1.47x13^{*} - 1.02x18^{*}$	8.75^{**}	4.50	.753
4.	$Y = 15.17 - 0.20x4^{**} + 1.13x13^{*} - 1.18x18^{*} + 1.11x22^{*}$	9.74^{**}	4.02	.820
5.	$Y = 15.89 - 0.18x4^{**} + 1.10x13^{*} - 1.04x18^{*} - 9.03x20 + 1.31x22^{*}$	9.11^{**}	3.84	.847

1/ SE = Standard error of the estimate
2/ Values of F; Total df = 23
* sign. p = .05; ** sign. p = .005

Table 31. Multiple regression equations expressing residual NO_3-N in 1' of soil as a function of soil and climatic variables (4' soil samples) without N topdressing.

	Equation	F [2/]	SE [1/]	R
1.	$Y = 22.77 - 1.12^{*}x17$	6.23^{*}	5.77	.470
2.	$Y = 27.22 - 0.94^{*}x17 - 11.04x20$	4.71^{*}	5.55	.556
3.	$Y = 19.30 - 1.18^{*}x17 - 17.13^{*}x20 + 1.46^{*}x22$	6.54^{**}	4.87	.704
4.	$Y = 16.66 + 0.61x13 - 1.10^{*}x17 - 17.24^{*}x20 + 1.26^{*}x22$	5.17^{*}	4.86	.722
5.	$Y = 2.04 - 0.09^{\#}x7 + 1.56^{*}x13 - 0.78^{\#}x17 - 14.82^{*}x20 + 2.14^{*}x22$	5.61^{**}	4.51	.780

1/ SE = Standard error estimate
2/ Values of F; Total df = 24
\# sign. p = .10; * sign. p = .05; ** sign. p = .005

Tables 32 and 33 contain the two models which predict residual NO_3-N after harvesting a winter wheat crop that had been fertilized with 180 and 80 lbs of N, respectively. In Table 32 soil NO_3-N in 4' is significantly related to residual NO_3-N at the 10% level; however, the multiple R is quite low. Application of this relationship is impractical at the present time (ie., application of 180 lbs of N is not needed with present wheat varieties and management systems). The models in Table 33 show a highly significant relationship between yield and residual NO_3-N. Only six locations in one year were available for analysis; therefore, until more data are available, use of these equations should be restricted. This limited analysis does demonstrate, though, what can be accomplished if more analysis of residual NO_3-N is accomplished in future experiments. Data from lower rates of N fertilizer should be gathered also.

Table 32. Multiple regression equation expressing residual NO_3-N in 1' of soil as a function of soil and climatic variables (180 - N treatments).

	Equation	F 2/	SE 1/	R
1.	$Y = 18.85 + \overset{\#}{0.36}x7$	3.26#	28.74	.41
2.	$Y = 30.31 + \overset{*}{0.50}x7 - 9.62x21$	2.27	28.54	.48

1/ SE = Standard error of the estimate
2/ Values of F; total df = 17
\# sign. p = .10; * sign. p = .05

Table 33. Multiple regression equation expressing residual NO_3-N in 1' of soil as a function of soil and climatic variables (80 - N treatments).

	Equation	F [2]	SE [1]	R
1.	$Y = 41.28^{**} - 0.91x23$	49.35**	1.60	.96
2.	$Y = 39.91^{**} - 1.01x23 + 10.26x19$	32.27*	1.42	.98

1/ SE = Standard error of the estimate
2/ Values of F; total df = 5
* sign. p = .05; ** sign. p = .005

SUMMARY AND CONCLUSIONS

Data from forty seven winter wheat fertility locations representing the alternate winter wheat-fallow producing areas of Montana and the growing seasons of 1970, 1971, 1972 and 1973 were analyzed by a stepwise multiple regression technique to generate a comprehensive N fertilizer management scheme. The following systems are proposed for soils having less than 120 lbs of NO_3-N in a depth of four ft. Variables are entered with decreasing order of influence.

1. Potential Yield (Bu/A) =

   $$32.87 + 2.38x16 - 19.72x19 + 1.86x21 \quad R = .64^{**}$$

2. N Fertilizer Requirement (lbs. N/A) =

   $$-43.26 - 0.54x7 + 1.86x2 + 41.63x19 + 2.74x13 \quad R = .76^{**}$$

3. Grain Protein (%) =

   $$14.73 - 0.11x2 + 0.02x7 + 0.02x3 + 0.30x21 - 0.15x16 \quad R = .64^{**}$$

Where: X2 = Potential yield predicted by equation 1

X3 = N fertilizer requirement predicted by equation 2

X7 = Soil NO_3-N (lbs N/Ac) (0-4')

X13 = Available soil water (inches) (0-4')

X16 = Rainfall (inches) (1-15 May thru 1-15 Aug.)

X19 = Evaporation rate (cm/day) (1-15 May thru 15-30 June)

X21 = Soil organic matter (%)

** significant correlation p = .005

Equation 1 predicts potential grain yield from soil and climatic variables; adequate nutrients and 3-5 inches of available soil water are the basic assumptions. Then the potential yield prediction is entered in equations with soil NO_3-N and a N fertilizer rate is predicted to achieve the potential yield. Next potential yield and N fertilizer rate are entered with other soil and climatic factors to predict the grain protein. These equations will enable a winter wheat producer to estimate his production, N fertilizer requirements and grain protein. If the protein is low then late applications of N during the heading stage of crop growth can be utilized to boost protein.

Models for predicting production and protein without N fertilizer additions are listed below.

4. Grain Yield (bu/A) =

$$30.09 + 0.05x7 - 20.93x19 + 1.12x16 + 2.11x21 \quad R = .66^{**}$$

5. Grain Protein (%) =

$$13.73 + 0.05x7 - 0.42x16 - 0.09x2 - 0.29x17 + 0.17x18 \quad R = .71^{**}$$

Where: X2 = Grain yield predicted by equation 4

X7 = Soil NO3-N (0-4') (lbs N/A)

X16 = Rainfall (inches) (1-15 May - 1-15 Aug)

X17 = Ave. soil temperature @ 50 cm (C^{o}) (1-15 May - 15-30 June)

X18 = Ave. soil temperature @ 50 cm (C^{o}) (15-30 June - 1-15 Aug)

X19 = Evaporation Rate (Cm/day) (1-15 May - 15-30 June)

X21 = Soil organic matter (%)

** significant correlation p = .005

These models are available for comparison with equations 1 and 3; consequently the effect of N fertilizer on yield and protein can be estimated.

The rainfall variable has a larger influence on R^2 than available soil water in all yield and protein prediction models. However, stored soil water was entered into the N fertilizer requirement model. Consequently a weakness in the system exists in that long term averages for rainfall and pan evaporation will have to be utilized in equation 1, rather than physical measurements, before equations 2 and 3 can be used. Some additional reliability can be attached to the rainfall factor through employment of rainfall probability tables. When the soil surveys are complete, soil temperature data (11) will become more available for application in equation 5.

For soils having NO_3-N contents greater than 120 lbs. N/4', the N management scheme is more complex because response to topdressed N fertilizer is less likely and erratic; also, sufficient data for modeling are lacking. However response to N additions have been observed (see appendix table 1); therefore, the equations generated from the data from all locations could be useful in a scheme similar to the one recommended for soils having NO_3-N contents less than 120 lbs. N/4'. These models are located in appendix tables 6-19.

Models for predicting residual soil NO_3-N (post harvest NO_3-N) were generated for 0 N, 80 lb N/Ac, and 180 lb N/Ac treatments. However, the practicality of the 180 lb N/Ac equations is questionable at the present time as that N rate far exceeds the requirement of most dryland winter wheat soils. Also, only six locations of the 80 lb N/Ac treatments were available for analysis. Consequently, extreme caution should be exercised in the application of equations developed from 80 and 180 N treatments. However these models do demonstrate what can be done if fertilizer plots are sampled after harvest. Soil NO_3-N available for the next crop and N pollution potential can be estimated as a function of N fertilizer rate. In addition, the latter estimate could be readily applied in conjunction with the universal soil loss equation. With increasing pressure from environmentalists and N fertilizer shortage, perhaps post harvest soil NO_3-N data should be a high priority research objective in conjunction with all soil fertility research plots.

6. Residual soil NO_3-N of 80 lb. N/Ac trts (lbs. N/A; 0-1' of soil) =

   $39.91 - 1.01x23 + 10.26x19 \quad R = .98$

7. Residual soil NO_3-N of 180 lb. N/Ac trts (lbs. N/A; 0-1' of soil) =

   $30.31 + 0.50x7 - 9.62x21 \quad R = .48$

8. Residual soil NO_3-N of 0-N trts (lbs. N/A; 0-1' of soil) =

   $15.89 - 0.18x4 + 1.10x13 - 1.04x18 - 9.03x20 + 1.31x22 \quad R = .85^{**}$

Where: X4 = Soil NO_3-N (lbs. N/A) (0-1' of soil)

X7 = Soil NO_3-N (lbs. N/A) (0-1' of soil)

X13 = Available soil water (inches) (0-4' of soil)

X18 = Ave. soil temperature @ 50 cm. (C°) (15-30 June - 1-15 Aug)

X19 = Pan evaporation rate (Cm/day) (1-15 May - 15-30 June)

X20 = Pan evaporation rate (Cm/day) (15-30 June - 1-15 Aug)

X21 = Soil organic matter (%)

X22 = Grain protein of 0 N plots (%)

X23 = Grain yield of 80 lb. N/Ac plots (Bu/A)

Again it should be emphasized that placing physical significance on variable coefficients of any model should be exercised with caution since the equations usually do not include all the variables that are important.

LITERATURE CITED

1. Alkier, A. C., G. J. Racz and R. J. Soper. 1972. Effects of foliar- and soil-applied nitrogen and soil nitrate-nitrogen level on the protein content of Neepawa wheat. Can. J. Soil Sci. 52: 301-309.

2. American Association of Cereal Chemists. 1962. Cereal Laboratory methods. (7th Edition). The Association, St. Paul, Minn.

3. Baier, W. and G. W. Robertson. 1967. Estimating yield components of wheat from calculated soil moisture. Can. J. Plant Sci. 47: 617-630.

