



Development of chemical tests for soil nitrate content as a factor for correlating soil and climatic properties with winter wheat (*Triticum aestivum* L.) yield
by Grant Dewayne Jackson

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Soils
Montana State University
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Abstract:

Winter wheat at seven locations in the Gallatin Valley, Montana was top dressed with N in the spring of 1969.

Multiple regression analysis and correlations were made for grain yield with N fertilizer rate, soil nitrates, available soil water, pan evaporation, growing season rainfall, depth to lime and soil temperature at 50 cm.

The best correlation ($R^2 = .99$) was obtained with available soil water, growing season rainfall, pan evaporation, depth to lime and soil temperature at 50 cm.

Only two locations responded to N fertilizer; therefore, the multiple regression equations predict a very slight response to added N and soil nitrate.

Colorimetric analysis of nitrate in soil extracts using chromotropic acid was studied and compared to the phenoldisulfonic acid procedure.

Extracting solutions of 0.5 M MgSO_4 , sat. CaSO_4 , and 0.1 gm Ca(OH)_2 / 50 ml of water were investigated. The three extractants were equally effective in recovering NO_3 . The Ca(OH)_2 - H_2O system was used for subsequent analyses since clear extracts were obtained.

A 1:5 soil to solution ratio and a shaking time of 15 minutes effectively extracted NO_3 and resulted in appropriate NO_3 concentration for color development.

Iron (II) and NO_2 were found to interfere at soil concentrations of 167 and 8.4 ppm respectively.

Three methods were used to compare the two procedures: 1) a nitrate recovery study, 2) linear regression and correlation analysis and 3) linear regression and correlation with winter wheat yield and response to N fertilizer. Equivalent amounts of NO_3 were recovered by both procedures. The correlation coefficient for the two procedures was 0.98**. Both procedures were similar in predicting wheat yield, but the phenoldisulfonic acid procedure produced a slightly better response correlation.

The new procedure has several advantages including rapidity, simplicity, sensitivity and relative freedom from interference.

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DEVELOPMENT OF CHEMICAL TESTS FOR SOIL NITRATE CONTENT AS
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WITH WINTER WHEAT (TRITICUM AESTIVUM L.) YIELD

by

GRANT DEWAYNE JACKSON

A thesis submitted to the Graduate Faculty in partial
fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Soils

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ABSTRACT

Winter wheat at seven locations in the Gallatin Valley, Montana was top dressed with N in the spring of 1969.

Multiple regression analysis and correlations were made for grain yield with N fertilizer rate, soil nitrates, available soil water, pan evaporation, growing season rainfall, depth to lime and soil temperature at 50 cm.

The best correlation ($R^2 = .99$) was obtained with available soil water, growing season rainfall, pan evaporation, depth to lime and soil temperature at 50 cm.

Only two locations responded to N fertilizer; therefore, the multiple regression equations predict a very slight response to added N and soil nitrate.

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INTRODUCTION

The response of wheat to N fertilizer depends upon several plant growth factors such as available soil N, available soil water, temperature, evapotranspiration, growing season rainfall, variety, disease, weed conditions, salts and alkali and possibly other variables.

In Montana, no attempt has been made to correlate more than 2 or 3 growth factors with wheat yield for the purpose of formulating N fertilizer recommendations.

The objective of this study was to check out the system necessary for measuring the growth factors in a state-wide research effort, and to develop a reliable, rapid $\text{NO}_3\text{-N}$ soil test that can be adapted for routine analysis.

LITERATURE REVIEW

Winter wheat plant and its environment

The literature contains many examples of winter wheat response to nitrogen fertilizer. In fact, Thompson (29) attributes the increase in wheat production since 1945 to the use of nitrogen fertilizer. Schlehüher and Tucker (23) also stated that nitrogen fertilization has contributed greatly to the wheat production in every wheat producing area in the U.S. Montana is no exception. Kittams, et al. (12) reported significant yield increases at 29 locations in 1966. Other researchers have found similar results (P. L. Brown, unpublished data).

In recent years, $\text{NO}_3\text{-N}$ levels in the soil profile are being used in formulating N fertilizer recommendations (13). The question that arises is what is the critical NO_3 level where no response to N occurs? Of course, this "gray zone" has received considerable attention. Sixty pounds of $\text{NO}_3\text{-N}$ in six feet of soil has been quoted by one researcher (P. L. Brown, personal communication) as the level where N response is questionable. The work was done in Gallatin County, Montana. In Nebraska (7), a moderate response was noted with 67, 73 and 151 pounds of $\text{NO}_3\text{-N}$ per six feet of soil. Similar results were reported in eastern Montana by the Soils Specialist, Montana Cooperative Extension Service (G. M. Smith, personal communication). Smika et al. (24) reported no relationship between grain yields and $\text{NO}_3\text{-N}$ in the Great Plains states. Obviously, the prediction of wheat response with nitrate levels in the soil is not a "cut and dry" process, but it depends on other management

and environment variables also.

The effect of available soil water and rainfall distribution has been well documented in the literature. Leggett (13) in Washington reported that winter wheat needed four inches of available water to produce grain and, thereafter, 5.8 bushels of grain was obtained per inch of additional available water. Smika et al. (24) also reported a positive relationship with stored available water in the Great Plains. Lehane and Staple (14) stated that five inches of available water was required before any grain was produced and each additional inch produced 3.5 - 4.0 bushels of Thatcher spring wheat in Canada. Young et al. (34) showed a significant relationship with winter wheat yield and available soil water to the depth of 122 cm in North Dakota. Eck and Tucker (9) in Oklahoma concluded that rainfall distribution was more important than total rainfall and that soil water in the spring was not indicative of yield. Apparently rainfall, rainfall distribution and intensity, and available soil water are important factors in wheat production. Apparently, the order of importance of these factors varies geographically.

Pelton (22) used a snow fence as a windbreak to study the effects of wind reduction on evaporation and wheat yield. The results were a 15-49% reduction in wind traveled, 12-23% reduction in evaporation measured from a pan, and a 24-43% increase in yield above the check. Staple and Lehane (26) studied the effect of field shelterbelts on wind

velocity, evaporation, soil water and crop yield, but measured very little differences.

The effect of depth to lime on wheat production has not been well established; however, two individuals have reported a positive relationship (R. T. Choriki, personal communication and G. E. Warrington, 1967. Effect of N fertilizer, available water and soil condition on dryland winter wheat production M. S. Thesis, Montana State University, Bozeman).

The effect of deep soil temperatures on plant growth is not well defined in the literature. However, the effect of the soil surface temperature has been investigated. Burleigh et al. (5) showed that the maximum coleoptile length of several winter wheat varieties occurred when the temperature was maintained at 80°F. Lengths were decreased above and below this temperature. Stewart and Whitfield (28) reported an increase in wheat growth when the root temperature in a controlled water bath was increased from 55° to 60°F. Woolley (33) showed that the growth of spring wheat increased with increasing root temperatures of 45, 54, 67 and 80°F.

Laboratory nitrogen determination

There are several methods available for measuring or estimating available N in the soil. Estimation by organic matter content (O.M.) and Kjeldahl N are probably the oldest methods used. In recent times, initial $\text{NO}_3\text{-N}$ and $\text{NO}_3\text{-N}$ released after incubation are being used in

predicting response to N fertilization.

The limitations of the O.M. and Kjeldahl methods are obvious in that available N is not measured directly. Smith (25) presented data to show that initial $\text{NO}_3\text{-N}$ and $\text{NO}_3\text{-N}$ released after incubation were better indexes of N availability on orchard grass grown in the greenhouse. Soil O.M. and total N were reported to be relatively nonrelated to N availability. Therefore, methods for determining $\text{NO}_3\text{-N}$ will be reviewed extensively.

The phenoldisulfonic acid procedure (4) is a traditional method for $\text{NO}_3\text{-N}$. The procedure has several limitations such as the evaporation of soil extracts which extends the time of the analysis and, if the samples get too hot, NO_3^- may be volatilized. Another disadvantage is that the Cl ion interferes in the color development.

The $\text{NO}_3\text{-N}$ method involving steam distillation as described by Bremner (4) apparently works quite well on soil extracts. Probably the main disadvantage is the amount of time required per sample.

In the past 20 years several colorimetric $\text{NO}_3\text{-N}$ procedures have been proposed to replace the phenoldisulfonic acid procedure. Eastoe and Pollard (8) modified the phenoldisulfonic acid method. They showed that nitration would take place in aqueous solution at higher temperatures. The problem was that the method was not sensitive enough, and it required boiling the extracts for 3-15 minutes. Lewis (16) described a xylenol procedure but it was slower than the phenoldisulfonic

acid method. Three procedures have been described for reducing NO_3^- to NO_2^- and colorimetrically measuring NO_2^- . Nelson et al. (21) used Zn-MnSO_4 to reduce the nitrate. Lowe and Hamilton (17) used a highly specific enzyme extracted from soybean nodules to reduce the NO_3^- . Apparently both methods work quite well and are relatively free from interferences. Middleton (18) reported a reduction procedure which used nascent hydrogen; however, the reaction is hard to control. Fisher et al. (10) reported a method for NO_3^- and NO_2^- using brucine hydrochloride for color development. The method is sensitive enough and the results agree with the phenoldisulfonic acid procedure. But the color is highly sensitive to temperature and light. A chromotropic acid procedure was developed for water analysis by West and Lyles (31). The procedure is rapid, almost free from interferences, and highly sensitive. There is no apparent reason why the procedure can't be modified for soil analysis.

A new method for $\text{NO}_3\text{-N}$ has recently been developed. The procedure involves the use of a nitrate sensitive electrode (20) which measures the activity of the NO_3^- ion. The problem with the procedure is that anything that affects the activity of the NO_3^- will cause interference. Differential salt conditions, temperature and pH will affect the readings and calibration. Chloride and HCO_3^- anions both interfere greatly. The Texas Agriculture Experiment Station, Lubbock is using a nitrate sensitive electrode procedure, on a limited basis, for non-saline alka-

line soils that do not contain gypsum or free calcium carbonate (A. B. Onken, personal communication). The staff at the Northern Great Plains Research Center, Mandan, North Dakota have been working with the probe but have found it unsatisfactory (J. F. Power, personal communication). Apparently, the procedure is hampered by calibration problems, and it is not very sensitive.

Systems for predicting response of small grains to N fertilizer applications

Collis-George and Davey (6) suggested in 1960 that the number of conventional field experiments should be restricted and replace some of them with completely instrumented experiments. They further stated that "until complete descriptions of experiments are available, the quantitative importance of environment and its interaction with fertilizer and cultivation practices cannot be determined". Since that time more research has been done to correlate soil and climatic factors with crop yield.

Leggett (13) devised one of the first systems for predicting N fertilizer additions for Washington state. He used available soil water + expected rainfall to determine maximum yield (Y_m). He then figured the yield (Y_n) one would expect from the initial soil $\text{NO}_3\text{-N}$ content to the depth of six feet, and the yield expected from the N that would be mineralized (recrop yield). If $Y_m > Y_n$, then additional N was added at the rate of 3 lb/bu $((Y_m - Y_n) \cdot 3 = \text{additional N})$. Perhaps

this method could be improved by additional climatic variables.

Several models have been proposed by the Canadian scientists for estimating wheat production. However, those methods reviewed assumed adequate nutrient supply. Williams and Robertson (32) devised a system of predicting wheat production from soil moisture data and monthly precipitation data during the growing season. Lehane and Staple (15) correlated available soil water and rainfall during the growing season with wheat yields. Their highest R^2 value was obtained on the medium textured soils. Baier and Robertson (2) correlated yield components (kernels/head, number of heads/unit area and 1000-kernel wt) with several soil moisture variables. Highest R^2 (0.50) was obtained using five soil water variables. This method, as expected, was no better than using actual yield.

In North Dakota, Young et al. (34) showed that available soil water at seeding time to the depth of 122 cm, stored soil $\text{NO}_3\text{-N}$ to 61 cm at seeding, precipitation from seeding to five days before harvest, and number of degree days above 21°C from five to sixty days before harvest had significant correlation with yield response to N fertilizer. The R^2 value was 0.49. This method was one of the first to successfully correlate N response to more than one climatic variable.

METHODS AND MATERIALS

Location of field plots

Seven sites were chosen in Gallatin County, Montana to provide a wide variation in rainfall and soil water. Table 1 lists the date of fertilizer application, cooperator, legal description and other pertinent data obtained from the cooperator. Figure 1 shows the approximate location of each site in the county. An attempt was made to locate the experiments on a Bozeman or Amsterdam silt loam. The soil at the Willow Creek site was classified as an Amsterdam loam. Plots were located on established stands.

Soils and sampling techniques

Table 2 contains the soil series name and other information about each site. All plots were located on soils with essentially the same parent material.