4. Bremner, J. M. 1965. Inorganic nitrogen. p. 1216-1217. In C. A. Black (ed). Methods of soil analysis. Part II, American Society of Agronomy, Inc., Madison, Wis.

5. Caprio, J. M. and J. S. Williams. 1973. Impacts of induced rainfall on the Great Plains of Montana - Section 4 - Agriculture Production. Montana Agri. Exp. Stat. Res. Report 42.

6. Choriki, R., H. Houlton, J. R. Sims, C. Smith and R. Wilson. 1971. Nitrogen is profitable for dryland grain. Montana Farmer-Stockman. 58: 11: 6-14.

7. Cole, J. S. and O. R. Mathews. 1954. Soil moisture studies of some Great Plains soils I. Field capacity and "minimum point" as related to the moisture equivalent. Soil Sci. Soc. Am. Proc. 18: 247-252.

8. Collis-George, N. and B. G. Davey. 1960. The doubtful utility of present-day field experimentation and other determinations involving soil-plant interactions. Soils and Fertilizer. 23: 307-310.

9. Commoner, B. 1968. The killing of a great lake. In World Book Year Book. Field Enterprises Education Corp. Chicago. 622 p.

10. Daniel, H. A., H. M. Elwell and H. J. Harper. 1938. Nitrate nitrogen content of runoff water from plots under different cropping systems on soil classified as Vernon fine sand loam. Soil Sci. Soc. Am. Proc. 3: 230-3.

11. Decker, G. L. and G. A. Nielsen. 1971. Application of the proposed National Cooperative Soil Survey coding system to soil pedon data in Montana. Agronomy Abstracts. p. 100.

12. Dixon, W. J. 1970. Biomedical computer programs. University of California Press, Berkley. p. 233-257d.

13. Duley, F. L. and J. C. Russel. 1941. Crop residues for protecting row crop land against runoff and erosion. Soil Sci. Soc. Am. Proc. 6: 484-7.

14. ____________ and ____________. 1942. Effect of stubble mulching on soil erosion and runoff. Soil Sci. Soc. Am. Proc. 7: 77-81.

15. Eck, H. V. and B. B. Tucker. 1968. Winter wheat yields and response to nitrogen as affected by soil and climatic factors. Agron. J. 60: 663-6.

16. Geist, J. M., J. O. Reuss and D. D. Johnson. 1970. Prediction of nitrogen fertilizer requirements of field crops II. Application of theoretical models to malting barley. Agron. J. 62: 385-9.

17. Gifford, R. O., G. L. Ashcroft and M. D. Magnuson. 1967. Probability of selected precipitation amounts in the Western Region of the United States. Nevada Agri. Exp. Sta. Report T-8.

18. Grosenbaugh, L. R. 1967. Rex-Fortran-4 System. U.S.F.S. research paper psw-44, Pacific Southwest Forest and Range Exp. Stat., Berkeley, CA.

19. Johnson, V. A., A. F. Dreier and P. H. Grabouski. 1973. Yield and protein response to nitrogen fertilizer of two winter wheat varieties differing in inherent protein content of their grain. Agron. J. 65: 259-263.

20. Klausner, S. D., P. J. Zwerman and D. F. Ellis. 1974. Surface runoff loss of soluble nitrogen and phosphorus under two systems of soil management. J. Envir. Qual. 3: 42-46.

21. Kloster, L. D. and N. K. Whittlesey. 1971. Production function analysis of irrigation water and nitrogen fertilizer in wheat production. Washington Agri. Exp. Stat. Bull. 746.

22. Leggett, G. E. 1959. Relationships between wheat yields, available moisture and available nitrogen in Eastern Washington dryland areas. Washington Agri. Exp. Stat. Bull. 609.

23. Lehane, J. J. and W. J. Staple. 1962. Effects of soil moisture tensions on growth of wheat. Can. J. Soil Sci. 42: 180-8.

24. ____________ and __________. 1965. Influence of soil texture, depth of soil moisture storage and rainfall distribution on wheat yields in Southwestern Saskatchewan. Can. J. Soil Sci. 45: 207-219.

25. Manges, H. L., L. A. Schmid and L. S. Murphy. 1971. Land disposal of cattle feedlot wastes. <u>In</u> Livestock waste management and pollution abatement. ASAE pub. proc. 271. Amer. Soc. Agri. Eng., St. Joseph, Mich. p. 62-65.

26. Martins, W. P. 1970. Soil as an animal waste disposal medium. J. Soil and Water Cons. 25: 43-45.

27. Massey, H. F., M. L. Jackson and O. E. Hays. 1953. Fertility erosion on two Wisconsin soils. Agron. J. 45: 543-7.

28. McGuire, C. F., J. R. Sims, F. H. McNeal and P. L. Brown. 1974. Fertilizing Montana wheats to improve grain yield and milling and baking quality. Montana Agric. Exp. Stat. Bull. 674.

29. Midgley, A. R. and D. E. Dunklee. 1945. Fertility runoff losses from manure spread during the winter. Bul. 523. Agri. Exp. Stat., Univ. of Vermont.

30. Moe, P. G., J. V. Mannering and C. B. Johnson. 1967. Loss of fertilizer N in surface runoff water. Soil Sci. 104: 389-394.

31. Pelton, W. L. 1967. The effect of a windbreak on wind travel, evaporation and wheat yield. Can. J. Plant Sci. 47: 209-214.

32. Read, D. W. L. and F. G. Warder. 1974. Influence of soil and climatic factors on fertilizer response of wheat grown on stubble land in Southwestern Saskatchewan. Agron. J. 66: 245-8.

33. Römkens, M. J. M., D. W. Nelson and J. V. Mannering. 1973. Nitrogen and phosphorus composition of surface runoff as affected by tillage method. J. Envir. Qual. 2: 292-5.

34. Schlehuber, A. M. and B. B. Tucker. 1967. Culture of wheat. <u>In</u> K. S. Wuisenberry and L. P. Reitz (ed.) Wheat and wheat improvement. Amer. Soc. Agron., Madison, Wisconsin.

35. Schuman, G. E., R. E. Burwell, P. F. Piest and R. G. Spomer. 1973. Nitrogen losses in surface runoff from agricultural watersheds on Missouri valley loess. J. Envir. Qual. 2: 299-302.

36. Sims, J. R. 1971. The resource inventory method of determining cropping practice for dryland farming. Proc. Saline Seep-Fallow Workshop. Great Falls, Mont.

37. __________. 1973. An early protein check would have advantages. Montana Farmer-Stockman. 60 (11): 15-17.

38. __________ and V. A. Haby. 1971. Simplified colorimetric determination of soil organic matter. Soil Sci. 112: 137-141.

39. __________ and G. D. Jackson. 1971. Field measurement of pan evaporation. Agron. J. 63: 339-340.

40. __________ and ______________. 1973. Boost wheat protein with nitrogen. Montana Farmer-Stockman. 60 (11): 22-23.

41. __________ and ______________. 1974. Montana wheat quality-fertilizer relationships. Montana Agri. Exp. Stat. Bull. 673.

42. Smika, D. E., A. L. Black and B. W. Greb. 1969. Soil nitrate, soil water, and grain yields in a wheat-fallow rotation in the Great Plains as influenced by straw mulch. Agron. J. 61: 785-7.

43. ____________ and B. W. Greb. 1973. Protein content of winter wheat as related to soil and climatic factors in the Semiarid Central Great Plains. Agron. J. 65: 433-6.

44. Staple, W. J. and J. J. Lehane. 1955. The influence of field shelterbelts on wind velocity, evaporation, soil moisture and crop yield. Can. J. Agri. Res. 35: 440-453.

45. Steel, R. G. D. and J. H. Towie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc. New York. 481 p.

46. Stewart, B. A. and C. J. Whitfield. 1965. Effects of crop residue, soil temperature and sulfur and the growth of winter wheat. Soil Sci. Soc. Am. Proc. 29: 752-5.

47. Taylor, A. C. and A. R. Gilmour. 1971. Wheat protein prediction from climatic factors in Southern New South Wales. Aust. J. Exp. Agri. and Animal Husb. 11: 546-9.

48. Timmons, D. R., R. F. Holt and J. J. Latterell. 1970. Leaching of crop residues as a source of nutrients in surface runoff waters. Water Resources Res. 6: 1367-1375.

49. Thomas, G. W. and J. D. Crutchfield. 1974. Nitrate-nitrogen and phosphorus contents of streams draining small agricultural watersheds in Kentucky J. Envir. Qual. 3: 46-49.

50. Thompson, L. M. 1969. Weather and technology in the production of wheat in the United States. J. Soil and Water Cons. 24: 219-224.

51. Wischmeier, W. H. and D. D. Smith. 1965. Predicting rainfall - erosion losses from cropland east of the Rocky Mountains. Agri. Handbook 282. A.R.S., U.S.D.A.

52. Witzel, S. A., N. M. Minshall, M. S. Nichols and J. Wilke. 1969. Surface runoff and nutrient losses of Fennimore watersheds. Amer. Soc. Agri. Eng. Trans. 12: 338-41.

53. White, E. M. and E. J. Williamson. 1973. Plant nutrient concentrations in runoff from fertilized cultivated erosion plots and prairie in Eastern South Dakota. J. Envir. Qual. 2: 453-455.

54. Young, R. A., L. J. Ozburn, A. Bauer and E. H. Vasey. 1967. Yield response of spring wheat and barley to nitrogen fertilizer in relation to soil and climatic factors. Soil Sci. Soc. Am. Proc. 31: 407-410.

APPENDIX

Appendix Table 1. Data used in the stepwise multivariate analysis.

Location: Ft. Benton - 1973 Investigator: Sims & Jackson

Variety: Cheyenne Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	35.6 **	11.3 *	61.1 *
30	41.0	12.5	61.0
60	41.8	12.9	60.3

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.8	2.1	3.3	4.4	5.5	6.6
Soil NO_3-N (lbs/Ac)	6.0	15.7	39.0	54.6	61.9	69.9

Organic matter (0-6" of soil): 2.1%

Rainfall (in): 3.2
ST_1 (C^o): 10
ST_2 (C^o): 20

EV_1 (cm/day): 0.35
EV_2 (cm/day): 0.67

Soil Type: Gerber

Classification: Vertic Argiborolls; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Coffee Creek - 1973 Investigator: Sims & Jackson

Variety: Itana Fertilizer w/seed: 75# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	30.1	12.2 *	63.2
30	33.7	13.3	63.1
60	34.5	14.1	62.3

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.7	3.6	5.7	7.2	-	-
Soil NO_3-N (lbs/Ac)	3.3	6.0	8.0	11.0	-	-

Organic matter (0-6" of soil): 3.5%

Rainfall (in): 4.3
ST_1 (C^o): 11
ST_2 (C^o): 18

EV_1 (cm/day): 0.69
EV_2 (cm/day): 0.35

Soil Type: Danvers

Classification: Typic Argiborolls; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Brady - 1973 Investigator: Sims & Jackson

Variety: Winalta Fertilizer w/seed: 50# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	25.0	13.6 *	60.6
30	24.1	15.2	60.5
60	23.3	16.3	60.4

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.2	3.4	4.9	5.6	6.6	7.6
Soil NO_3-N (lbs/Ac)	29.3	37.7	42.4	49.1	74.0	126.5

Organic matter (0-6" of soil): 2.2%

Rainfall (in): 1.9
ST_1 (C^o): 13
ST_2 (C^o): 21

EV_1 (cm/day): 0.83
EV_2 (cm/day): 0.83

Soil Type: Marias clay

Classification: Ustertic Torriorthents; fine, montmorillonitic, calcareous, frigid

Appendix Table 1. Continued.

Location: Chinook - 1973 Investigator: Sims & Jackson

Variety: Winalta Fertilizer w/seed: 50# 11-48-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	23.3 **	11.5	62.7
30	30.6	12.2	62.5
60	35.5	13.7	62.1

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.8	2.6	3.5	4.0	-	-
Soil NO_3-N (lbs/Ac)	7.4	17.1	26.2	34.2	-	-

Organic matter (0-6" of soil): 1.9%

Rainfall (in): 5.1
ST_1 (C°): 12
ST_2 (C°): 20

EV_1 (cm/day): 0.65
EV_2 (cm/day): 0.62

Soil Type: Williams loam

Classification: Typic Argiborolls, fine-loamy, mixed

Appendix Table 1. Continued.

Location: Broadview - 1973 Investigator: Sims & Jackson

Variety: Cheyenne Fertilizer w/seed: 45# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	24.5	14.4 *	59.1 *
30	24.3	15.8	58.4
60	28.8	16.5	58.1

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.7	3.5	4.5	4.6	-	-
Soil NO_3-N (lbs/Ac)	4.9	14.9	21.6	23.6	-	-

Organic matter (0-6" of soil): 1.9%

Rainfall (in): 2.3
ST_1 (C^o): 12
ST_2 (C^o): 17

EV_1 (cm/day): 0.56
EV_2 (cm/day): 0.56

Soil Type: Bainville clay loam

Classification: Ustic Torriorthents; fine-silty, mixed (calcareous), mesic

Appendix Table 1. Continued.

Location: Bootlegger Trail - 1973 Investigator: Sims & Jackson

Variety: Cheyenne Fertilizer w/seed: 8 gal. 30-10-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	30.1	10.8 **	60.4 *
30	30.0	12.3	60.2
60	30.3	13.8	59.5

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.9	4.4	7.0	8.7	9.9	11.0
Soil NO_3-N (lbs/Ac)	46.5	92.1	168.3	204.5	243.0	282.7

Organic matter (0-6" of soil): 2.9%

Rainfall (in): 2.5
ST_1(C^o): 11
ST_2(C^o): 20

EV_1(cm/day): 1.00
EV_2(cm/day): 0.71

Soil Type: Unknown

Classification: Unknown

Appendix Table 1. Continued.

Location: Coffee Creek - 1972 Investigator: Sims & Jackson

Variety: Winalta Fertilizer w/seed: 70# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	23.3	13.4 **	59.6
20	23.0	14.1	59.3
40	23.9	15.1	59.2
80	23.3	15.5	59.1

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.7	2.4	3.5	4.5	4.9	5.1
Soil NO_3-N (lbs/Ac)	21.7	38.9	50.0	54.6	57.3	57.3

Organic matter (0-6" of soil): 3.3%

Rainfall (in): 1.9
ST_1 (C^o): 13.5
ST_2 (C^o): 18

EV_1 (cm/day): 0.67
EV_2 (cm/day): 0.67

Soil Type: Danvers

Classification: Typic Argiborolls; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Bootlegger Trail - 1972 Investigator: Sims & Jackson

Variety: Cheyenne Fertilizer w/seed: 8 gal 10-34-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	22.8	11.2 **	57.7
20	22.9	12.7	57.7
40	23.2	13.4	57.5
80	23.7	14.3	57.3

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.9	1.8	2.2	2.9	3.6	5.0
Soil NO_3-N (lbs/Ac)	26.4	29.1	32.4	32.4	37.1	50.8

Organic matter (0-6" of soil): 2.6 %

Rainfall (in): 1.3
ST_1(C^o): 12.5
ST_2(C^o): 17

EV_1(cm/day): 0.69
EV_2(cm/day): 0.69

Soil Type: Unknown

Classification: Unknown

Appendix Table 1. Continued.

Location: Brady - 1972 Investigator: Sims & Jackson

Variety: Winalta Fertilizer w/seed: 50# 11-48-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	22.6 **	7.5 **	60.3
20	27.3	8.0	60.4
40	29.8	8.8	60.1
80	35.1	10.5	59.1

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.9	3.6	5.2	6.6	7.6	9.5
Soil NO_3-N (lbs/Ac)	5.2	11.2	13.2	14.5	17.8	28.5

Organic matter (0-6" of soil): 2.2%

Rainfall (in): 2.8
ST_1 (C^o): 11
ST_2 (C^o): 16.5

EV_1 (cm/day): 0.56
EV_2 (cm/day): 0.56

Soil Type: Marias clay

Classification: Ustertic Torriorthents; fine, montmorillonitic, calcareous, frigid

Appendix Table 1. Continued.

Location: Volborg - 1972 Investigator: Sims & Jackson

Variety: Winalta Fertilizer w/seed: 50# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	25.4 *	10.4 **	62.5 *
20	29.8	10.9	62.3
40	33.4	11.7	61.8
80	32.9	14.0	61.2

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.6	3.4	4.6	5.7	6.8	7.4
Soil NO_3-N (lbs/Ac)	7.2	17.4	33.4	44.5	52.5	58.5

Organic matter (0-6" of soil): 2.2%

Rainfall (in): 5.0
ST_1 (C^o): 15
ST_2 (C^o): 18

EV_1 (cm/day): 0.48
EV_2 (cm/day): 0.48

	80 - N	0 - N
NO_3-N after harvest (0-1') #N/A	12.0	18.6

Soil Type: Vana-Remmit fine sandy loam

Classification: Ustollic Camborthids; coarse-loamy, mixed, mesic

Appendix Table 1. Continued.

Location: Broadview - 1972 Investigator: Sims & Jackson

Variety: Cheyenne Fertilizer w/seed: 45# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	29.6 **	7.3 **	59.1 **
20	35.8	7.3	59.1
40	38.8	9.1	59.9
80	42.2	11.3	59.7

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.5	1.6	3.1	3.6	-	-
Soil NO_3-N (lbs/Ac)	10.0	13.3	17.0	20.6	-	-

Organic matter (0-6" of soil): 1.7%

Rainfall (in): 4.4
ST_1 (C^o): 11.5
ST_2 (C^o): 14

EV_1 (cm/day): 0.57
EV_2 (cm/day): 0.57

NO_3-N after harvest (0-1') #N/A

80 - N	0 - N
4.0	5.0

Soil Type: Bainville clay loam

Classification: Ustic Torriorthents; fine-silty, mixed (calcareous), mesic

Appendix Table 1. Continued.

Location: Joliet - 1972. Investigator: Sims & Jackson

Variety: Warrior (recrop) Fertilizer w/seed: 60# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	18.4	8.6	59.5
20	25.6	8.9	59.5
40	28.2	9.8	59.7
80	34.8	13.2	58.5

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.8	3.4	3.8	3.9	-	-
Soil NO_3-N (lbs/Ac)	1.3	2.6	4.0	4.0	-	-

Organic matter (0-6" of soil): 1.9%

Rainfall (in): 5.5
ST_1 (C^o): 13
ST_2 (C^o): 18

EV_1 (cm/day): 0.65
EV_2 (cm/day): 0.65

	80 - N	0 - N
NO_3-N after harvest (0-1') #N/A	10.0	6.4

Soil Type: Nerrow clay loam

Classification: Borollic Paleargids; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Cut Bank - 1972 Investigator: Sims & Jackson

Variety: Winalta Fertilizer w/seed: 45# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	26.4	10.4 **	64.5
20	22.8	12.0	64.1
40	27.3	12.7	64.0
80	25.0	14.4	63.6

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.7	1.9	3.1	4.2	5.6	6.7
Soil NO_3-N (lbs/Ac)	10.5	15.8	16.5	16.5	17.8	17.8

Organic matter (0-6" of soil): 2.5%

Rainfall (in): 5.2
ST_1(C^o): 10
ST_2(C^o): 15

EV_1(cm/day): 0.38
EV_2(cm/day): 0.38

	80 - N	0 - N
NO_3-N after harvest (0-1') #N/A	19.0	10.8

Soil Type: Unknown

Classification: Unknown

Appendix Table 1. Continued.

Location: Chinook - 1972 Investigator: Sims & Jackson

Variety: Winalta Fertilizer w/seed: 50# 11-48-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	30.4 *	9.4 **	60.5 *
20	35.4	10.7	60.5
40	36.3	11.7	60.7
80	35.7	13.3	60.0

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.8	2.5	4.1	5.6	6.8	8.3
Soil NO_3-N (lbs/Ac)	9.9	24.4	30.4	33.7	38.7	51.9

Organic matter (0-6" of soil): 2.1%

Rainfall (in): 3.9
ST_1(C^o): 12.5
ST_2(C^o): 16.5

EV_1(cm/day): 0.55
EV_2(cm/day): 0.39

	80 - N	0 - N
NO_3-N after harvest (0-1') #N/A	6.0	19.6

Soil Type: Williams loam

Classification: Typic Argiborolls; fine-loamy, mixed

Appendix Table 1. Continued.