SCS Soil Scientists, Bud Giese and Fred Boettcher, described areas three, four and five, and noted the differences at all the other sites except location 6. Location six was omitted since it is the original site for the typical Amsterdam silt loam. The representative soil series descriptions and notes made by the SCS Soil Scientists are included in appendix table 16.

Two core samples for nitrate analysis and two core samples for soil moisture were taken from each location at the time the plots were fertilized. Nitrate samples were taken at 0-6 in, 6-12 in, 1-2 ft,

Table 1. Cooperator, date of top dressing, legal description, wheat variety, row spacing previous crop and fertilizer applied w/seed of winter wheat fertilizer experiments, 1969.

Loca- cation No.	Coop- erator	Top- dressing date	Legal desc- ription	Wheat variety	Row Spacing	Prev- ious ^{1/} crop	Fertilizer w/seed		
							lb N	lb P	Source
1	V. Bates	4-21	NW $\frac{1}{4}$ S21T 2SR3E	Itana	7 in..	S C	24	11	24-24-0
2	A. Bates	4-21	SW $\frac{1}{4}$ S8T 1SR3E	Winalta	7 in.	W W	16	19	18-46-0
3	J. Kuipers	4-19	SE $\frac{1}{4}$ S20 T1NR3E	Winalta	14 in.	W W	14	16	18-46-0
4	J. Cooper	4-14	SW $\frac{1}{4}$ S28 T1NR1E	Winalta	10 in.	W W	8	5.0	16-20-0
5	J. Ham- ilton	4-16	NE $\frac{1}{4}$ S14 T2NR4E	Cheyenne	7 in.	W W	9	11	18-46-0
6	MT Ag Exp St	4-28	SE $\frac{1}{4}$ S7T 2SR5E	Psamont	18 in.	W W	none		
7	MT Ag Exp St Ft Ellis	5-5	NW $\frac{1}{4}$ S16T 2SR6E	Delmar	7 in.	B A	none		

^{1/} These crops were followed by a growing season fallow period prior to the crop fertilized in this study. S C = sweet clover, W W = winter wheat, B A = barley.

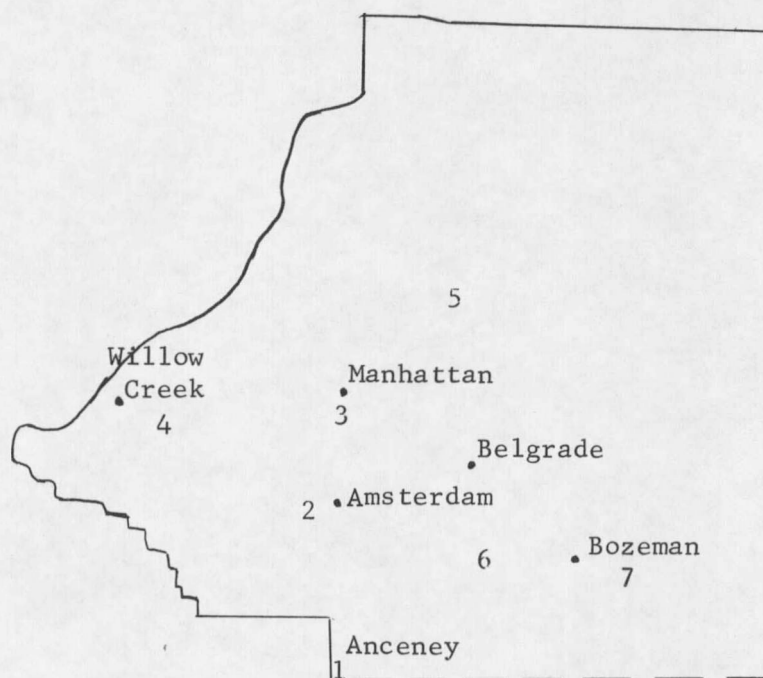


Figure 1. Approximate location of winter wheat N fertilizer experiments in Upper Gallatin County, 1969.

Table 2. Soil classification, texture, slope and aspect, and depth to lime for each location.

Location	Soil series name	Texture	Slope %	Aspect	Depth ^{1/} to lime
1	Amsterdam	sil	1.0	E	0 in.
2	Amsterdam	sil	2.0	E	7 in.
3	Amsterdam	sil	3.0	N	7 in.
4	Amsterdam	L	1.0	NW	0 in.
5	Amsterdam	sil	4.0	SE	7 in.
6	Amsterdam	sil	1.0	S	15 in.
7	Bozeman	sil	1.0	S	28 in.

^{1/} Strong effervescence with HCl.

2-3 ft, 3-4 ft, 4-5 ft and 5-6 ft depths and dried immediately. Soil water samples were taken in foot increments to the depth of six feet.

Ped samples were taken from pits at locations where an estimate of bulk density was needed. The samples were taken in each horizon.

Plot design and treatments

Each plot area was organized into a randomized complete block design with 8 treatments and 4 replications. Plot size was 7.5 ft x 40 ft. Treatments were 0, 6.7, 13.3, 20, 26.7, 33.3, 40.0 and 46.7 pounds of nitrogen per acre (lbs N/A) as ammonium nitrate. An error was made in application, therefore, the rates shown are only one-third of the amount of N we intended to apply.

The fertilizer was applied at the two leaf growth stage at all locations.

Precipitation

Rainfall was measured at each location with a Tru-Chek^{1/} Accuracy rain gauge at approximately weekly intervals. Evaporation was prevented by placing a layer of mineral oil (approximately 1 cm thick) on top of 0.15 inches of water in the rain gauge. This procedure was necessary since the water would float on top of the oil if the oil was poured in the bottom of the wedge-shaped gauge. Time of measurement was from the date of initiation of each site until August 5, 1969.

^{1/} Edwards Mfg. Co., Albert Lea, Minnesota

Evaporation

Evaporation was measured at each site from a No. 1 wash tub^{1/} covered with a chicken wire screen. The water level in the tub was maintained between 12 and 17 cm of water to give an average diameter of the surface of about 46 cm (Figure 2). Measurements were taken at approximately weekly intervals throughout the growing season with a meter stick.

A tub was installed at both the Montana State University Campus and Agronomy farm weather stations to correlate the evaporation from the tub with the standard weather bureau pan. Readings from both stations were used in the linear regression analysis. The resulting equation is $Y = 1.12 X + .02$ where Y is the predicted evaporation in inches and X is the evaporation from the tub in inches. The correlation coefficient was 0.97 which was significant at the 1% level.

Soil temperature

Soil temperature was measured at the 50 cm depth at the same time as precipitation and evaporation were measured. This depth was chosen to minimize day and night fluctuation, and it is also the depth used by the SCS in classifying soils. Temperature was measured with a Wesson dial thermometer with an eight inch stem. Measurements were taken in the alley between replications or adjacent to the plots. The

^{1/} Martin Ware Cl, General Metalware Co., Minneapolis, Minnesota.

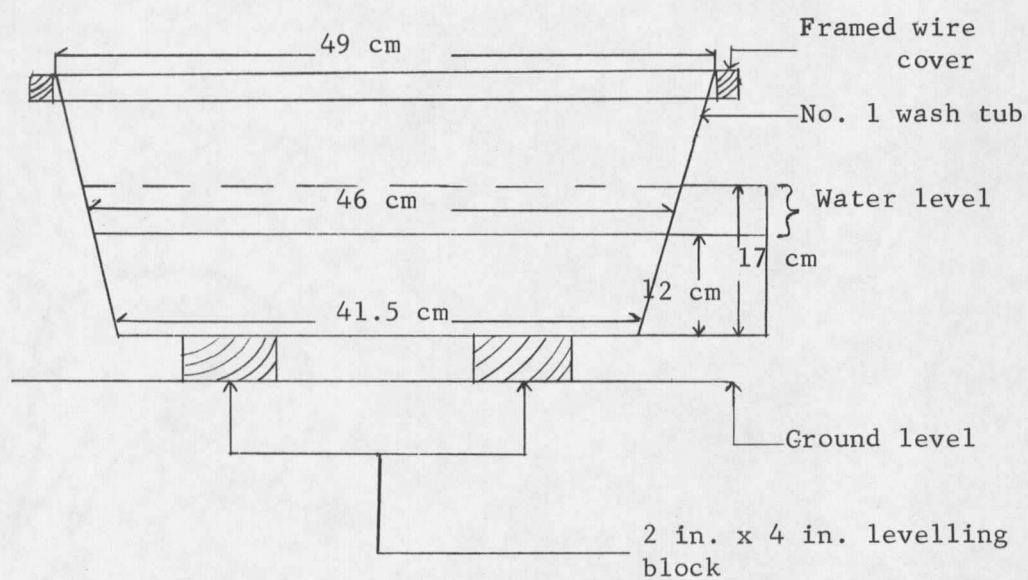


Figure 2. Illustration of an evaporimeter made from a No. 1 wash tub.

same pit was open and refilled each time for measurement. Approximately four inches of soil was shaved off the side of the pit each week, and the temperature measured in that area by inserting the stem horizontally into the soil.

Harvest procedure

The plots were harvested with a small sickle mower. The resulting bundle was weighed with a milk scale (to the nearest tenth of a pound), and threshed with a Vogel thresher. Moisture samples were taken from two replications of treatments one and eight to determine the average moisture content of the bundles from each location. The area harvested depended upon the row spacing of each site; however, a 36 ft length of 1, 2, or 3 rows was cut from the middle of each plot. The area harvest from sites 1, 2, 3, 4, 5, 6 and 7 was 63, 63, 42, 60, 63, 54 and 63 square feet, respectively.

The grain was stored in a shed until cleaned and weighed.

Soils analysis procedures

The water content of the soil at each location was determined after the sample dried for 48 hours at 60° C in a forced draft oven. A study with these soils indicated that a difference of less than 1% occurred between 60° and 105° C drying temperature (P. L. Brown, personal communication). It should be recognized that such a drying procedure may not be appropriate for very fine textured soils. The moisture content at 15 atm tension was determined using conventional

pressure membrane equipment with a sausage casing membrane.

Bulk density (B.D.) was determined by the ped method using paraffin wax as a coating.

Available water in inches was calculated by multiplying the B.D. and the depth times the difference between percent water in the soil and percent water at 15 atm tension.

Electrical conductivity and pH were determined by the methods of the Soil Testing Laboratory (19) on 0 to 6 in depth soil samples from each location.

Organic matter was analyzed by the procedure of the Montana State University Soil Testing Laboratory. The colorimetric method is correlated with the Walkley-Black titration procedure. The method is described in appendix table 17.

Phosphorous was determined on NaHCO_3 extracts using ascorbic acid method developed by Watanabe and Olsen (30).

Nitrate analysis was accomplished by the phenoldisulfonic acid method (4), with slight modifications, and the chromotropic acid procedure which will be described in another section of this thesis. Specifically, the procedures used for the phenoldisulfonic acid method are as follows: 1) extracting solution consisted of 1 liter of 0.6% Ag_2SO_4 and 20 g of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ diluted to 10 liters, 2) 10 g of soil was extracted with 50 ml of extracting solution, 3) a 10 ml aliquot was evaporated on an electric hot plate at about 45-50° C, and 4) 3 ml of the

phenoldisulfonic acid reagent was used to dissolve the evaporated residue.

Available Ca, Mg, Na and K were determined by the following procedure of the Montana State University Soil Testing Laboratory. The extraction was performed on a 2.5 gm sample with 50 ml of neutral $\text{-N NH}_4\text{OAc}$. Shaking time was 30 minutes followed by an additional 30 minutes reaction time. Then the extracts were filtered, and a 5 ml aliquot taken. Five ml of 0.3% Sr Cl_2 was added to the aliquot, and the concentration of the respective elements determined with a Parken-Elmer 290B atomic absorption spectrophotometer.

Lab analysis data are summarized in appendix table 18.

Grain samples

After a six week drying period, the grain samples were cleaned and weighed. Test weight was determined with a standard test weight apparatus which required about 1000 g of grain to fill the standard volume measure. Yield was reported in bu/A using the test weight for each plot. Subsamples were taken for protein analysis.

Grain protein was determined by the Udy dye method 46-14 (1). Preparation of samples consisted of drying the grain for 48 hours at 55°C , and grinding the material fine enough to meet the specifications of the analysis.

Straw samples

Straw samples were collected from each plot and ground in a Wiley

mill for nitrogen analysis. Subsamples were dried for 48 hours at 60° C, and analyzed for nitrogen by a semimicro-Kjeldahl procedure (3) with the following modifications; 1) approximately one-half g sample was used, 2) 20 ml of conc. H_2SO_4 was used in digestion of the sample, 3) approximately 5 g of the Se- K_2SO_4 mixture was used in digestion and 4) A 0.014 N NaHSO_4 was used as the standard acid.

Statistical Procedures

All data were analyzed using the statistical methods of Steel and Torrie (27). Randomized complete block design, simple and multiple linear regression analyses were the statistical methods applied in the study. Computations were made on the SDS Sigma 7 computer in the Montana State University's Computing Center.

Chromotropic acid analysis for soil NO_3

A 0.1% stock solution of practical grade chromotropic acid (4,5-dihydroxy-2,7-naphthalenedisulfonic acid disodium salt) in conc. reagent grade H_2SO_4 was prepared by dissolving 1.84 gms of chromotropic acid in 1 liter of conc. H_2SO_4 (specific gravity = 1.84 gms/cc). A 0.01% working solution of chromotropic acid was prepared by diluting 100 ml of the 0.1% stock and 10 ml of conc HCl to 1 liter with conc. H_2SO_4 . The 0.01% chromotropic acid reagent was used in all subsequent analyses.

The color was developed from a 3 ml aliquot and 7 ml of 0.01% chromotropic acid.

The spectrum of absorption was determined with a Bausch and Lomb Spectronic 20 spectrophotometer by using 0.3, 0.6, 1.0, 2.0, 5.0 and 8.0ppm N as NO_3^- (final concentration). Cuvettes with 1.3 cm path lengths were used. Nitrate standards were prepared from reagent grade KNO_3 . All volumes were measured with volumetric pipets.

A cation interference study was designed to evaluate the possible interference of various concentrations of K^+ , Na^+ , NH_4^+ , Ca^+ , Mg^+ , Mn^{+2} , Fe^{+2} and Fe^{+3} . Nitrate free SO_4 salts were used for all cations except Fe^{+3} . Ferric Chloride was used for Fe^{+3} . Also an anion interference study was devised to check various concentrations of NO_2^- and Cl^- . Reagent grade NaNO_2 and NaCl salts were used for the respective anions.

Calcium sulfate, MgSO_4 and Ca(OH)_2 solutions were evaluated as extracting solutions. Water, 0.5M MgSO_4 , sat. CaSO_4 and 0.05-, 0.10-

and 0.20-g of $\text{Ca}(\text{OH})/50$ ml of water were the concentrations of the extractants tested.

Soil: extractant ratios of 1:2.5, 1:5 and 1:10 and shaking times of 15, 20 and 30 minutes were evaluated for their ability to extract $\text{NO}_3\text{-N}$.

A $\text{NO}_3\text{-N}$ recovery study was designed to compare the chromotropic acid procedure with the phenoldisulfonic acid procedure. Zero, 10, 40 and 120 ppm N- as KNO_3 was added to the C horizon samples of Amsterdam silt loam. Quadruplet subsamples were then analyzed by both procedures. To further compare the two methods, a correlation analysis was performed on 70 soil samples collected from several locations throughout Montana.

Winter wheat response and yield correlations were made by regressing, separately, $\text{NO}_3\text{-N}$ content in 2, 3, 4, 5 and 6 feet of soil against the difference between the check and the highest yielding treatment and the yield of the check treatment, respectively. The yield data were taken from the 7 locations used in this study (Table 3).

Nitrate electrode procedure

An attempt was made to adapt the nitrate electrode for analyzing soil samples. Two systems, water and CaCO_3 suspended in a citric acid- Na_2HPO_4 buffer system were used in an effort to standardize the electrode with known levels of NO_3^- . Also, an experiment was initiated to study the interference of HCO_3^- , $\text{CO}_3^{=}$, Cl^- and $\text{SO}_4^{=}$.

RESULTS AND DISCUSSION

Grain yield and response

Average yields at all locations for all treatments are shown in table 3. A statistical difference between treatments ($p = 0.05$) occurred only at locations two and five.

A yield response of 3 bu/A was measured at location one. However, the data should be interpreted with caution since a small herd of cattle trampled the bundles before they were threshed.

At location two, a response of seven bu/A was observed. A relatively poor stand was a problem at this site.

A three and five bu/A response was noted at locations three and four, respectively. No yield limiting factors other than those studied were observed.

A tremendous response (18 bu/A) occurred at location five; in fact, maximum yield was not obtained.

At location six, a response of about four bu/A was measured. Lodging and winter kill were major problems at this site and probably accounts for the yield variation.

At location seven, a response of five bu/A was observed. Wild oats was a problem at this site but didn't seem to limit grain yield.

Appendix tables 23, 24, 25 and 26 contain the data for test weight, total yield, grain protein and percent nitrogen in the straw.

Table 3. Grain yield of winter wheat for the various fertilizer treatments at the seven locations used in this study.

Trt lb N/A	Location							Mean
	1	2*	3	4	5**	6	7	
	Bu/A							
0.0	41.6	37.8	47.4	49.3	24.3	53.3	59.7	44.8
6.7	45.6	38.2	49.6	48.6	24.2	44.6	59.5	44.3
13.3	37.7	39.0	44.6	48.9	26.9	48.8	64.7	44.4
20.0	36.6	43.7	46.7	51.7	34.2	47.8	63.3	46.3
26.7	43.3	42.8	50.1	54.5	32.8	47.7	60.4	47.4
33.3	44.2	45.6	46.8	50.4	37.2	56.2	65.0	49.3
40.0	44.5	44.2	43.7	55.0	39.1	56.2	63.3	49.4
46.7	41.9	44.3	48.6	54.6	42.5	57.2	61.5	50.1
Mean	41.9	42.0	47.2	51.6	32.7	51.5	62.2	

* Significant difference between treatments $p = .05$

** Significant difference between treatments $p = .05$

Yield and response in relation to soil and climatic factors

Linear regression equations obtained by correlating yield with soil and climatic factors from each location are listed in table 4; r and r^2 values for each equation are presented also.

Soil water data was tabulated as the accumulation of available water in inches in 0-3, 0-4 and 0-6 ft of soil (appendix table 19) for each location. These values did not correlate well with yield (see equations 5-8 in table 4). This was probably the result of the high growing season rainfall.

Precipitation was found to be organized into three patterns by plotting accumulated rainfall vs time (figure 3). To avoid confusion, only three locations are shown. The three rainfall periods were from the beginning of each experiment until May 22, rainfall prior to June 23, and the entire period of measurement. The best correlation was obtained from the total rainfall data (equation 4). Rainfall data are tabulated in appendix table 20.

Care must be exercised in interpreting the water data since more than enough water was available during the growing season to produce maximum yields if the other growth factors were favorable.

A significant correlation ($p = 0.05$) was obtained with yield bu/A and soil nitrates lbN/A) in 0-2, 0-3, 0-4, 0-5 and 0-6 feet of soil. Equations 21 or 22 accounted for 74% of the variation in wheat production. According to these equations, 3-4 lb of N as NO_3^- produced one bu

Table 4. Linear regression equations for predicting grain yield as a function of soil and climatic variables

Equation ^{1/}	r	r ²
1. $Y = 45.93 + 0.61$ (Depth to lime) ^{2/}	0.75	0.56
2. $Y = 57.79 - 6.19$ (April-May rainfall)	-0.27	0.07
3. $Y = 25.51 + 6.46$ (April-May-June rainfall)	0.71	0.50
4. $Y = 17.35 + 3.91$ (Growing season rainfall)	0.86*	0.75
5. $Y = 61.30 - 2.51$ (Avail soil water in 3')	-0.48	0.23
6. $Y = 57.83 - 1.32$ (Avail soil water in 4')	-0.29	0.09
7. $Y = 54.37 - 0.51$ (Avail soil water in 5')	-0.13	0.02
8. $Y = 52.56 - 0.16$ (Avail soil water in 6')	-0.05	0.003
9. $Y = 28.41 + 1.83$ (Soil water in 3' + G.S. rainfall)	0.43	0.18
10. $Y = 4.46 + 242.88$ (Pan evap rate during 1st period)	0.72	0.52
11. $Y = 67.93 - 103.65$ (Pan evap rate during 2nd period)	-0.34	0.11
12. $Y = 67.94 - 93.78$ (Pan evap rate during 3rd period)	-0.58	0.33
13. $Y = 12.35 + 3.78$ (Mean soil temp - 1st period)	0.18	0.03
14. $Y = 14.68 + 2.63$ (Mean soil temp - 2nd period)	0.09	0.008
15. $Y = 73.18 - 1.78$ (Mean soil temp - 3rd period)	0.13	0.017
16. $Y = 103.63 - 3.04$ (Mean soil temp - 4th period)	-0.69	0.47
17. $Y = 169.36 - 7.49$ (Mean soil temp - 5th period)	-0.49	0.24
18. $Y = 156.28 - 7.37$ (Mean soil temp - 6th period)	-0.40	0.16
19. $Y = 34.36 + 0.39$ (Soil NO ₃ -N in 1')	0.52	0.27
20. $Y = 22.32 + 0.38$ (Soil NO ₃ -N in 2')	0.78*	0.61
21. $Y = 22.30 + 0.31$ (Soil NO ₃ -N in 3')	0.86*	0.74
22. $Y = 23.56 + 0.29$ (Soil NO ₃ -N in 4')	0.86*	0.74
23. $Y = 24.63 + 0.25$ (Soil NO ₃ -N in 5')	0.85*	0.72
24. $Y = 25.51 + 0.23$ (Soil NO ₃ -N in 6')	0.82*	0.68

^{1/} Yield values bu/A from the check plot were used in the NO₃-N equations; maximal yield values from each location were used with the other equations.

^{2/} Factor in parenthesis is the variable X; units are as follows: depth to lime-, soil water-, rainfall-inches, evaporation rate-inches/day, soil temperature-C°, soil NO₃-N- lb N/A (phenoldisulfonic acid procedure).

* Statistical significance $p = 0.05$

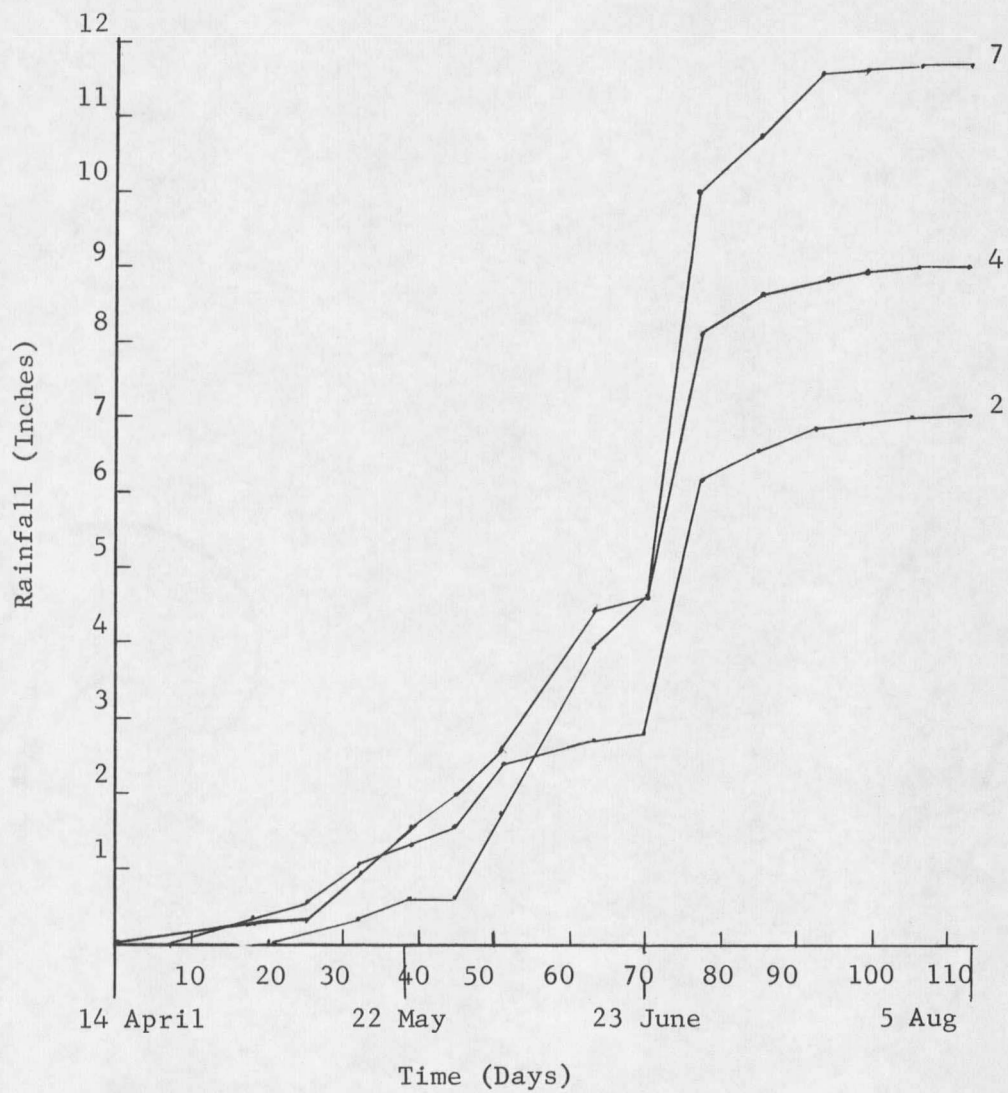


Figure 3. Accumulated rainfall vs time at three locations used in this study.

of wheat depending on the depth of sampling. The equations were valid for yield's approaching 50-60 bu. The intercept of the equations predicted a 20-25 bu yield without any $\text{NO}_3\text{-N}$ initially, in other words, enough $\text{NO}_3\text{-N}$ would be mineralized to produce a 20-25 bu crop. Table 5 and 6 contain the $\text{NO}_3\text{-N}$ data.