Location: Brady - 1971 Investigator: R. L. Wilson

Variety: Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	32.5	10.4	62.2
20	36.1	10.7	62.7
40	35.3	11.8	61.7
60	39.2	12.7	61.0
80	37.3	13.5	61.1
100	39.3	13.8	60.7
140	39.6	15.0	60.5
180	39.5	15.7	60.3

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.0	4.0	5.5	6.5	7.0	7.5
Soil NO_3-N (lbs/Ac)	25.6	33.6	36.4	41.2	67.2	105.2

Organic matter (0-6" of soil): 2.0%

Rainfall (in): 2.9
ST_1 (C^o): 11
ST_2 (C^o): 15

EV_1 (cm/day): 0.54
EV_2 (cm/day): 0.39

Soil Type: Marias clay

Classification: Ustertic Torriorthents; fine, montmorillonitic, calcareous, frigid

Appendix Table 1. Continued.

Location: Homestead - 1971 Investigator: R. L. Wilson

Variety: Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	44.0	13.3	61.4
20	46.0	13.3	60.9
40	46.4	14.2	60.5
60	42.0	14.3	60.9
80	42.4	14.8	60.5
100	41.5	15.0	60.4
140	41.5	15.2	60.5
180	40.0	15.5	60.4

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.5	3.9	5.5	6.6	7.8	9.1
Soil NO_3-N (lbs/Ac)	35.2	61.7	75.7	82.4	85.7	90.4

Organic matter (0-6" of soil): 3.8%

Rainfall (in): 4.4
ST_1 (C°): 10
ST_2 (C°): 15

EV_1 (cm/day): 0.48
EV_2 (cm/day): 0.31

Soil Type: Williams heavy loam

Classification: Typic Argiborolls; fine-loamy, mixed

Appendix Table 1. Continued.

Location: Brusett - 1971 Investigator: R. L. Wilson

Variety: Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	32.7	15.1	60.5
20	33.1	15.4	60.2
40	34.2	15.4	59.8
60	38.7	15.4	59.8
80	34.2	15.6	59.9
100	33.8	15.9	59.7
140	35.5	16.1	59.6
180	36.3	16.0	60.5

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.4	5.0	7.9	10.1	11.8	13.3
Soil NO_3-N (lbs/Ac)	68.4	83.6	98.8	116.0	134.0	146.0

Organic matter (0-6" of soil): 3.1%

Rainfall (in): 4.3
ST_1 (C^o): 11
ST_2 (C^o): 17

EV_1 (cm/day): 0.45
EV_2 (cm/day): 0.85

Soil Type: Cherry

Classification: Aridic Haploborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Amsterdam - 1971 (Bates) | Investigator: J. R. Sims

Variety: Winalta | Fertilizer w/seed: 100# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	39.5 *	9.2 **	64.4 *
20	45.0	10.2	64.0
40	49.2	10.7	64.0
60	50.8	11.4	62.9
80	50.0	12.8	62.1
100	44.4	14.0	61.9
140	46.2	15.1	61.1
180	45.8	15.5	61.1

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	3.0	5.8	6.8	7.7	8.5	9.5
Soil NO_3-N (lbs/Ac)	56.1	70.6	74.2	76.6	79.6	81.4

Organic matter (0-6" of soil): 2.2%

Rainfall (in): 5.1
ST_1 (C^o): 13
ST_2 (C^o): 19

EV_1 (cm/day): 0.33
EV_2 (cm/day): 0.78

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	6.4	0.0

Soil Type: Amsterdam silt loam

Classification: Typic Cryoborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Wibaux - 1971 Investigator: J. R. Sims

Variety: Froid Fertilizer w/seed: 80# 11-48-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	31.8	13.2	61.7
20	39.9	13.5	61.6
40	37.4	14.3	60.7
60	40.6	14.1	61.6
80	40.6	15.2	60.1
100	42.6	15.3	60.7
140	41.4	14.9	61.5
180	45.3	14.8	61.7

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.8	1.7	2.2	2.9	4.2	6.1
Soil NO_3-N (lbs/Ac)	43.1	75.7	84.9	90.0	98.6	113.3

Organic matter (0-6" of soil): 3.8%

Rainfall (in): 4.2
ST_1(C^o): 18
ST_2(C^o): 20.5

EV_1(cm/day): 0.45
EV_2(cm/day): 0.78

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	72.5	1.2

Soil Type: Morton silt loam

Classification: Typic Argiborolls; fine, loamy, mixed

Appendix Table 1. Continued.

Location: Columbus - 1971 Investigator: J. R. Sims

Variety: Fertilizer w/seed: 100# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	38.0	9.3 **	63.1 **
20	45.5	11.0	62.8
40	41.3	10.4	63.1
60	46.0	11.2	62.4
80	46.8	12.2	62.8
100	40.8	13.9	62.4
140	46.1	14.6	62.0
180	41.2	15.6	62.5

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.1	4.8	6.9	8.0	9.0	9.8
Soil NO_3-N (lbs/Ac)	66.9	84.1	100.1	109.9	119.7	131.3

Organic matter (0-6" of soil): 2.4%

Rainfall (in): 6.9
ST_1 (C°): 17
ST_2 (C°): 21

EV_1 (cm/day): 0.55
EV_2 (cm/day): 0.63

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	4.7	0.0

Soil Type: Nerrow clay loam

Classification: Borollic Paleargids; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Amsterdam - 1971 (Dyk)

Investigator: J. R. Sims

Variety:

Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	37.4 **	11.4 *	62.4 *
20	37.3	12.6	62.4
40	41.2	12.8	61.7
60	40.0	13.9	61.7
80	44.2	14.8	61.3
100	41.4	14.7	61.7
140	37.7	15.6	61.3
180	37.0	15.7	60.7

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.6	6.2	7.7	8.7	9.5	10.5
Soil NO_3-N (lbs/Ac)	41.6	50.7	51.9	52.5	55.5	60.9

Organic matter (0-6" of soil): 1.3%

Rainfall (in): 4.0
ST_1(C^o): 13
ST_2(C^o): 18

EV_1(cm/day): 0.40
EV_2(cm/day): 0.55

Soil Type: Amsterdam silt loam

Classification: Typic Cryoborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Forsyth - 1971 Investigator: J. R. Sims

Variety: Cheyenne Fertilizer w/seed: 80# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	39.6 **	9.5 **	62.8 **
20	43.3	10.7	63.1
40	45.3	11.0	63.3
60	44.2	12.2	62.7
80	46.8	13.2	63.1
100	47.9	14.9	61.6
140	45.9	15.0	61.9
180	45.9	15.7	61.5

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.8	1.6	2.4	3.4	3.7	-
Soil NO_3-N (lbs/Ac)	14.5	26.4	31.7	39.4	59.7	-

Organic matter (0-6" of soil): 1.1%

Rainfall (in): 4.4
ST_1 (C^o): 20
ST_2 (C^o): 22.5

EV_1 (cm/day): 0.45
EV_2 (cm/day): 0.45

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	64.8	2.0

Soil Type: Chama silt loam

Classification: Typic Haploborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Rosebud - 1971 Investigator: J. R. Sims

Variety: Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	39.5 **	10.1 **	63.1 **
20	43.3	10.3	64.1
40	45.8	11.8	63.7
60	45.8	12.8	63.7
80	50.0	13.8	63.6
100	46.4	14.4	63.3
140	44.4	14.8	63.3
180	46.1	15.3	63.1

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.6	3.5	4.6	5.5	6.2	6.6
Soil NO_3-N (lbs/Ac)	17.2	41.0	51.0	56.8	61.8	66.5

Organic matter (0-6" of soil): 1.2%

Rainfall (in): 3.6
ST_1(C^o): 19
ST_2(C^o): 23.5

EV_1(cm/day): 0.45
EV_2(cm/day): 1.00

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	42.7	0.0

Soil Type: Chama silt loam

Classification: Typic Haploborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Joliet - 1971 Investigator: J. R. Sims

Variety: Warrior Fertilizer w/seed: 50# 34-0-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	38.2	8.4 **	61.3 **
20	39.6	9.2	61.1
40	45.3	10.1	61.1
60	39.0	11.7	59.3
80	39.0	14.2	58.4
100	43.5	13.0	58.9
140	35.6	15.5	55.1
180	36.8	15.5	54.8

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.0	3.1	4.3	5.8	-	-
Soil NO_3-N (lbs/Ac)	18.9	32.5	42.7	52.4	-	-

Organic matter (0-6" of soil): 2.2%

Rainfall (in): 5.2
ST_1(C^o): 17
ST_2(C^o): 20.5

EV_1(cm/day): 0.75
EV_2(cm/day): 0.75

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	5.3	0.0

Soil Type: Nerrow clay loam

Classification: Borollic Haplargids; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Broadview - 1971   Investigator: J. R. Sims

Variety: Cheyenne   Fertilizer w/seed: 50# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	32.6	9.8 **	62.1 **
20	33.5	11.9	61.9
40	38.2	12.3	62.3
60	34.2	13.6	61.2
80	37.7	13.4	61.5
100	36.3	15.4	59.7
140	36.3	15.1	60.5
180	32.5	15.4	60.8

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.3	2.9	4.0	4.0		
Soil NO_3-N (lbs/Ac)	34.9	39.8	41.7	41.7		

Organic matter (0-6" of soil): 2.0%

Rainfall (in): 1.7 EV_1(cm/day): 0.40
ST_1(C^o): 13 EV_2(cm/day): 0.90
ST_2(C^o): 17.5

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	23.3	0.0

Soil Type: Bainville clay loam

Classification: Ustic Torriorthents; fine-silty, mixed (calcareous), mesic

Appendix Table 1. Continued.