To present the free water evaporation on a relative basis, evaporation (inches) vs time (days) was plotted for all seven locations (figure 4). It was obvious that three (3) distinct periods of pan evaporation occurred. The first period was from the date of the experiment initiation until May 29, the second from May 29 to June 23, and the third between June 23 and August 5. The average pan evaporation rate was calculated for the 3 periods and used in the regression analysis. The accumulated pan evaporation data are in appendix table 21. Equation 10 in table 4 indicates a positive relation between yield and pan evaporation rate during the first period. It is reasonable to assume that higher pan evaporation rates are associated with warmer temperatures. In some areas of Montana, this relationship is necessary and expected for the proper development of winter wheat. The equation representing the third period probably is the most useful since it indicates a negatively correlated comparison. The third period in relation to the wheat plant is quite important because it represents the filling, soft and hard dough growth stages. A hot-dry climatic condition during this time would seriously reduce yields; therefore, a negative relationship would

Table 5. Soil NO₃-N in the spring at the seven locations used in this study as determined by the phenoldisulfonic acid method.

Depth	Location						
	1	2	3	4	5	6	7
	lb N/A						
0-6"	2.0	15.5	12.6	27.5	4.0	6.5	17.5
6-12"	14.5	15.5	16.5	25.0	3.0	7.0	18.5
1-2'	58.5	15.0	42.5	21.0	2.0	59.0	30.0
2-3'	8.0	2.0	21.0	6.0	0.0	48.0	16.0
3-4'	0.0	0.0	4.0	6.0	0.0	18.0	4.0
4-5'	2.0	0.0	8.60	2.0	0.0	8.0	2.0
5-6'	8.0	2.0	12.0	2.0	0.0	8.0	4.0
6-7'	2.0	0.0	2.0	2.0	0.0	6.0	4.0
7-8'	0.0	0.0	-	0.0	0.0	6.0	-
8-9'	0.0	0.0	-	0.0	0.0	8.0	-
Total 2'	65.0	50.0	73.6	73.5	10.0	62.5	66.0
3'	73.0	52.0	94.6	79.5	10.0	101.0	82.0
4'	73.0	52.0	98.6	85.5	10.0	119.0	86.0
5'	75.0	52.0	106.6	87.5	10.0	127.0	88.0
6'	83.0	54.0	118.6	89.5	10.0	135.0	92.0

- Indicates data unavailable

Table 6. Soil NO₃-N in the spring at the 7 locations used in this study as determined by the chromotropic acid method.

Depth	Location						
	1	2	3	4	5	6	7
	lb N/A						
0-6'	5.0	18.0	18.4	38.4	9.4	9.4	21.0
6-12"	19.4	20.0	23.4	28.0	5.0	10.0	24.8
1-2'	68.8	24.0	46.8	28.0	6.8	68.8	42.0
2-3'	12.0	5.2	23.2	20.0	0.0	26.8	4.8
3-4'	6.8	4.8	5.2	10.0	0.0	26.8	4.8
4-5'	4.8	3.2	20.0	3.2	0.0	10.0	5.2
5-6'	15.2	3.2	17.2	0.0	0.0	8.8	8.0
Total 2'	93.2	62.0	88.6	94.4	21.2	88.2	87.8
3'	105.2	67.2	111.8	114.4	21.2	153.8	109.8
4'	112.0	72.0	117.0	124.4	21.2	180.6	114.6
5'	116.8	75.2	137.0	127.6	21.2	190.6	119.8
6'	132.0	78.4	154.2	127.6	21.2	199.4	127.8

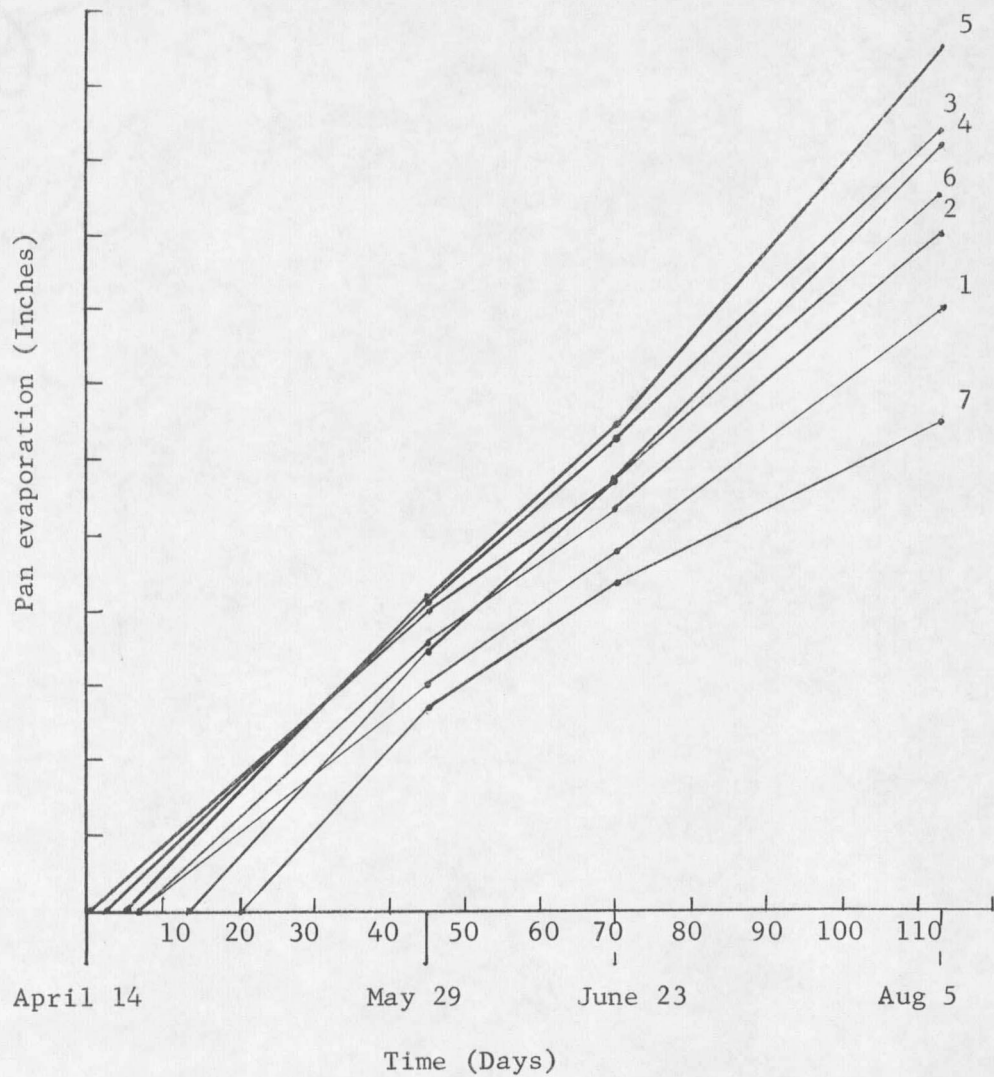


Figure 4. Accumulated pan evaporation vs time at the seven locations used in this study.

be observed with yield and pan evaporation rate.

The correlation involving depth to lime (equation 1) is positively correlated but was not statistically significant. The effect of the lime depth on yields is not clearly understood, but it could be due to effects on several factors and/or their interaction. The increased Ca in the root zone may precipitate the P thus reducing yields, or perhaps the indirect effect of a higher pH on the availability of the minor elements such as Zn, Fe, Cu and Mn. The equation predicted approximately a half bushel increase in yield above 45 bushels for every inch increase in the depth of lime.

Soil temperature data (appendix table 22) were summarized arbitrarily into six periods; 1) a mean for the month of May, 2) a mean for the month of June, 3) a mean for the months of May and June, 4) a mean for July, 5) a mean for June and July, and 6) an overall mean for the period of measurement. The equation for the fourth period gave the best correlation of the six equations.

According to the linear regression analysis, the following factors would give the best fit to the yield data in a multiple regression analysis; soil moisture at 0-3', growing season rainfall, soil nitrates at 0-4', third period evaporation, depth to lime, and soil temperature during the fourth period. However, other criteria are available for eliminating variables and will be discussed in the next section.

Multiple correlation and regressions

In using multiple regression analysis for making fertilizer recommendations an approach similar to the Washington method (13) was used. Two regression equations were developed; one using climatic factors and soil moisture to predict maximum yield and the other expressing yield as a function of the above variables, soil nitrate content and fertilizer rate.

In utilizing multiple regression analysis, one must bear in mind that practically anything can be correlated with something else. Therefore, the problem arises in eliminating or choosing which soil and climatic factors to apply in the analyses. Four methods were used to select the components of the regression analysis; 1) trial and error, 2) linear regression analysis, 3) applying the standard partial regression coefficients of multiple correlation and 4) the experience of the observer.

Before discussing the equations, several points should be discussed. First of all, only one year's data from a small number of locations is available to interpret. Secondly, differences in some variables between sites were quite small; thus, large correlation coefficients were obtained. Maximum yield from N fertilizer was not achieved at location five. Also, the equations are applicable only in the range of measurement for each factor.

Table 7 contains the equations for predicting maximal yield. It

Table 7. Mutiple linear regression equations for predicting maximum grain yield of winter wheat as a function of soil and climatic variables.

Equation ^{1/}	R ²	
1. $Y = 221.8 - 2.70 \text{ SM} + 92.63* \text{ EV} + 0.34* \text{ RF} + 0.77* \text{ DL} - 13.10* \text{ ST}_1$	0.98	
2. $Y = 36.44 - 6.73* \text{ SM} - 182.3* \text{ EV} - 3.85* \text{ RF} + 1.45* \text{ DL} + 5.47* \text{ ST}_2$	0.999	
3. $Y = 65.8 - 3.05 \text{ SM} - 39.08 \text{ EV} - 0.06 \text{ RF} + 0.55 \text{ DL}$	0.91	
4. $Y = 136.8 - 1.01 \text{ SM} + 24.90 \text{ EV} + 3.71 \text{ RF} - 8.32 \text{ ST}_1$	0.89	
5. $Y = 40.26 - 1.67 \text{ SM} - 63.15 \text{ EV} + 2.76 \text{ RF} + 0.28 \text{ ST}_2$	0.86	
6. $Y = 43.59 - 1.61 \text{ SM} - 54.64 \text{ EV} + 2.72* \text{ RF}$	0.86	
7. $Y = 59.85 - 3.10 \text{ SM} - 0.31 \text{ RF} + 0.70 \text{ DL}$	0.87	
8. $Y = 113.70 - 1.21 \text{ SM} + 3.39* \text{ RF} - 6.13 \text{ ST}_1$	0.89	
9. $Y = 54.01 - 1.15 \text{ SM} + 2.77^{\oplus} \text{ RF} - 1.30 \text{ ST}_2$	0.83	33
10. $Y = 24.08 - 1.03 \text{ SM} + 3.60* \text{ RF}$	0.78	

SM = Avail soil water in 0-3' of soil (inches) EV = evaporation during the 3rd period (inches/day), RF = rainfall during growing season (inches), DL - depth to lime (inches), ST₁ = soil temp. during the 6th period (C°) and ST₂ = soil temp. during the 4th period.

^{1/} Yield (Bu/A) values used were maximum measured for each location.

[⊕] = Significant correlation p = 0.10

* = Significant correlation p = 0.05

** = Significant correlation p = 0.01

is apparent that the addition of factors will increase R^2 or the predicting power of the equations, and the sign of the partial regression coefficient (B_i 's) is not consistent with those from the simple regression equations. This occurrence is not uncommon when the overall effect of the variables is considered in the multiple regression analysis.

According to the predicted values for each observation, equation 2 gave the most accurate prediction of the set of equations, although equations 1 and 2 are essentially equal in formulating an expected yield value. The addition of soil temperature, depth to lime and evaporation rate to available soil water and growing season rainfall increased R^2 20% (equations 1 and 10).

Table 8 contains the equations for expressing yield as a function of soil chemical and climatic factors. Again an increase in the number of factors resulted in an increased R^2 (i.e. more variation is accounted for). The sign of the B_i 's is consistent with the slopes of the simple regression equation until five factors are used (i.e. equations 1 to 10). And the signs again become erratic and inconsistent.

Obviously, more factors other than soil nitrates, soil water and rainfall need to be considered in a fertilizer recommendation. Variables such as evaporation rate, depth to lime and soil temperature increased R^2 enough (40%) to warrant their inclusion in the final regression equation.

Table 8. Multiple linear regression equations expressing grain yield of winter wheat as a function of fertilizer rate, soil and climatic variables.

Equation	R ²
1. $Y=29.34+0.14^{**} FR+0.19^{**} SN_1$	0.49
2. $Y=38.73+0.14^{**} FR+0.17^{**} SN_1-1.99^{**} SM_1$	0.57
3. $Y=47.29+0.14^{**} FR+0.14^{**} SN_1-80.98^{**} EV$	0.61
4. $Y=4.63+0.14^{**} FR+0.16^{**} SN_1+3.21^{**} RF$	0.76
5. $Y=26.90+0.14^{**} FR+0.16^{**} SN_1+0.60^{**} DL$	0.71
6. $Y=84.57+0.14^{**} FR+0.15^{**} SN_1-3.06^{**} ST_1$	0.75
7. $Y=66.34+0.14^{**} FR+0.09^{**} SN_1-2.85^{**} SM_1-106.4^{**} EV$	0.76
8. $Y=10.98+0.14^{**} FR+0.14^{**} SN_1-0.94^{*} SM_1+2.96^{**} RF$	0.78
9. $Y=38.79+0.14^{**} FR+0.13^{**} SN_1-2.59^{**} SM_1+0.57^{**} DL$	0.84
10. $Y=90.23+0.14^{**} FR+0.13^{**} SN_1-1.68^{**} SM_1-2.93^{**} ST_2$	0.81
11. $Y=36.40+0.14^{**} FR+0.10^{**} SN_1-1.79^{**} SM_1-65.52^{**} EV+2.06^{**} RF$	0.83
12. $Y=51.38+0.14^{**} FR+0.10^{**} SN_1-2.85^{**} SM_1-48.59^{**} EV+0.44^{**} DL$	0.87
13. $Y=101.3+0.14^{**} FR+0.16^{**} SN_1-0.88^{*} SM_1+75.60^{*} EV-4.68^{**} ST_1$	0.82
14. $Y=61.78+0.14^{**} FR+0.10^{**} SN_1-3.45^{**} SM_1-47.17^{**} EV-1.15^{*} RF+0.63^{**} DL$	0.87
15. $Y=68.31+0.14^{**} FR+0.15^{**} SN_1-0.54^{*} SM_1+61.81^{*} EV+1.66^{*} RF-3.48^{**} ST_1$	0.87
16. $Y=-9.51+0.14^{**} FR-0.29^{**} SN_1-24.82^{*} SM_1-912.5^{**} EV-20.43^{**} RF+5.04^{**} DL+27.15^{**} ST_1$	0.90
17. $Y=250.3+0.14^{**} FR+0.05^{*} SN_1-3.51^{**} SM_1+79.66^{*} EV-0.75^{*} RF+0.88^{**} DL-14.91^{**} ST_2$	0.90
18. $Y=42.5+0.14^{**} FR+0.04^{*} SN_2-6.66^{**} SM_2-287.6^{**} EV-3.91^{**} RF+1.38^{**} DL+5.97^{**} ST_1$	0.90

Y = grain yield (bu/A), FR = fertilizer rate (lb N/A), SN_1 = NO_3 -N in 0-4' of soil (lb N/A), SN_2 = NO_3 -N in 0-5' of soil (lb N/A, phenoldisulfonic acid method), SM_1 = available soil water in 0-3' of soil (inches), SM_2 = avail. water in 0-4' of soil, EV = pan evaporation rate during 3rd period (inches/day), RF = growing season rainfall (inches), DL = depth to lime (inches), ST_1 = soil temp. during 4th period and ST_2 = soil temp. during 6th period ($^{\circ}C$).

** = significant correlation $P = 0.01$.

* = significant correlation $P = 0.05$.

The set of equations also points out the problem of interpreting one year's data. For example, in 1969 essentially no response to N was observed, since the nitrate levels in the soil were all high. This fact is reflected in the partial regression coefficient for soil nitrates (i.e. there is very little yield change due to soil nitrates), and in the partial regression coefficient for fertilizer rate. Or in other words, a higher R^2 value is attained when soil nitrates and fertilizer rate are left out of the regression analysis.

The regression analysis does support the philosophy that more measurable climatic factors need to be included or considered in quantitatively predicting response to added chemical fertilizers.

Analysis of soil nitrate with chromotropic acid

Figure 5 shows the spectrum of absorption of 0.3, 0.6, 1.0, 2.0, 5.0 and 8.0 ppm N as NO_3^- . Maximum absorbance occurred at 430 $\text{m}\mu$ on the Baush and Lomb (B & L) Spectronic 20 Spectrophotometer and was subsequently used in all research with the procedure. West and Lyles (31) reported two peaks of absorbance at 415 and 357 $\text{m}\mu$; however, a Beckman D K recording spectrophotometer was used in the research. The reported peak at 357 $\text{m}\mu$ could not be found on the B & L Spectronic 20.

Figure 6 is a typical standard curve which follows Beer's law from 0-2 ppm $\text{NO}_3\text{-N}$.

The results of the interference study are tabulated in table 9. Iron (II) and NO_2^- will cause interference in final concentrations of 10

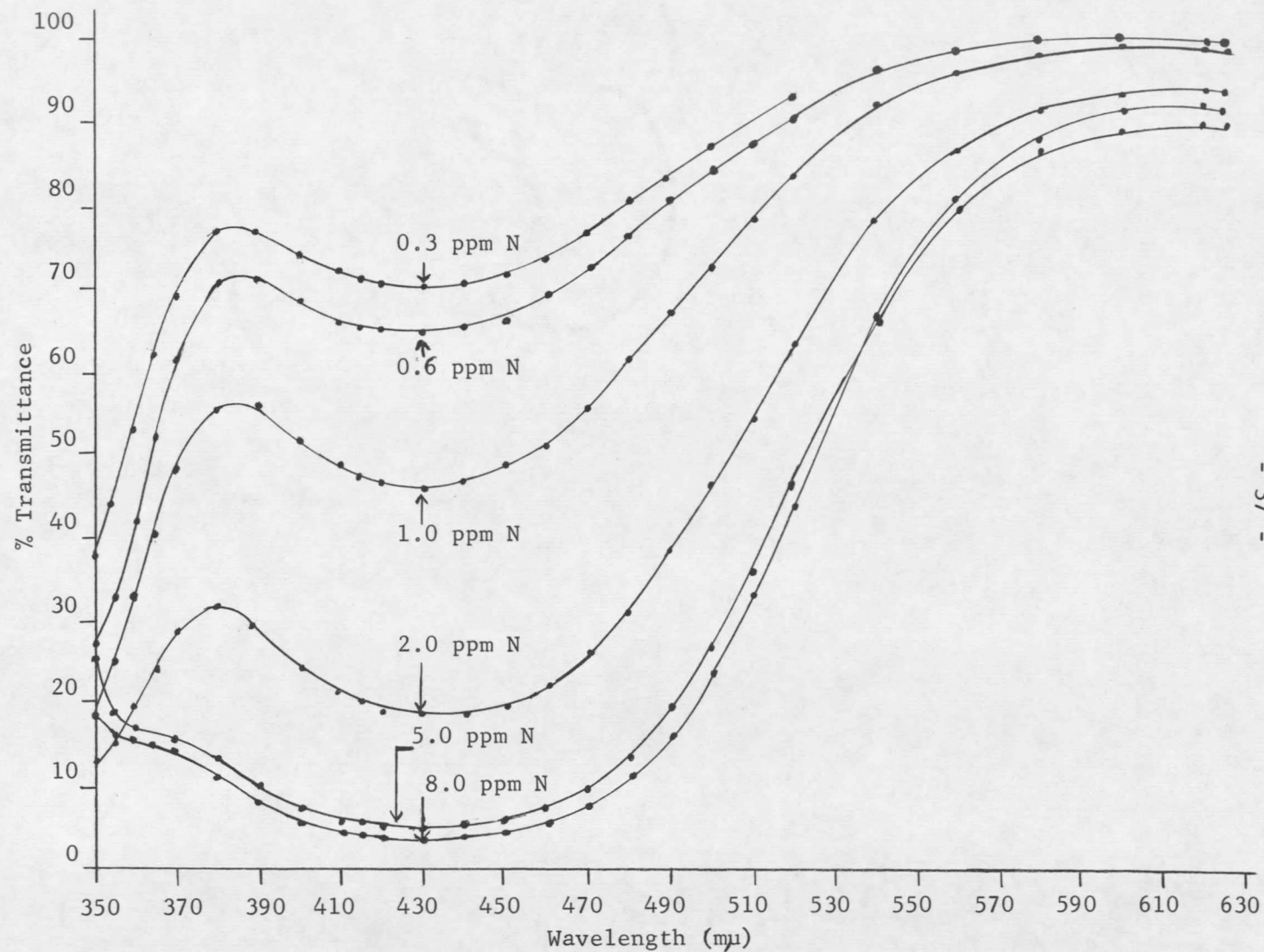


Figure 5. Absorption spectra of NO_3^- in chromotropic acid reagent

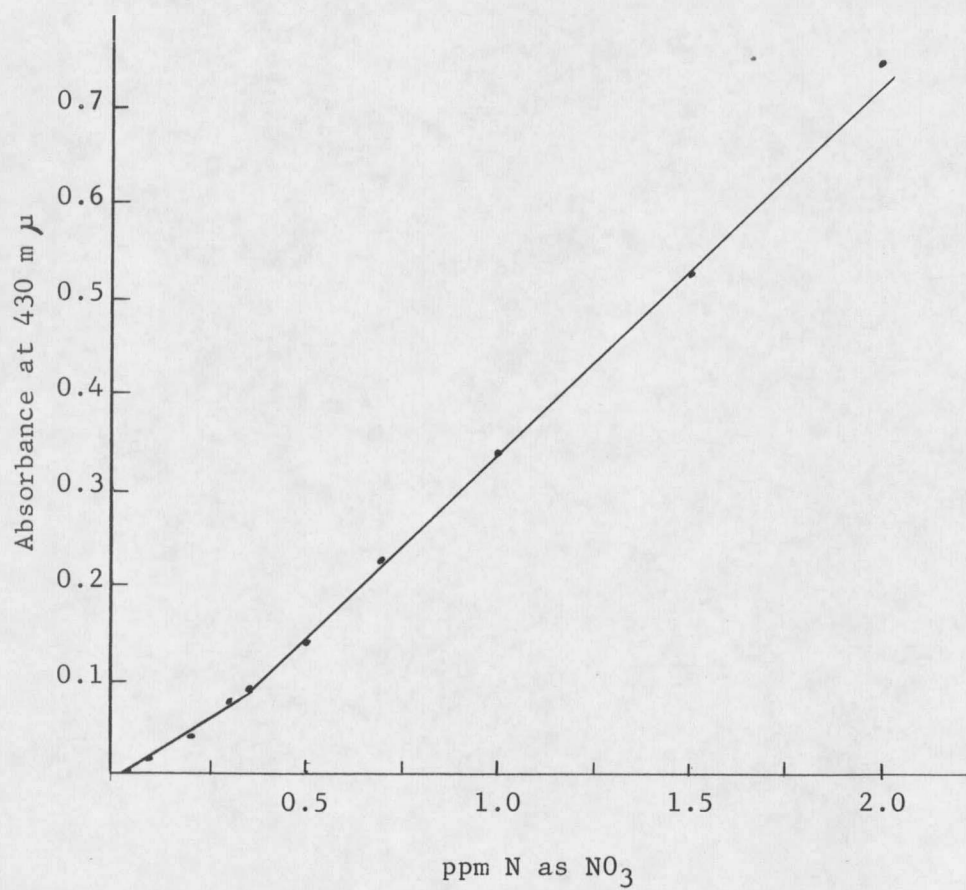


Figure 6. Standard curve of the chromotropic acid procedure

Table 9. NO₃-N detected in the presence of other ions in an interference study with the chromotropic acid procedure.

Ion	NO ₃ -N added ppm	Final concentration of interfering ion ppm			
		0.1	0.5	1.0	10.0
		NO ₃ -N detected, ppm			
NH ₄ ⁺	0	0.00	--	0.00	--
	0.6	0.60	--	0.60	--
Na ⁺	0	0.00	--	0.00	--
	0.6	0.58	--	0.60	--
K ⁺	0	0.00	--	0.00	--
	0.6	0.62	--	0.60	--
Ca ²⁺	0	0.00	--	0.00	--
	0.6	0.57	--	0.60	--
Mg ²⁺	0	0.00	--	0.00	--
	0.6	0.62	--	0.56	--
Mn ²⁺	0	0.10	0.07	--	--
	0.2	0.19	0.19	--	--
	0.5	--	--	--	0.50
Fe ²⁺	0	0	0	--	0.00
	0.2	0.20	0.22	--	--
	0.5	--	--	--	0.35
Fe ³⁺	0	0	0	--	--
	0.2	0.24	0.24	--	0.00
	0.5	--	--	--	0.54
Cl ⁻	0	0	0	0	0
	0.5	0.52	0.45	0.47	0.47
NO ₂ ⁻	0	0.00	0.18	0.30	2.5
	0.2	--	0.27	--	--
	0.5	0.48	0.60	1.25	2.5

-- Indicates analysis was not performed

and 0.5 ppm, respectively. These concentrations would represent 167 ppm Fe^{2+} and 8.4 ppm NO_2^- in the soil which would rarely be encountered except under reducing conditions. Also, the pH of the extracting solution (pH 12.4) would tend to suppress the solubility of Fe and other transition elements.