Location: Broadus - 1971 Investigator: J. R. Sims

Variety: Fertilizer w/seed: 45# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	29.0	12.0	59.9
20	33.4	11.4	61.2
40	31.2	13.8	57.9
60	32.8	14.6	57.1
80	31.4	15.1	56.7
100	30.6	14.8	58.7
140	29.4	15.8	55.7
180	34.0	15.5	56.8

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.0	4.1	5.1	5.9	7.1	7.8
Soil NO_3-N (lbs/Ac)	28.7	54.3	100.5	148.2	205.1	237.5

Organic matter (0-6" of soil): 2.7%

Rainfall (in): 6.1
ST_1 (C°): 18
ST_2 (C°): 21

EV_1 (cm/day): 0.35
EV_2 (cm/day): 0.81

Soil Type: Heldt silty clay loam

Classification: Ustollic Camborthids; fine, montmorillonitic, mesic

Appendix Table 1. Continued.

Location: Pryor - 1971 Investigator: J. R. Sims

Variety: Winalta Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	20.1	15.3 **	58.3
20	22.0	16.5	57.9
40	24.8	16.7	57.5
60	20.5	18.1	57.3
80	21.7	18.5	56.8
100	20.8	18.9	56.7
140	23.0	18.2	58.0
180	22.7	18.0	57.5

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.1	3.8	4.8	5.7		
Soil NO_3-N (lbs/Ac)	57.2	95.2	113.7	118.3		

Organic matter (0-6" of soil): 1.8%

Rainfall (in): 2.7
ST_1 (C^o): 17.5
ST_2 (C^o): 21.0

EV_1 (cm/day): 0.57
EV_2 (cm/day): 0.92

Soil Type: Coburn silty clay loam

Classification: Abruptic Argiborolls; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Rapelje - 1971 Investigator: J. R. Sims

Variety: Fertilizer w/seed: 35# 16-20-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	55.1	13.1	61.6
20	56.6	13.4	61.9
40	55.0	14.3	61.7
60	55.1	14.6	61.9
80	47.6	15.0	60.5
100	55.9	15.1	61.3
140	57.9	15.3	61.7
180	52.7	15.5	60.8

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.0	3.3	5.5	7.3	8.7	
Soil NO -N (lbs/Ac)	65.3	113.3	123.5	130.7	144.1	

Organic matter (0-6" of soil): 3.6%

Rainfall (in): 5.4
ST_1(C^o): 15
ST_2(C^o): 17

EV_1(cm/day): 0.65
EV_2(cm/day): 0.65

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	44.6	5.7

Soil Type: Berry clay loam

Classification: Borollic Paleargids; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Homestead - 1970 Investigator: R. L. Wilson

Variety: Fertilizer w/seed: 100# 11-48-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	26.6	12.6	
20	30.8	13.1	
40	31.4	12.8	
60	32.0	14.0	
80	31.2	14.9	
100	30.9	15.4	
140	28.7	15.1	
180	31.3	16.8	

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.4	4.4	5.5	7.2	7.7	7.9
Soil NO_3-N (lbs/Ac)	85.8	196.7	224.9	247.8	287.8	324.6

Organic matter (0-6" of soil): 2.9%

Rainfall (in): 5.8
ST_1 (C^o): 14.5
ST_2 (C^o): 20.5

EV_1 (cm/day): 0.55
EV_2 (cm/day): 0.55

Soil Type: Williams heavy loam

Classification: Typic Argiborolls; fine-loamy, mixed family

Appendix Table 1. Continued.

Location: Brady - 1970 Investigator: R. L. Wilson

Variety: Fertilizer w/seed: 50# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	31.5	12.1	
20	34.7	12.3	
40	37.6	13.6	
60	38.5	14.9	
80	36.7	15.2	
100	35.7	15.3	
140	39.2	15.8	
180	39.8	15.4	

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.0	2.2	3.6	4.4	4.6	4.7
Soil NO_3-N (lbs/Ac)	65.7	86.6	104.5	121.5	138.3	164.3

Organic matter (0-6" of soil): 2.8%

Rainfall (in): 3.9
ST_1(C^o): 18
ST_2(C^o): 19

EV_1(cm/day): 0.37
EV_2(cm/day): 0.54

Soil Type: Marias clay

Classification: Ustertic Torriorthents; fine, montmorillonitic, calcareous, frigid

Appendix Table 1. Continued.

Location: Jordan - 1970
(Stanton)

Investigator: R. L. Wilson

Variety:

Fertilizer w/seed: 30# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	25.5	15.1	
20	27.2	15.0	
40	25.5	15.5	
60	26.6	16.0	
80	27.1	16.7	
100	28.8	17.2	
140	26.4	17.1	
180	25.5	17.1	

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	0.0	1.8	3.3	3.7	4.7	5.1
Soil NO_3-N (lbs/Ac)	90.6	124.9	139.2	149.7	161.8	171.5

Organic matter (0-6" of soil): 2.1%

Rainfall (in): 3.8
ST_1(C^o): 15
ST_2(C^o): 21

EV_1(cm/day): 0.53
EV_2(cm/day): 0.71

Soil Type: Devon, thin solum

Classification: Aridic Argiborolls; fine-loamy, mixed

Appendix Table 1. Continued.

Location: Circle - 1970 Investigator: R. L. Wilson

Variety: Fertilizer w/seed: 40# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	32.6	12.1	
20	34.2	13.2	
40	33.5	13.3	
60	36.9	13.1	
80	37.6	14.5	
100	31.3	14.5	
140	34.9	15.1	
180	33.3	15.2	

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	5.2	8.1	10.8	10.8	-	-
Soil NO_3-N (lbs/Ac)	60.4	110.4	131.6	145.1	156.2	166.2

Organic matter (0-6" of soil): 2.2%

Rainfall (in): 3.3
ST_1 (C^o): 17.5
ST_2 (C^o): 20

EV_1 (cm/day): 0.49
EV_2 (cm/day): 0.58

Soil Type: Vida loam

Classification: Typic Argiborolls; fine-loamy, mixed

Appendix Table 1. Continued.

Location: Vida - 1970 Investigator: R. L. Wilson

Variety: Fertilizer w/seed: 40# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	33.6	12.2	
20	33.5	13.5	
40	37.1	13.9	
60	32.4	14.5	
80	34.4	15.0	
100	34.9	15.3	
140	38.8	15.6	
180	35.0	15.7	

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.4	4.2	7.3	8.8	10.1	11.4
Soil NO_3-N (lbs/Ac)	45.6	71.3	90.5	105.9	125.2	146.3

Organic matter (0-6" of soil): 2.8%

Rainfall (in): 4.1
ST_1 (C°): 14.5
ST_2 (C°): 19

EV_1 (cm/day): 0.61
EV_2 (cm/day): 0.61

Soil Type: Vida loam

Classification: Typic Argiborolls; fine-loamy, mixed

Appendix Table 1. Continued.

Location: Jordan - 1970 (Coulter)

Investigator: R. L. Wilson

Variety:

Fertilizer w/seed: 30# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	33.0	12.4	
20	37.7	13.0	
40	37.0	13.9	
60	37.9	14.5	
80	37.8	15.4	
100	35.2	16.4	
140	35.2	16.6	
180	33.9	17.0	

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.0	3.8	6.1	7.3	8.6	8.6
Soil NO_3-N (lbs/Ac)	53.5	78.7	90.0	95.8	104.1	117.9

Organic matter (0-6" of soil): 3.6%

Rainfall (in): 3.9
ST_1(C^o): 14.5
ST_2(C^o): 20

EV_1(cm/day): 0.87
EV_2(cm/day): 0.80

Soil Type: Cherry

Classification: Aridic Haploborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: N of Cut Bank - 1970 Investigator: H. A. R. Houlton

Variety: Winalta Fertilizer w/seed: 70# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	36.3	11.0	64.5
20	35.7	10.7	64.3
40	38.2	12.2	64.3
60	38.7	13.1	64.1
80	39.5	13.4	64.4
100	41.7	14.0	63.7
140	40.5	14.2	63.9
180	42.8	15.7	63.6

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.3	2.5	3.6	4.6	5.3	-
Soil NO_3-N (lbs/Ac)	28.0	38.3	42.1	44.9	48.3	-

Organic matter (0-6" of soil): 3.1%

Rainfall (in): 5.3
ST_1 (C^o): 11
ST_2 (C^o): 15

EV_1 (cm/day): 0.58
EV_2 (cm/day): 0.58

Soil Type: Kevin clay loam

Classification: Aridic Haploborolls; fine-loamy, mixed

Appendix Table 1. Continued.

Location: Kremlin - 1970 Investigator: H. A. R. Houlton

Variety: Winalta Fertilizer w/seed: 75# 11-48-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	28.8	12.0	61.6
20	30.0	12.7	61.6
40	33.0	13.7	61.6
60	31.7	14.1	61.7
80	31.6	14.9	61.6
100	30.9	14.9	61.3
140	30.5	15.4	61.1
180	30.4	15.6	61.3

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.5	2.2	2.6	3.0	3.5	-
Soil NO_3-N (lbs/Ac)	10.1	16.2	20.8	27.1	32.7	-

Organic matter (0-6" of soil): 1.4%

Rainfall (in): 5.2
ST_1(C°): 14
ST_2(C°): 19

EV_1(cm/day): 0.81
EV_2(cm/day): 0.56

Soil Type: Illiad loam

Classification: Aridic Argiborolls; fine-loamy, mixed

Appendix Table 1. Continued.

Location: Wagner - 1970 Investigator: H. A. R. Houlton

Variety: Winalta Fertilizer w/seed: 40# 11-48-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	45.5	12.3	62.6
20	52.1	13.7	63.6
40	53.7	14.5	62.1
60	58.6	14.9	61.0
80	56.5	14.3	62.2
100	58.0	15.2	61.6
140	57.6	15.2	61.5
180	56.2	15.7	61.9

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.3	2.5	4.2	5.7	6.7	-
Soil NO_3-N (lbs/Ac)	20.3	55.7	87.1	121.3	164.7	-

Organic matter (0-6" of soil): 3.1%

Rainfall (in): 5.9
ST_1(C°): 16
ST_2(C°): 20

EV_1(cm/day): 0.76
EV_2(cm/day): 0.60

Soil Type: Scobey loam

Classification: Aridic Argiborolls; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Broadview - 1970 Investigator: J. R. Sims

Variety: Cheyenne Fertilizer w/seed: 35# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	33.0	9.3 **	62.4
20	37.0	9.6	62.9
40	44.3	11.3	62.6
60	40.1	12.6	61.3
80	32.7	13.4	60.7
100	34.2	14.9	59.6
140	30.3	15.7	58.3
180	39.7	16.0	60.1

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.0	3.2	5.5	5.5	-	-
Soil NO_3-N (lbs/Ac)	49.9	57.6	65.3	65.3	-	-

Organic matter (0-6" of soil): 2.0%

Rainfall (in): 6.7
ST_1(C°): 13
ST_2(C°): 16.5

EV_1(cm/day): 0.52
EV_2(cm/day): 0.67

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	50.0	6.7

Soil Type: Bainville clay loam

Classification: Ustic Torriorthents; fine-silty, mixed (calcareous), mesic

Appendix Table 1. Continued.