No other ions evaluated caused significant interference. The slight interference encountered with Mg^{2+} was within the error of the procedure.

Water, 0.5 M MgSO_4 , sat. CaSO_4 , and 0.05, 0.10 and 0.20 gms of Ca(OH)_2 /50 mls of water were evaluated as potential extracting solutions. All solutions were found to be equivalent in extracting NO_3^- ; however, Ca(OH)_2 in water was found to give the clearest extracts in some soils. Therefore, 0.1-0.2 gms Ca(OH)_2 /50 mls of water was used in subsequent analysis.

A shaking time of 15 minutes was observed to extract maximum $\text{NO}_3\text{-N}$. And a soil-extractant ratio of 1:5 was shown to effectively extract NO_3^- and give NO_3^- concentration ranges suitable for routine analysis of most soils. An aliquot must be diluted, however, if NO_3 in the soil exceeds 30 ppm.

Table 10 shows the results of a $\text{NO}_3\text{-N}$ recovery study which compared the chromotropic acid (CTA) and phenoldisulfonic acid (PDA) procedures. Note that there is less variation in the data from the CTA procedure than for the PDA procedure for the 0 and 10 ppm $\text{NO}_3\text{-N}$ treatments;

Table 10. Recovery of initial + added $\text{NO}_3\text{-N}$ by the chromotropic and phenoldisulfonic acid procedures.

Added NO ₃ -N ppm	NO ₃ -N detected ^{1/} ppm				Mean	% Recovery
Chromotropic acid procedure						
0	5.8	6.7	5.3	5.8	5.4	0
10	13.3	15.7	16.7	17.8	15.9	99
40	47.5	50.0	55.0	40.0	48.1	105
120	120	115	120	110	116	92
Phenoldisulfonic acid procedure						
0	5.5	6.0	6.6	7.2	6.3	0
10	11.5	15.6	15.6	17.6	15.1	92
40	47.5	50.0	50.0	50.0	49.4	107
120	120	135	125	128	127	99

^{1/} Data show is from four subsamples.

however, the reverse is true for the 40 and 120 ppm treatments. The CTA procedure more efficiently measured nitrate than the PDA method from the 10 and 40 ppm treatments. However, the PDA procedure more efficiently recovered NO_3^- from the 120 ppm treatment. The more efficient recovery of the low nitrate contents by the CTA procedure suggests that it is more sensitive than the PDA method.

To further compare the two procedures, 70 soil samples submitted by farmers from many areas of the state were analyzed by both procedures. Regression and correlation analyses were used to relate the two procedures. In the regression analysis, the equation $Y = -0.76 + 0.90 X$ was obtained with $r = 0.98$ (significant $p = 0.01$) where $Y = \text{PDA NO}_3\text{-N}$ (ppm in soil) and $X = \text{CTA NO}_3\text{-N}$ (ppm in soil). The data are plotted in figure 7. This analysis also indicates the CTA procedure to be the most sensitive.

Tables 11, 12, 13 and 14 contain regression equations and correlation coefficients that relate wheat yield and yield response to added N for both procedures. In comparing tables 11 and 13, CTA procedure has better correlation in 2 and 3 feet of soil; however, PDA procedure gave better correlations for the lower depths (equations 3, 4 and 5). The PDA method produced a slightly better correlation for predicting N response (tables 12 and 14) than the CTA procedure. Also, the equations from tables 11 and 13 indicate the CTA procedure more sensitive than the PDA procedure (compare the slopes of the regression equations).

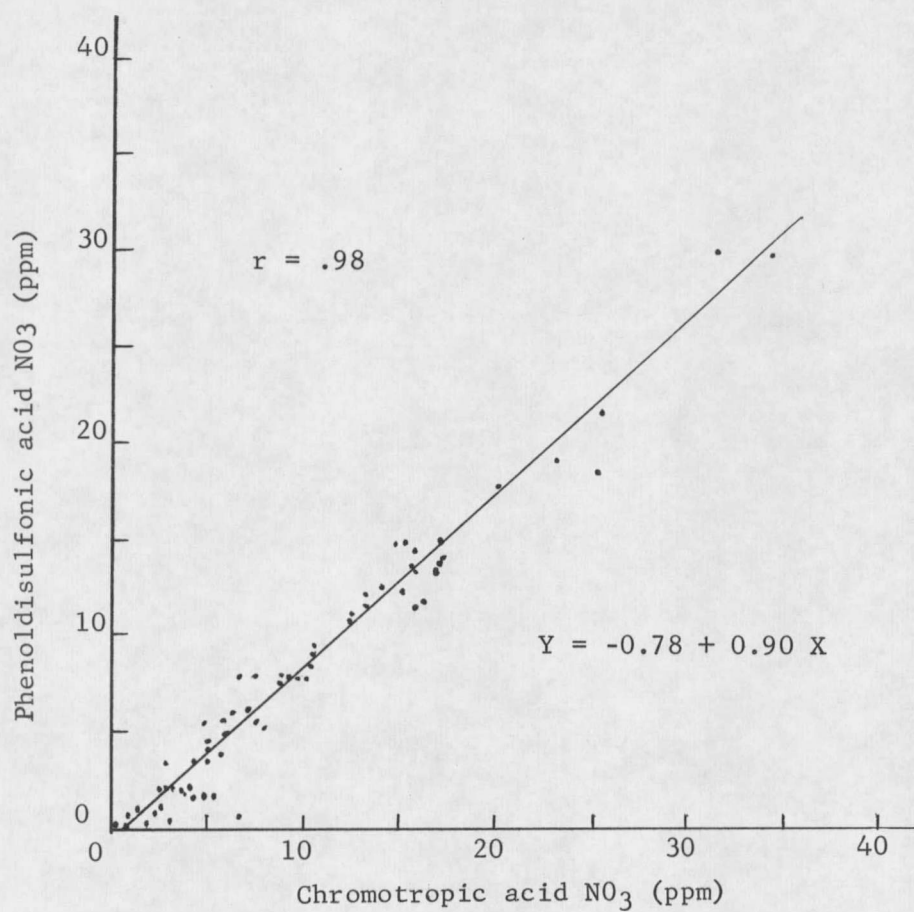


Figure 7. Correlation of phenoldisulfonic acid nitrate and chromotropic acid nitrate.

Table 11. Linear regression and correlation analysis of winter wheat yield with CTA $\text{NO}_3\text{-N}$ from seven locations.

Equation	Depth, ft	r	r^2
1. $Y = 16.86 + 0.37 X$	2	.84*	0.71
2. $Y = 21.52 + 0.24 X$	3	.87*	0.75
3. $Y = 24.06 + 0.20 X$	4	.83*	0.69
4. $Y = 24.42 + 0.18 X$	5	.82*	0.68
5. $Y = 24.83 + 0.17 X$	6	.81*	0.66

Y = Yield in bu/A

X = $\text{NO}_3\text{-N}$ in lb N/A in the respective soil depth

* Significant $p = .05$

Table 12. Linear regression and correlation analysis of winter wheat response to N fertilizer with CTA $\text{NO}_3\text{-N}$ from seven locations.

Equation	Depth, ft	r	r^2
1. $Y = 29.95 - 0.29 X$	2	-.95**	.90
2. $Y = 24.19 - 0.16 X$	3	-.86*	.74
3. $Y = 22.37 - 0.13 X$	4	-.82*	.67
4. $Y = 22.38 - 0.13 X$	5	-.83*	.69
5. $Y = 22.63 - 0.12 X$	6	-.85*	.72

Y = Increase in yield over the check (bu/A)

X = $\text{NO}_3\text{-N}$ in lb N/A in the respective soil depth

* Significant $p = .05$

** Significant $p = .01$

Table 13. Linear regression and correlation analysis of winter wheat yield with PDA $\text{NO}_3\text{-N}$ from seven locations.

Equation	Depth, ft	r	r^2
1. $Y = 22.32 + 0.38 X$	2	.78*	.61
2. $Y = 22.30 + 0.31 X$	3	.86*	.74
3. $Y = 23.56 + 0.29 X$	4	.86*	.74
4. $Y = 24.63 + 0.25 X$	5	.85*	.72
5. $Y = 25.51 + 0.23 X$	6	.82*	.68

Y = Estimated yield in Bu/A

X = $\text{NO}_3\text{-N}$ in lb N/A in the respective soil depth

* Significant $p = .05$

Table 14. Linear regression and correlation analysis of winter wheat response to N fertilizer with PDA $\text{NO}_3\text{-N}$ from seven locations.

Equation	Depth, ft	r	r^2
1. $Y = 27.85 - 0.34 X$	2	-.96**	.91
2. $Y = 24.96 - 0.24 X$	3	-.92**	.85
3. $Y = 23.00 - 0.20 X$	4	-.87*	.76
4. $Y = 22.22 - 0.18 X$	5	-.86*	.73
5. $Y = 22.01 - 0.17 X$	6	-.86*	.73

Y = Increase in yield over the check (bu/A)

X = $\text{NO}_3\text{-N}$ in lb N/A in the respective soil depth

* Significant $p = .05$

** Significant $p = .01$

Proposed procedure for NO₃-N analysis of soil samples

Based on the results of this study the following procedure is recommended for NO₃-N analysis of soil samples.

1. Weigh 10 g of soil into an extracting flask
2. Add 0.1 g of Ca(OH)₂
3. Add 50 ml of distilled water
4. Shake for 15 minutes and filter^{1/}
5. Pipette a 3 ml^{2/}
6. Pipette or burette 7 ml of 0.01% chromotropic acid
7. Let samples cool and determine absorbance at 430 m μ ^{3/} using 3 ml of extracting solution and 7 ml of 0.01% chromotropic acid for a blank.

The 0.01% chromotropic acid will keep at least three weeks unprotected from light. The 0.1% stock solution has been stored for six months when stored in a darkened container.

Color developed from soil extracts remained unchanged for at least four hours; however, the color developed from standard NO₃ solutions become unstable after one hour.

-
- ^{1/} If clay and O.M. are still suspended an additional 0.1 g of Ca(OH)₂ can be used.
 - ^{2/} The aliquot can be reduced and water added for a total of 3 ml.
 - ^{3/} The exact maximum in the absorbance band should be located on each individual instrument.

Problems with the procedure

The only problem observed was a slight purple color from soils which were low in $\text{NO}_3\text{-N}$. The interferring color had maximum absorbance at $500\text{ m}\mu$ and would disappear when NO_3^- was added. It was postulated that dissolved organic matter O.M. was causing the problem. Evidence to support the hypothesis was obtained by noting that sucrose in chromotropic acid gave the same purple color. Apparently the color is not a problem when sufficient NO_3^- is present to compete with the O.M. The blank (0.1 g Ca(OH)_2 in 50 mls of distilled water shaken for 15 minutes) gave a slight purple color, but it reads only 98% transmittance when compared with distilled water. Probably enough organic material is contained in the air and water to give the slight interference. The data from several soils are shown in table 15 to indicate the intensity of the color with varying NO_3^- concentrations. The data from table 15 indicates that approximately $2\text{-}3\text{ ppm NO}_3\text{-N}$ will eliminate the purple color; however, these figures are not sacred because the color apparently depends upon the amount of O.M. extracted. Also, addition of Ca(OH)_2 to the extraction flask was shown to decrease the intensity of the purple color.

In most soils the interference was not a problem, but in some cases the color could be a significant interference. One way to eliminate the color is to add NO_3^- to the soil extracts and subtract the amount added after analysis.

The CTA procedure is a much more rapid and simpler technique for

Table 15. CTA and PDA $\text{NO}_3\text{-N}$ and the intensity of the purple color observed from six soil samples.

Soil NO.	PDA $\text{NO}_3\text{-N}$, ppm	CTA $\text{NO}_3\text{-N}$, ppm	Intensity purple color
2550	0.5	6.7	high
2551	1.5	5.5	medium
2554	2.0	2.8	none
JH 4-5'	0	0	slight
FE 5-6'	1.0	2.2	none
JK 3-4'	1.0	1.3	none

determining soil NO_3^- than the PDA procedure. With appropriate correlation studies with crop response to N fertilizer it can be adopted as a routine laboratory procedure.