Location: Fort Ellis - 1970 Investigator: J. R. Sims

Variety: Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	53.8	10.1	64.1
20	57.1	10.3	64.4
40	58.7	10.6	64.4
60	56.8	11.3	64.4
80	50.8	11.7	64.2
100	56.6	11.3	64.4
140	54.8	12.6	64.4
180	54.7	12.9	64.0

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.3	2.6	4.2	6.0	7.6	9.0
Soil NO_3-N (lbs/Ac)	19.9	71.8	94.6	103.9	120.4	115.7

Organic matter (0-6" of soil): 4.9%

Rainfall (in): 7.6
ST_1(C°): 12
ST_2(C°): 17

EV_1(cm/day): 0.51
EV_2(cm/day): 0.68

NO_3-N after harvest (0-1') #N/A

180 - N	0 - N
22.8	2.0

Soil Type: Bozeman silt loam

Classification: Argic Pachic Cryoborrolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Willow Creek - 1970 Investigator: J. R. Sims

Variety: Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	22.8	12.3	61.5 *
20	22.8	13.2	61.7
40	24.2	13.8	60.8
60	24.9	13.5	61.2
80	21.2	14.5	61.1
100	29.0	14.2	60.9
140	24.9	15.1	60.7
180	26.9	15.0	60.8

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.0	2.4	2.6	2.6	-	-
Soil NO_3-N (lbs/Ac)	13.5	41.9	52.5	52.5	-	-

Organic matter (0-6" of soil): 1.4%

Rainfall (in): 4.0
ST_1(C°): 13
ST_2(C°): 19

EV_1(cm/day): 0.63
EV_2(cm/day): 0.49

Soil Type: Un-named loam

Classification: Typic Cryoborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Raplje - 1970 Investigator: J. R. Sims

Variety: Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	41.8	12.9 *	64.0 *
20	41.9	12.3	63.8
40	45.4	12.5	63.4
60	38.9	12.9	63.3
80	43.0	13.2	63.5
100	41.1	13.2	63.3
140	39.0	13.7	62.7
180	37.4	14.2	62.5

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.9	4.4	6.9	9.5	9.5	9.5
Soil NO_3-N (lbs/Ac)	15.4	34.6	57.2	128.5	175.7	192.2

Organic matter (0-6" of soil): 3.7

Rainfall (in): 3.9
ST_1 (C°): 13
ST_2 (C°): 17.5

EV_1 (cm/day): 0.86
EV_2 (cm/day): 0.66

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	82.3	14.8

Soil Type: Berry clay loam

Classification: Borollic Paleargids; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Pryor - 1970 Investigator: J. R. Sims

Variety: Winalta Fertilizer w/seed: 50# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	27.9	11.2 **	64.1 **
20	31.4	11.5	64.3
40	34.3	12.5	64.1
60	37.1	12.9	63.6
80	38.9	13.7	63.4
100	38.4	13.5	63.3
140	36.6	14.6	62.9
180	35.5	15.2	61.6

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.4	4.6	6.0	7.1	8.0	9.0
Soil NO_3-N (lbs/Ac)	12.2	49.8	67.0	73.1	79.7	86.3

Organic matter (0-6" of soil): 3.0%

Rainfall (in): 8.7
ST_1(C^o): 13.5
ST_2(C^o): 19

EV_1(cm/day): 0.71
EV_2(cm/day): 0.59

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	73.2	12.0

Soil Type: Coburn silty clay loam

Classification: Abruptic Argiborolls; fine, montmorillonitic

Appendix Table 1. Continued.

Location: Volborg - 1970 Investigator: J. R. Sims

Variety: Fertilizer w/seed: 80# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	38.1	12.2	
20	39.3	13.2	
40	36.7	13.9	
60	44.9	14.5	
80	37.1	15.2	
100	41.7	15.1	
140	36.7	14.6	
180	38.0	15.4	

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.4	5.0	6.7	9.0	11.4	12.9
Soil NO_3-N (lbs/Ac)	28.4	77.2	83.2	106.2	143.8	191.6

Organic matter (0-6" of soil): 3.0%

Rainfall (in): 7.2
ST_1 (C^o): 14.5
ST_2 (C^o): 19.5

EV_1 (cm/day): 0.47
EV_2 (cm/day): 0.73

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	99.1	11.2

Soil Type: Farland silt loam

Classification: Typic Argiborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Amsterdam - 1970 Investigator: J. R. Sims

Variety: Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	35.8	13.9 *	60.6
20	38.0	13.6	61.0
40	36.0	14.7	59.7
60	39.4	14.5	61.0
80	34.6	15.2	59.8
100	36.9	14.7	61.0
140	36.4	14.6	60.3
180	40.4	15.0	61.2

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.0	4.1	6.2	8.0	10.3	11.6
Soil NO_3-N (lbs/Ac)	7.9	47.5	98.1	105.0	108.6	112.2

Organic matter (0-6" of soil): 2.0%

Rainfall (in): 4.5
ST_1 (C^o): 13
ST_2 (C^o): 18

EV_1 (cm/day): 0.65
EV_2 (cm/day): 0.65

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	92.4	18.0

Soil Type: Amsterdam silt loam

Classification: Typic Cryoborolls; fine-silty, mixed

Appendix Table 1. Continued.

Location: Hardin - 1970 (Torske)

Investigator: J. R. Sims

Variety:

Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	26.0 *	10.7 **	62.1 **
20	32.0	10.9	61.9
40	30.1	12.4	60.4
60	33.2	15.3	58.9
80	31.0	14.9	57.7
100	33.0	15.9	57.5
140	28.4	17.0	55.7
180	29.0	17.0	55.4

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.3	5.2	7.1	8.3	9.6	11.0
Soil NO_3-N (lbs/Ac)	19.2	50.7	75.0	90.6	106.6	136.2

Organic matter (0-6" of soil): 2.0%

Rainfall (in): 5.2
ST_1(C^o): 15
ST_2(C^o): 21.5

EV_1(cm/day): 0.58
EV_2(cm/day): 0.78

Soil Type: Gilt edge silty clay loam

Classification: Ustollic Natrargids; fine, montmorillonitic, mesic

Appendix Table 1. Continued.

Location: Hardin - 1970 (Kelly)

Investigator: J. R. Sims

Variety:

Fertilizer w/seed:

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	23.4 **	11.4 **	63.6 **
20	32.0	11.3	63.4
40	33.2	12.1	62.7
60	35.2	12.9	61.6
80	34.9	13.3	61.0
100	36.4	13.9	61.3
140	35.3	14.6	60.4
180	34.2	15.0	60.1

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	2.0	3.7	5.3	6.6	-	-
Soil NO_3-N (lbs/Ac)	16.7	42.7	51.5	58.1	-	-

Organic matter (0-6" of soil): 1.5%

Rainfall (in): 5.9
ST_1 (C^o): 15
ST_2 (C^o): 21

EV_1 (cm/day): 0.62
EV_2 (cm/day): 0.68

Soil Type: Keiser silty clay loam

Classification: Ustollic Haplargids; fine-silty, mixed, mesic

Appendix Table 1. Continued.

Location: Joliet - 1970 Investigator: J. R. Sims

Variety: Warrior Fertilizer w/seed: 50# 18-46-0

Treatment (lbs N/Ac)	Yield (Bu/Ac)	Protein (%)	Test Weight (lbs/Bu)
0	35.9	7.9 **	61.2 *
20	41.4	8.3	61.9
40	45.0	9.7	62.4
60	45.3	10.4	62.0
80	40.3	11.3	59.5
100	43.1	12.5	59.1
140	39.9	14.6	56.0
180	39.0	14.9	58.0

* Sign. (P = .05)
** Sign. (P = .01)

Soil depth (feet)	0-1	0-2	0-3	0-4	0-5	0-6
Avail Soil Water (in)	1.7	4.0	5.0	5.1	-	-
Soil NO_3-N (lbs/Ac)	7.2	35.9	43.6	43.6	-	-

Organic matter (0-6" of soil): 2.4%

Rainfall (in): 5.0
ST_1(C^o): 14
ST_2(C^o): 19.5

EV_1(cm/day): 0.50
EV_2(cm/day): 0.65

	180 - N	0 - N
NO_3-N after harvest (0-1') #N/A	17.6	6.0

Soil Type: Nerrow clay loam

Classification: Borollic Haplargids; fine, montmorillonitic

Appendix Table 2. Multiple linear regression equations expressing grain protein of winter wheat as a function of potential yield, N fertilizer, soil and climatic variables (1' soil samples; group II data).

Equation	F 1/	SE 2/	R
1. $Y = 12.56 + 0.03x3$	1.57	1.39	.429
2. $Y = 11.33 + 0.04x3 + 0.02x4$	1.48	1.36	.575
3. $Y = 9.09 + 0.05x2 + 0.03x3 + 0.03x4$	1.30	1.37	.662
4. $Y = 9.63 + 0.07x2 + 0.02x3 + 0.03x4 - 0.33x10$	1.39	1.39	.733
5. $Y = 16.19 + 0.04x2 + 0.001x3 + 0.02x4 - 0.58x10 - 7.15x20$	0.89	1.49	.773
6. $Y = 31.11 + 0.11x2 - 0.05x3 - 0.02x4 - 1.14x10 - 11.43x20 - 2.61x21$	1.59	1.20	.909
7. $Y = 45.40 + 0.11x2 - 0.11x3 - 0.06x4 - 1.6x10 + 0.75x16 - 31.49x20 - 4.13x21$	3.86	0.77	.982

1/ F ratio due to regression; total df = 8
2/ SE = Standard error of the estimate

Appendix Table 3. Multiple linear regression equations expressing grain protein of winter wheat as a function of potential yield, N fertilizer, soil and climatic variables (2' soil samples; group II data).