Analysis of nitrate with the nitrate electrode

Several attempts were made to calibrate the nitrate electrode, and good calibrations were made using the CaCO_3 - buffer system and NO_3^- standards; however, the procedure did not appear to be sensitive enough. Chloride and HCO_3^- ions were found to interfere with the electrode, and the procedure was abandoned in favor of the chromotropic acid procedure.

SUMMARY AND CONCLUSIONS

The two most significant contributions of this research report are: 1) the adaptation of the chromotropic acid procedure for the analysis of soil nitrates and 2) the development of multiple regression equations expressing grain yields of winter wheat as a function of soil and climatic variables.

In the chromotropic acid procedure, extracting solutions of 0.5 M MgSO_4 , sat. CaSO_4 , and 0.1 gm Ca(OH)_2 suspended in 50 ml of water were evaluated. The solutions were equally effective in extracting NO_3^- ; however, clearer extracts were obtained with Ca(OH)_2 . The Ca(OH)_2 -water system was used for subsequent analysis. Soil: solution ratio of 1:2.5, 1:5 and 1:10 were evaluated. A soil: solution ratio of 1:5 effectively extracted NO_3^- in concentrations appropriate for color development. Maximum NO_3^- was extracted with a shaking time of 15 minutes.

Iron (II) and NO_2^- in soil concentrations of 167 and 8.4 ppm, respectively, were shown to interfere with the procedure. In well drained soils, these concentrations of Fe^{2+} and/or NO_2^- would rarely be encountered.

The chromotropic acid procedure was compared to the phenoldisulfonic acid procedure by three methods: 1) a NO_3^- recovery study, 2) simple linear regression and correlation analysis of 70 soil samples and 3) correlation of both procedures with winter wheat yield and response to N fertilizer.

Equivalent amounts of nitrate were recovered by both procedures in the nitrate recovery study.

In the regression analysis, the equation $Y = -0.76 + 0.90 X$ was obtained with $r = .98$ (significant $p = .01$) where X = chromotropic acid $\text{NO}_3\text{-N}$ (ppm) and Y = phenoldisulfonic acid $\text{NO}_3\text{-N}$ (ppm). This method of analysis indicates the methods are closely related with the chromotropic acid procedure being slightly more sensitive. Both methods were positively related ($p = .05$) to winter wheat yield and negative related ($p = .05$) with winter wheat response to N fertilizer. The procedures are similar in predicting yield, but the phenoldisulfonic acid procedure gave a slightly better correlation with response to N fertilizer.

Dissolved organic matter (O.M.) was thought to be the cause of an off-color interference. However, the interference was only observed in soils with low NO_3^- , and the color would disappear when NO_3^- was added. Therefore, the interference was not considered a serious problem.

In conclusion, the new procedure is much more rapid than the phenoldisulfonic acid procedure (almost twice as many samples can be run per day). Also it is slightly more sensitive, simpler and free from Cl^- interference.

Multiple regression analysis was used to correlate soil and climatic properties with winter wheat yield. Two different types of equations were developed: one for predicting maximal yield using available

soil water, growing season rainfall, depth to lime, pan evaporation, and soil temperature at 50 cm as factors, and the other for predicting yield by regressing N fertilizer rate, soil nitrates, and the other factors listed previously. Excellent correlations were observed (R^2 ranged from 0.49 to 0.99). The highest R^2 values were recorded when all the soil and climatic properties were included in the analysis. However, the equations need refinement before being used for N fertilizer recommendations. Due to initially high soil $\text{NO}_3\text{-N}$ content, only two locations out of seven responded to N. Thus, very little increase in yield was predicted from high fertilizer rates and soil nitrates. The N fertilizer trials should be repeated in a large number of locations to obtain a wider range of soil and climatic properties.

In conclusion, it is apparent that more than one year's data from seven locations must be included in a multiple regression analysis before a useful equation for recommending N fertilizer is obtained. Also, it is apparent that other environmental and soil factors besides soil nitrates, soil moisture and rainfall need to be studied before a system for N fertilizer recommendations can be quantitatively devised.

APPENDIX

Table 16. Typical profile descriptions and on-site descriptions of the Amsterdam and Bozeman soil series upon which the field portion of this study was concluded.

The Amsterdam series consists of Typic Cryoboroll, members of a fine silty, mixed family. The typical profile has a dark grayish brown silt loam Ap horizon, brown prismatic heavy silt loam B2 horizon, thin light yellowish brown prismatic silt loam B3ca, and pale yellow silt loam Clca horizon which is underlain by strongly calcareous very fine sandy loam IIC2ca horizon containing considerable shards of volcanic glass.

Typifying Profile: Amsterdam silt loam, cultivated
(Colors for dry conditions unless otherwise noted)

Ap	0-8"	Dark grayish brown (10YR 4/2) heavy silt loam; very dark brown (10YR 2/2) moist; moderate fine and very fine granular structure; hard, very friable, slightly sticky and slightly plastic;
B21	8-10"	Brown (10YR 4/3 rubbed with 4/2 coats) heavy silt loam, dark brown (10YR 3/3 rubbed with 3/2 coats) moist; moderate medium prismatic structure; separating to strong fine blocks; very hard, very friable, slightly sticky and slightly plastic, clear boundary. 0 to 3 inches thick.
B22	10-15"	Brown (1Y 5/3) heavy silt loam; brown (1Y 4/3) moist; moderate medium prismatic structure; separating to weak fine and medium blocks; hard very friable, slightly sticky and slightly plastic; clear boundary, 4 to 8 inches thick.
B3ca	15-20"	Light yellowish brown (2.5Y 6/3 rubbed, 1Y 5/3 uncrushed) silt loam, olive brown (2.5Y 4/3 rubbed, 1Y 4/3 uncrushed) moist; moderate medium prismatic structure; hard, very friable, slightly sticky and slightly plastic; calcareous with a few nodules or threads of segregated lime; 3 to 6 inches thick.
Clca	20-28"	Light gray (2.5Y 7/2 and 8/0) silt loam; grayish brown (2.5Y 5/2 and 5/3) moist; moderate medium and coarse prismatic structure; hard very friable, slightly sticky and slightly plastic; strongly calcareous with lime disseminated and segregated as common soft nodules and

Table 16. continued..

		threads with a few very coarse (1 to 2 inches) masses of pure CaCO_3 ; gradual boundary; 6 to 10 inches thick.
IIC2ca	28-42"	Pale yellow (2.5Y 7/3) very fine sandy loam; grayish brown (2.5Y 5/2) moist; massive structure; but with a tendency to separate to weak plates; soft, very friable, nonsticky and non-plastic; strongly calcareous with lime disseminated and segregated as common soft nodules; numerous volcanic glass shards visible with unaided eye; diffused boundary; 12 to 16 inches thick.
IIC3	42-60"	Light yellowish brown (2.5Y 6/3) very fine sandy loam in upper part but containing less clay and more fine and very fine sand in lower part below 50 inches; grayish brown (2.5Y 5/2) moist; massive or weak platy structure; soft, very friable nonsticky and non-plastic; moderately calcareous, many shards visible with unaided eye.

The Bozeman series comprises well-drained Chernozem soils (Typic Cryoboroll) developed in deep loeses in valleys of the northern Rocky Mountains. The Bozeman series has distinct horizonation with: 1) thick black or very dark brown (moist) A1 or Ap horizon, 2) a thick prismatic-blocky B2 horizon that has a distinct increase in clay and Munsell chroma over the A1 or C; and 3) a distinct or prominent horizon of accumulated lime in segregated form in the C horizon. The percent age of clay increases with depth in the A1 horizons, reaching a maximum in the B22 horizon, decreasing through the Cca horizon and reaching a distinct minimum below the Cca horizon.

Soil Profile: Bozeman silt loam, Pasture

A11	0-4"	Very dark gray (10YR 3/1 dry) 10YR 2/1 moist; silt loam, moderate, fine platy to moderate, fine crumbs, soft, friable and slightly sticky; many clear sand grains coating peds, slightly acid to mildly alkaline, pH 6.5 to 7.5; clear smooth lower boundary.
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- A12 4-8" Very dark gray (10YR 3/1 dry) 10YR 2/1 moist, light silty clay loam; moderate, medium prismatic to moderate medium and fine granular; hard, friable, slightly sticky and slightly plastic; many clear sand grains coating peds; slightly acid to mildly alkaline, pH 6.5 to 7.5; clear smooth lower boundary. A1 is 6 to 12 inches thick.
- B1 8-13" Very dark grayish brown (10YR 3/2 dry) 10YR 2/2 moist moist, silty clay loam, moderate, medium prismatic to strong, medium angular blocks; very hard, friable, sticky and plastic; thin continuous clay films on all ped faces with many clear sand grains; slightly acid to mildly alkaline, pH 6.5 to 7.5, clear smooth lower boundary, 0 to 6" thick.
- B21 13-20" Dark grayish brown (10YR 4.2 dry) 10YR 3/2 moist; silty clay loam; moderate, medium prismatic to very strong, fine subangular blocks; very hard, firm, sticky and plastic; moderately thick continuous clay films on all ped faces with many clear sand grain coatings; slightly acid to mildly alkaline, pH 6.5 to 7.5, diffused lower boundary.
- B22 20-28" Brown (10YR 5/3 dry) 10YR 4/3 moist, silty clay loam; moderate, medium prismatic strong medium and fine subangular blocks; very hard, firm, sticky and plastic, thin continuous clay film on all ped faces with thick patchy clay films on vertical faces, slightly acid to mildly alkaline, pH 6.5 to 7.8, clear wavy lower boundary. B2 is 10 to 20 inches thick.
- Cca 28-48" Pale brown (10YR 6/3 dry) 10YR 4/2 moist; silt loam; moderate to weak, coarse prismatic to weak, medium and coarse blocks; hard, friable, slightly sticky and slightly plastic; very strongly calcareous with calcium carbonate occurring as thread lime in root cavities, soft soil nodules with carbonate films, and disseminated lime flour; gradual lower boundary, 15 to 30" thick.
- C 48-64" Light yellowish brown (1YR 6/3 dry) 1Y 5/3 moist; silt loam; massive; slightly hard, friable, slightly sticky and slightly plastic; strongly calcareous, calcium carbonate mostly disseminated but some thread

Table 16. continued ..

lime and soft nodules.

On July 24-25, 1969, six Fertilizer Trial plots were studied in Gallatin County for the purpose of identifying and classifying the soils. Personnel participating in this study included:

Bud Giese, State Soil Scientist, SCS
Fred Boettcher, Soil Scientist, SCS
Gerald Nielsen, Plant & Soils Department, MSU
Grant D. Jackson, Plant & Soils Department, MSU
James R. Sims, Plant & Soils Department, MSU

Detailed soils descriptions were taken at two of the sites and soils at the other sites were studied sufficiently to note differences from the typical.

Stop #1:

Soil type: Amsterdam silt loam
Location: John Hamilton farm - Dry Creek Bench
Vegetation: Winter wheat (Cheyenne)
Classification: Typic Cryoboroll - fine, silty, mixed family
Parent Material: Loess
Physiography: Rolling bench land
Relief: Smooth
Elevation: 4800 feet
Slope: 4 percent
Aspect: Southeast
Erosion: Estimated 5 to 7 inches removed
Permeability: Moderate
Moisture: Dry in upper 10 inches, moist below
Climate: 13 - 15 inches annual precipitation
Ground Water: Very deep
Root distribution: Plentiful to 60 inches, few below
Stoniness: None
Described by: B. Giese and F. Boettcher

Soil Profile: Amsterdam silt loam

Ap 0-7" Dark grayish brown (10YR 4.4/2/4) silt loam, very dark
 grayish brown (10YR 3/2.5) moist; weak fine and medium

Table 16. continued..

		subangular blocky structure with moderate fine platy in the lower parts hard, friable, slightly sticky and slightly plastic; few fine vesicular and tubular and many root pores; pH 8.4; slight effervescence with dilute HCl in spots; abrupt smooth boundary.
B ₂ Ca	7-15"	Very pale brown (10Yr 7/3 and 8/3) silt loam, brown (10YR 5/3) and light gray (10YR 7/2) moist; weak and moderate medium prismatic structure breaking to moderate fine and medium subangular blocks; hard, friable, slightly plastic and slightly sticky, very strongly calcareous with few lime segregations and cicada casts; many very fine roots and pores; pH 8.4; clear wavy boundary.
C ₁	15-29"	Very pale brown (10YR 7/3 and 8/3) silt loam, brown (10YR 5/3) and light gray (10YR 7/2) moist; weak medium and coarse prismatic structure; slightly hard, very friable, slightly sticky and slightly plastic; strongly calcareous with few lime segregations and cicada casts; many very fine roots and pores; pH 8.6; gradual wavy boundary.
C ₂	29-41"	Very pale brown (10YR 7/3) silt loam, brown (10YR 5/3) moist; massive; soft, very friable, very slightly sticky and very slightly plastic; strongly calcareous; pH 8.8; gradual wavy boundary; common fine and very fine root pores.
C ₃	41-60"	This horizon is identical to C ₂ above except for having few fine and very fine roots and pores.