Equation	F 1/	SE 2/	R
1. $Y = 13.41 + 0.02x3 - 0.20x10$	0.98	1.44	.499
2. $Y = 22.38 - 0.01x3 - 0.53x11 - 11.34x20$	1.64	1.29	.704
3. $Y = 24.31 - 0.01x3 - 0.56x11 - 11.90x20 - 0.50x21$	1.13	1.40	.728
4. $Y = 25.73 + 0.09x2 - 0.03x3 - 0.64x11 - 12.67x20 - 1.76x21$	1.39	1.29	.835
5. $Y = 15.09 + 0.12x2 - 0.06x3 - 0.72x11 + 0.54x18 - 16.58x20 - 1.07x21$	0.91	1.49	.856
6. $Y = - 7.89 + 0.22x2 - 0.21x3 - 0.04x5 - 1.40x11 + 2.72x18 - 48.59x20 + 0.87x21$	2.44	0.96	.972

1/ F ratio due to regression; total df = 8
2/ SE = Standard error of the estimate

Appendix Table 4. Multiple linear regression equations expressing grain protein of winter wheat as a function of potential yield, N fertilizer, soil and climatic variables (3' soil samples; group II data).

Equation	F 1/	SE 2/	R
1. $Y = 15.20 + 0.02x3 - 3.95x20$	0.92	1.46	.484
2. $Y = 22.57 - 0.01x3 - 0.49x12 - 10.70x20$	1.27	1.37	.657
3. $Y = 26.81 - 0.03x3 - 0.93x12 + 3.65x19 - 16.79x20$	1.34	1.33	.757
4. $Y = 15.45 - 0.09x3 - 1.54x12 + 0.93x17 + 14.66x19 - 25.43x20$	1.71	1.20	.861
5. $Y = 0.59 - 0.15x3 + 2.04x12 + 1.54x17 + 0.51x18 + 23.33x19 - 35.44x20$	2.15	1.06	.930
6. $Y = - 54.00 - 0.29x3 - 3.03x12 + 2.99x17 + 2.21x18 + 38.78x19 - 58.05x20 + 3.95x21$	4.35	0.73	.984

1/ F ratio due to regression; total df = 8
2/ SE = Standard error of the estimate

Appendix Table 5. Multiple linear regression equations expressing grain protein of winter wheat as a function of potential yield, N fertilizer, soil and climatic variables (4' soil samples; group II data).

Equation	F 1/	SE 2/	R
1. $Y = 14.03 + 0.02x3 - 0.01x7$	1.02	1.44	.503
2. $Y = 17.48 + 0.02x3 - 0.01x7 - 4.80x20$	0.81	1.50	.571
3. $Y = 21.72 - 0.00x3 - 0.01x7 - 0.27x13 - 8.52x20$	0.78	1.53	.662
4. $Y = 29.22 - 0.03x3 - 0.01x7 - 0.97x13 + 6.69x19 - 18.50x20$	1.38	1.30	.835
5. $Y = 30.93 - 0.07x3 - 0.01x7 - 1.18x13 + 0.60x16 + 9.22x19 - 24.09x20$	1.95	1.10	.924
6. $Y = 37.68 - 0.16x2 - 0.07x3 - 0.04x7 - 1.12x13 + 1.60x16 + 14.02x19 - 30.73x20$	6.41	0.60	.989

1/ F ratio due to regression; total df = 8

2/ SE = Standard error of the estimate

Appendix Table 6. Multiple linear equations expressing potential grain yield of winter wheat as a function of soil and climatic variables (all locations).

Equation	F 1/	SE 2/	R
1. Y = 24.80 + 2.74x16**	14.18**	7.78	.490
2. Y = 19.78 + 2.49x16** + 2.53x21#	9.46**	7.55	.548
3. Y = 24.01 + 2.42x16** - 7.74x19 + 2.74x21*	6.72**	7.54	.565
4. Y = 19.94 + 2.34x16** + 0.30x17 - 7.56x19 + 2.83x21*	5.08**	7.59	.571
5. Y = 27.80 + 2.33x16** + 0.81x17 - 0.83x18 - 5.68x19 + 2.63x21#	4.29**	7.58	.586
6. Y = 27.19 + 0.23x12 + 2.30x16** + 0.85x17 - 0.86x18 - 5.85x19 + 2.54x21#	3.52**	7.66	.588
7. Y = 27.11 + 0.28x13 + 2.27x16** + 0.88x17 - 0.88x18 + 6.03x19 + 2.43x21	3.54**	7.65	.589

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10; * sign, p = .05; ** sign. p = .005

Appendix Table 7. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (1' soil samples; all locations).

	Equation	F 1/	SE 2/	R
1.	Y = 12.97 + 1.12x2*	8.76*	22.66	.404
2.	Y = 0.22 + 1.10x2** - 0.41x4**	10.28**	20.67	.564
3.	Y = 7.34 + 1.36x2** - 0.34x4* - 7.77x21*	8.89**	19.90	.619
4.	Y = 29.89 + 1.36x2** - 0.31x4* - 1.18x18 - 8.35x21*	6.80**	19.97	.627
5.	Y = 30.26 + 1.21x2** - 0.31x4* + 1.75x16 - 1.31x18 - 8.46x21*	5.52**	20.06	.634
6.	Y = 30.83 + 1.21x2* - 0.31x4* + 1.90x16 - 1.62x18 + 8.30x20 - 8.78x21*	4.52**	20.28	.636
7.	Y = 31.66 + 1.21x2* - 0.31x4* - 0.84x10 + 1.94x16 - 1.61x18 + 7.80x20 - 8.71x21*	3.79**	20.52	.638

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
* sign. p = .05; ** sign. p = .005

Appendix Table 8. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (2' soil samples; all locations).

	Equation	F [1/]	SE [2/]	R
1.	$Y = 43.52 - \overset{**}{0.28}x5$	$\overset{**}{10.11}$	22.38	.428
2.	$Y = 1.22 + \overset{**}{1.15}x2 - \overset{*}{0.29}x5$	$\overset{**}{12.16}$	20.10	.597
3.	$Y = 6.58 + \overset{**}{1.36}x2 - \overset{*}{0.24}x5 - \overset{\#}{6.50}x21$	$\overset{**}{9.49}$	19.65	.631
4.	$Y = 3.94 + \overset{*}{1.12}x2 - \overset{**}{0.26}x5 + 2.64x16 - \overset{\#}{6.29}x21$	$\overset{**}{7.60}$	19.53	.648
5.	$Y = 17.49 + \overset{*}{1.12}x2 - \overset{*}{0.24}x5 + 2.67x16 - 0.72x18 - \overset{\#}{6.78}x21$	$\overset{**}{6.01}$	19.71	.650
6.	$Y = 15.54 + \overset{*}{1.14}x2 - \overset{*}{0.24}x5 + 2.69x16 - 0.79x18 + 5.18x19 - \overset{\#}{7.04}x21$	$\overset{**}{4.91}$	19.93	.651

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10; * sign, p = .05; ** sign. p = .005

Appendix Table 9. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (3' soil samples; all locations).

Equation	F [1/]	SE [2/]	R
1. $Y = 45.08 - 0.25^{**}x6$	11.34^{**}	22.13	.449
2. $Y = 2.92 + 1.15^{**}x2 - 0.25^{**}x6$	13.04^{**}	19.84	.610
3. $Y = 7.49 + 1.34^{**}x2 - 0.21^{**}x6 - 6.00x21$	9.85^{**}	19.50	.638
4. $Y = 4.87 + 1.10^{*}x2 - 0.22^{**}x6 + 2.66x16 - 5.76x21$	7.89^{**}	19.37	.655
5. $Y = -0.68 + 1.13^{*}x2 - 0.22^{**}x6 + 2.67x16 + 9.07x19 - 6.08x21$	6.24^{**}	19.55	.658
6. $Y = 5.45 + 1.16^{*}x2 - 0.21^{*}x6 + 2.70x16 - 0.50x17 + 8.83x19 - 6.50x21$	5.12^{**}	19.75	.659
7. $Y = 10.42 + 1.18x2 - 0.20x6 - 1.01x12 + 2.76x16 - 0.71x17 + 9.82x19 - 6.55x21$	4.34^{**}	19.94	.662

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
* sign. p = .05; ** sign. p = .005

Appendix Table 10. Multiple linear regression equations expressing N fertilizer requirements of winter wheat as a function of potential yield, soil and climatic variables (4' soil samples; all locations).

	Equation	F 1/	SE 2/	R
1.	Y = 45.33 - 0.22x7**	11.77**	22.05	.455
2.	Y = 2.26 + 1.18x2** - 0.23x7**	14.00**	19.58	.624
3.	Y = 6.33 + 1.35x2** - 0.19x7** - 5.36x21	10.21**	19.36	.645
4.	Y = 3.58 + 1.11x2* - 0.20x7** + 2.69x16 - 5.09x21	8.20**	19.21	.662
5.	Y = - 4.09 + 1.15x2* - 0.21x7** + 2.72x16 + 12.64x19 - 5.46x21	6.56**	19.33	.667
6.	Y = 2.13 + 1.17x2* - 0.19x7* - 0.98x13 + 2.81x16 + 14.07x19 - 5.15x21	5.44**	19.49	.671
7.	Y = 7.45 + 1.21x2* - 0.17x7* - 1.31x13 + 2.88x16 - 0.73x17 + 13.9x19 - 5.71x21	4.62**	19.66	.674

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
* sign. p = .05; ** sign. p = .005

Appendix Table 11. Multiple linear regression equations expressing grain protein of winter wheat as a function of potential yield, N fertilizer, soil and climatic variables (1' soil samples; all locations).

Equation	F 1/	SE 2/	R
1. Y = 13.99 - 0.04x2 #	3.33 #	1.35	.262
2. Y = 13.50 - 0.04x2 # + 0.02x4 #	3.41 #	1.32	.367
3. Y = 13.22 - 0.05x2 # + 0.01x4 + 0.31x21	2.86 #	1.31	.408
4. Y = 13.16 - 0.06x2 # + 0.01x3 + 0.02x4 + 0.38x21	2.31	1.32	.425
5. Y = 13.25 - 0.06x2 + 0.01x3 + 0.01x4 - 0.09x16 + 0.39x21	1.90	1.33	.433
6. Y = 12.80 - 0.05x2 # + 0.01x3 + 0.02x4 # - 0.09x16 + 0.71x19 + 0.35x21	1.60	1.34	.440
7. Y = 12.88 - 0.05x2 # + 0.01x3 + 0.02x4 # - 0.12x10 - 0.08x16 + 0.75x19 + 0.36x21	1.38	1.35	.446
8. Y = 12.23 - 0.05x2 + 0.01x3 + 0.02x4 - 0.12x10 - 0.09x16 + 0.04x18 + 0.66x19 + 0.38x21	1.20	1.36	.449

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10

Appendix Table 12. Multiple linear regression equations expressing grain protein of winter wheat as a function of potential yield, N fertilizer, soil and climatic variables (2' soil samples; all locations).

Equation	F 1/	SE 2/	R
1. Y = 13.50 - 0.05x2# + 0.40x21#	3.19#	1.33	.356
2. Y = 13.32 - 0.05x2# + 0.01x5 + 0.30x21	2.54	1.32	.388
3. Y = 13.27 - 0.06x2# + 0.01x3 + 0.01x5 + 0.35x21	2.03	1.33	.402
4. Y = 13.28 - 0.05x2# + 0.01x3 + 0.01x5 - 0.13x16 + 0.36x21	1.76	1.33	.420
5. Y = 13.60 - 0.05x2# + 0.01x3 + 0.01x5 - 0.08x11 - 0.12x16 + 0.35x21	1.49	1.35	.427
6. Y = 13.28 - 0.05x2# + 0.01x3 + 0.01x5 - 0.08x11 - 0.12x16 + 0.51x19 + 0.33x21	1.27	1.36	.431
7. Y = 13.02 - 0.05x2 + 0.01x3 + 0.01x5 - 0.01x11 - 0.12x16 + 0.50x19 + 0.43x20 + 0.32x21	1.09	1.38	.433

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10

Appendix Table 13. Multiple linear regression equations expressing grain protein of winter wheat as a function of potential yield, N fertilizer, soil and climatic variables (3' soil samples; all locations).

	Equation	F 1/	SE 2/	R
1.	$Y = 13.36 - 0.05x2^{\#} + 0.004x6 + 0.33x21$	2.31	1.33	.373
2.	$Y = 13.45 - 0.04x2^{\#} + 0.004x6 - 0.09x16 + 0.31x21$	1.81	1.34	.384
3.	$Y = 13.41 - 0.05x2^{\#} + 0.01x3 + 0.01x6 - 0.11x16 + 0.36x21$	1.55	1.35	.399
4.	$Y = 12.99 - 0.06x2 + 0.01x3 + 0.01x6 - 0.12x16 + 0.03x17 + 0.40x21$	1.29	1.36	.403
5.	$Y = 12.79 - 0.05x2 + 0.01x3 + 0.01x6 - 0.12x16 + 0.04x17 + 0.32x19 + 0.38x21$	1.09	1.38	.405

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
\# sign. p = .10

Appendix Table 14. Multiple linear regression equations expressing grain protein of winter wheat as a function of potential yield, N fertilizer, soil and climatic variables (4' soil samples; all locations).

	Equation	1/ F	2/ SE	R
1.	$Y = 13.39 - 0.05x2^{\#} + 0.003x7 + 0.32x21$	2.29	1.33	.371
2.	$Y = 13.48 - 0.04x2^{\#} + 0.003x7 - 0.09x16 + 0.31x21$	1.79	1.34	.382
3.	$Y = 13.46 - 0.05x2^{\#} + 0.01x3 + 0.01x7 - 0.12x16 + 0.35x21$	1.54	1.35	.397
4.	$Y = 13.03 - 0.06x2^{\#} + 0.01x3 + 0.01x7 - 0.12x16 + 0.03x17 + 0.39x21$	1.28	1.36	.401

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10

Appendix Table 15. Multiple linear regression equations expressing grain yield of winter wheat as a function of soil and climatic variables without spring applied N fertilizer (all locations).

Equation	F 1/	SE 2/	R
1. Y = 22.15 + 4.12x21**	11.47**	7.24	.451
2. Y = 17.20 + 1.33x16# + 3.70x21**	8.13**	7.01	.520
3. Y = 21.78 + 1.25x16# − 8.37x19 + 3.94x21**	6.03**	6.96	.544
4. Y = 17.86 + 1.18x16# + 0.28x17 − 8.20x19 + 4.02x21**	4.58**	7.00	.551
5. Y = 24.49 + 1.17x16# + 0.72x17 − 0.70x18 − 6.61x19 + 3.85x21**	3.84*	7.01	.565
6. Y = 23.99 + 0.69x10 + 1.13x16 + 0.71x17 − 0.71x18 − 6.72x19 + 3.76x21**	3.20*	7.07	.570
7. Y = 23.76 + 0.41x11 + 1.13x16 + 0.76x17 − 0.76x18 − 6.55x19 + 3.79x21**	3.19*	7.07	.569
8. Y = 22.60 + 0.69x12 + 1.07x16 + 0.85x17 − 0.80x18 − 7.13x19 + 3.58x21*	3.40*	7.00	.581
9. Y = 22.44 + 0.83x13 + 0.99x16 + 0.9x17 − 0.85x18 − 7.65x19 + 3.28x21*	3.67*	6.91	.596

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10; * sign, p = .05; ** sign. p = .005

Appendix Table 16. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables without spring applied N fertilizer (1' soil samples; all locations).

Equation	F 1/	SE 2/	R
1. Y = 10.42 + 0.03x4 *	7.94 *	1.84	.387
2. Y = 11.62 + 0.03x4 * - 0.27x16	5.36 *	1.81	.443
3. Y = 10.76 + 0.03x4 - 0.32x16 # + 0.50x21	4.57 *	1.78	.492
4. Y = 11.54 - 0.05x2 + 0.03x4 * - 0.25x16 + 0.67x21 #	3.84 *	1.77	.517
5. Y = 9.08 - 0.04x2 + 0.03x4 * - 0.28x16 + 0.13x18 + 0.73x21 *	3.28 *	1.77	.534
6. Y = 8.76 - 0.04x2 + 0.03x4 * - 0.27x16 - 0.10x17 + 0.21x18 + 0.70x21 *	2.75 *	1.78	.541
7. Y = 8.69 - 0.04x2 + 0.03x4 * - 0.28x16 - 0.11x17 + 0.25x18 - 1.00x20 + 0.74x21 *	2.34 *	1.80	.544
8. Y = 8.54 - 0.04x2 + 0.03x4 * - 0.28x16 - 0.10x17 + 0.24x18 + 0.43x19 - 0.97x20 + 0.71x21 #	2.01 #	1.82	.545

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05

Appendix Table 17. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables without spring applied N fertilizer (2' soil samples; all locations).

Equation	F 1/	SE 2/	R
1. Y = 10.23 + 0.02x5**	9.36**	1.81	.415
2. Y = 11.72 + 0.02x5** - 0.36x16*	7.48**	1.74	.504
3. Y = 11.04 + 0.02x5* - 0.39x16* + 0.39x21	5.59**	1.73	.530
4. Y = 11.80 - 0.04x2 + 0.02x5* - 0.33x16# + 0.55x21	4.59**	1.72	.551
5. Y = 10.29 - 0.04x2 + 0.02x5* - 0.34x16# + 0.08x18 + 0.60x21#	3.69*	1.73	.557
6. Y = 10.05 - 0.04x2 + 0.02x5* - 0.33x16# - 0.08x17 + 0.15x18 + 0.58x21	3.06*	1.75	.561
7. Y = 10.30 - 0.04x2 + 0.02x5* - 0.09x11 - 0.33x16# - 0.10x17 + 0.15x18 + 0.56x21	2.60*	1.77	.564

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005

Appendix Table 18. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables without spring applied N fertilizer (3' soil samples; all locations).

	Equation	F 1/	SE 2/	R
1.	Y = 10.13 + 0.02x6**	9.89**	1.80	.425
2.	Y = 11.61 + 0.02x6** - 0.36x16*	7.77**	1.73	.511
3.	Y = 11.01 + 0.02x6* - 0.38x16* + 0.36x21	5.67**	1.73	.532
4.	Y = 11.75 - 0.04x2 + 0.02x6* - 0.33x16# + 0.52x21	4.63**	1.72	.553
5.	Y = 10.64 - 0.04x2 + 0.02x6* - 0.33x16# + 0.06x18 + 0.56x21	3.67*	1.74	.556
6.	Y = 10.48 - 0.04x2 + 0.02x6* - 0.33x16# - 0.05x17 + 0.10x18 + 0.55x21	3.00*	1.76	.557

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
\# sign. p = .10; * sign. p = .05; ** sign. p = .005

Appendix Table 19. Multiple linear regression equations expressing grain protein of winter wheat as a function of yield, soil and climatic variables without spring applied N fertilizer (4' soil samples; all locations).

	Equation	F 1/	SE 2/	R
1.	Y = 10.12 + 0.02x7**	10.22**	1.80	.430
2.	Y = 11.62 + 0.02x7** - 0.37x16*	8.11**	1.72	.519
3.	Y = 11.11 + 0.02x7* - 0.39x16* + 0.32x21	5.73**	1.72	.534
4.	Y = 11.88 - 0.04x2 + 0.02x7* - 0.33x16# + 0.48x21	4.72**	1.71	.557
5.	Y = 11.04 - 0.04x2 + 0.02x7* - 0.33x16# + 0.04x18 + 0.51x21	3.71*	1.73	.558
6.	Y = 10.89 - 0.04x2 + 0.02x7* - 0.33x16# - 0.04x17 + 0.08x18 + 0.50x21	3.04*	1.75	.559
7.	Y = 11.06 - 0.04x2 + 0.02x7* - 0.33x16# - 0.05x17 + 0.08x18 - 0.41x19 + 0.51x21	2.55	1.77	.560

1/ F ratio due to regression; total df = 46
2/ SE = Standard error of the estimate
sign. p = .10; * sign. p = .05; ** sign. p = .005