Stop #2

Soil type: Amsterdam silt loam

Location: John Kuiper farm southwest of Manhattan

Classification: Typic Cryoboroll - fine silty, mixed family

Vegetation: Winter wheat

Parent Material: Loess

Physiography: Uniform sloping bench

Relief: Smooth

Table 16. continued..

Elevation: 4400 feet
Slope: 3 percent
Aspect: North
Erosion: Estimated 5 to 7 inches removed
Permeability: Moderate
Moisture: Dry in upper 7 inches, moist below
Climate: 12 - 14 inches annual precipitation
Ground Water: Very deep
Root distribution: Plentiful to 48 inches, few below
Stoniness: None
Described by: B. Giese and F. Boettcher

Remarks: This profile has 37 inches of loess mantle over very strongly calcareous gravelly heavy silt loam. This profile also becomes more calcareous with depth and lacks lime segregation above 37 inches.

Stop #3

Soil type: Amsterdam silt loam
Location: Avery Bates farm, 3 miles west of Amsterdam
Vegetation: Winter wheat
Classification: Typic Cryoboroll - fine silty, mixed family
Parent Material: Loess
Physiography: Uniform sloping bench
Relief: Smooth
Elevation: 4800 feet
Slope: 2 percent
Aspect: East
Erosion: Estimated 5 to 7 inches removed
Permeability: Moderate
Moisture: Dry in upper 7 inches, moist below
Climate: 13 - 15 inches annual precipitation
Ground water: Very deep
Root distribution: Plentiful to 50 inches, few below
Stoniness: None
Described by: B. Giese and F. Boettcher

Remarks: This profile differs from Stop #1 in having a very fine sandy loam texture below 28 inches.

Table 16. continued ..

Stop #4

Soil type: Amsterdam silt loam
Location: Virgil Bates farm west of Anceney

Remarks: This profile differs from Stop #1 in being uniformly calcareous at the surface.

Stop #5

Fort Ellis Agricultural Experiment Station east of Bozeman.
This stop was made primarily to observe a profile of the Bozeman silty clay loam. This soil is representative of the Bozeman series.

Stop #6

Soil type: Unnamed loam
Location: Jack Cooper farm, southeast of Willow Creek
Vegetation: Winter wheat
Classification: Typic Cryoboroll - fine loamy, mixed
Parent Material: Loess over old alluvium
Physiography: Old terraces
Relief: Smooth
Elevation: 4500 feet
Slope: 1 percent
Aspect: Northwest
Erosion: Estimated 5 to 7 inches removed
Permeability: Moderate
Moisture: Dry in upper 7 inches, moist below
Climate: 11 - 13 inches annual precipitation
Ground water: Very deep
Root distribution: Plentiful to 33 inches, few below
Stoniness: None
Described by: B. Giese and F. Boettcher

Soil Profile: Unnamed loam

Ap ₁	0-3"	Grayish brown (10YR 5/2) loam, dark brown (10YR 3/3) moist; weak medium and fine subangular blocky structure; slightly hard, friable, slightly sticky and
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Table 16. continued ..

		plastic; pH 8.4; many fine roots and pores; strongly calcareous; clear smooth boundary.
Ap ₂	3-7"	Grayish brown (10YR 5/2) loam, very dark grayish brown (10YR 3/2) moist; moderate coarse platy structure; slightly hard, friable, slightly sticky and slightly plastic; many roots that tend to follow horizontal planes of platy structure; few fine pores; strongly calcareous; pH 8.4; abrupt smooth boundary.
B ₂ ca	7-23"	Light gray (10YR 7/2) silt loam, pale brown (10YR 6/3) moist; weak medium and coarse prismatic structure; slightly hard, very friable; slightly sticky and slightly plastic; many fine and very fine roots and pores; very strongly calcareous; pH 8.4; gradual wavy boundary.
IIc ₁ ca	23-33"	Very pale brown (10YR 7/3) silt loam, light brownish gray (10YR 6/2) moist; massive; hard, friable, slightly sticky and slightly plastic; many very fine and fine roots concentrated in pockets; very strongly calcareous; pH 8.4; gradual wavy boundary.
IIIc ₂ ca	33-50"	Very pale brown (5Y 7/3 and 8/3) clay loam, 70% brown (5Y 5/3) and 30% very pale brown (5Y 7/3) moist; massive; hard, friable, slightly sticky and slightly plastic; 15 to 30% gravels of 2mm to 3 inch size; very few fine roots, common fine pores; strongly to very strongly calcareous; pH 8.2; gradual wavy boundary.
IIIc ₃ ca	50-60"	Very pale brown (5Y 7/3 and 8/3) coarse sandy loam, brown (5Y 5/3) and very pale brown (5Y 7/3) moist; massive; hard friable, slightly sticky and slightly plastic; 1/8 to 1/2 inch thick, with horizontal lenses of gypsum; few quartzitic gravels; no roots; common fine pores; strongly calcareous; pH 8.2.
Remarks:	1.	At base of the B ₂ ca horizon at the lithologic discontinuity there is a slight increase in clay content. Roots are concentrated along vertical ped faces. Vertical pores have some dark brown coatings that look like clay films. Many fine roots and many fine pores.

Table 16. continued..

2. In IIc₁ca horizon - roots are concentrated in pockets.
3. In IIIc₃ca horizon - horizontal 1/8 to 1/2 inch thick lenses of white gypsum.

Table 17. Procedure for the determination of soil organic matter

Equipment: Oxidation racks containing 10 - 125 ml Erlenmeyer Flasks, Filter tube racks, filter paper, balance and colorimeter.

Reagents: 1 N Potassium dichromate ($K_2Cr_2O_7$) - Weigh 98.08 g of potassium dichromate into a 2 liter volumetric flask, dissolve in about 1000 ml of distilled water and bring to volume.

Concentrated Sulfuric Acid (H_2SO_4)

Distilled Water

Procedure: (The following method must be correlated with the titration method of Walkley and Black, 1947, Soil Science 63:251). The following method was modified by J. Sims and V. Haby (unpublished from Graham, (Soil Science 65:181 (1948) and Carolan, Soil Science 66:241 (1948)),

1. Weigh 1 g of soil into each oxidation flask.
2. Add 10 ml of 1 N $K_2Cr_2O_7$.
3. Add 20 ml of conc H_2SO_4 and allow to react 20 minutes.
4. Add water to bring the volume to 100 ml.
5. Filter into filtration tubes.
6. Analyze on the "Spectronic 20" colorimeter at 600 m μ *

* Note: The colorimeter is equipped with a flow-through cuvette having a 1.3 cm light path.

** If the % OM in the sample is > 7.0 , use $\frac{1}{2}$ g of soil; if less than 1.5% use 2 g of soil. The correlation follows Beer's law between 1.5 and 7.0% OM..

Table 18. Selected chemical properties of the soil samples from the seven locations used in this study.^{1/}

Loc	pH	E.C. mmhos/cm	O.M. %	Avail P		K ^{2/} ppm	Ca ^{2/} meg/ 100g	Na ^{2/} meg/ 100g	Mg ^{2/} meg/ 100g
				NaHCO ₃ ppm	Bray ppm				
1	7.8	0.8	3.9	3.3	15	540	>12.0	0.6	6.2
2	7.7	0.8	3.6	6.2	40	700	>12.0	0.7	4.6
3	7.8	0.9	3.7	6.2	45	960	>12.0	0.6	3.4
4	7.8	1.2	3.0	5.7	25	620	>12.0	0.7	3.2
5	7.8	0.8	3.7	5.7	25	620	>12.0	0.7	5.4
6	7.2	0.6	4.1	7.4	37	600	>12.0	0.6	6.2
7	6.7	1.3	5.2	12.8	43	420	>12.0	0.8	6.0

^{1/} Methods are described in the Materials and Methods section; 0 to 6" sampling depth.

^{2/} Neutral - N NH₄OAc extractable cations.

Table 19. Available soil water at various depth intervals at the seven locations used in this study as determined at the time of fertilizer application.

Depth ft	Location						
	1	2	3	4	5	6	7
	Inches of water						
0-3	4.14	5.45	4.78	0.84	4.53	4.20	3.28
0-4	5.56	6.40	5.41	1.02	4.90	5.60	4.69
0-5	6.62	7.23	6.35	1.16	5.13	6.85	6.04
0-6	7.69	8.16	7.77	1.16	5.77	7.94	7.56

Table 20. Precipitation from May 2 to Aug 5, 1969 at the seven locations used in this study.

Date	Location						
	1	2	3	4	5	6	7
	Inches of water						
5 - 2	0.32	0.11	0.11	0.19	0.08	0.00	0.00
5 - 9	0.17	0.03	0.05	0.14	0.00	0.13	0.00
5 - 16	0.50	0.34	0.48	0.66	0.64	0.33	0.31
5 - 23	0.34	0.40	0.22	0.70	0.21	0.38	0.32
5 - 29	0.17	0.15	0.20	0.32	0.07	0.00	0.01
6 - 4	0.93	1.50	0.87	0.72	0.67	0.99	1.10
6 - 16	0.30	1.90	1.55	1.75	1.08	2.64	2.25
6 - 23	0.09	0.15	0.25	0.25	0.16	0.35	0.67
6 - 30	3.30	2.70	2.65	3.45	4.16	4.05	5.35
7 - 8	0.37	0.31	0.37	0.49	0.63	0.39	0.73
7 - 16	0.37	0.15	0.11	0.23	0.10	0.87	0.90
7 - 22	0.00	0.00	0.00	0.00	0.22	0.00	0.00
7 - 29	0.09	0.29	0.11	0.06	0.12	0.10	0.06
8 - 5	0.00	0.04	0.00	0.07	0.00	0.08	0.00
Total	6.95	8.07	6.97	8.97	8.14	10.31	11.69

Table 21. Accumulative pan evaporation for the seven locations used in this study.

Date	Location						
	1	2	3	4	5	6	7
Inches of water							
5 - 2	0.95	1.63	2.15	2.94	2.21	-	-
5 - 9	2.51	3.04	4.15	4.21	3.76	1.69	-
5 - 16	3.75	4.62	5.67	5.69	5.46	3.61	2.25
5 - 23	4.54	5.57	6.72	6.63	6.59	4.97	3.63
5 - 29	6.06	7.11	8.32	8.01	8.13	6.94	5.31
6 - 4	6.86	8.07	9.45	8.97	9.34	8.16	6.30
6 - 16	8.66	9.56	11.34	10.47	11.57	10.39	7.84
6 - 23	9.65	10.67	12.60	11.47	12.97	11.68	8.79
6 - 30	10.13	11.07	13.01	12.34	14.42	12.83	9.19
7 - 8	11.13	12.18	14.10	13.20	15.76	14.16	9.68
7 - 16	12.35	13.64	15.90	14.83	17.47	15.50	10.88
7 - 22	13.38	14.80	17.32	16.16	19.18	16.53	11.51
7 - 29	14.51	16.37	17.08	18.30	20.99	17.62	12.03
8 - 5	16.02	17.93	20.86	20.71	23.15	19.08	12.97

Table 22. Soil temperature data at a depth of 50 cm at the seven locations used in this study.

Date	Location						
	1	2	3	4	5	6	7
	C°						
5 - 2	6	5	5	7	6	5	7
5 - 9	10	9	10	10	10	9	-
5 - 16	11	11	11	11	11	11	11
5 - 23	12	11	11	12	12	11	11
5 - 29	13	14	13	13	15	14	14
6 - 4	14	15	15	15	15	15	15
6 - 16	13	13	13	13	14	14	13
6 - 23	15	14	15	15	16	15	15
6 - 30	13	13	13	12	13	12	12
7 - 8	14	14	14	14	15	14	14
7 - 16	15	16	17	16	18	18	14
7 - 22	19	19	20	20	20	20	17
7 - 29	19	20	20	21	22	20	18
8 - 5	20	21	21	21	24	21	18
Mean	13.9	13.9	14.1	14.3	15.1	14.2	13.9
Mean 5 ^{1/}	10.4	10.0	10.0	10.6	10.8	10.0	10.8
Mean 6 ^{2/}	13.8	13.8	14.0	13.8	14.5	14.0	14.3
Mean 5 6 ^{3/}	11.9	11.7	11.8	12.0	13.3	11.8	12.5
Mean 7 ^{4/}	16.7	17.3	17.8	17.8	18.8	18.0	13.3
Mean 6&7 ^{5/}	15.3	15.5	15.9	15.8	16.6	16.0	15.0

- ^{1/} Calculated for the month of May
^{2/} Calculated for the month of June
^{3/} Calculated for the months of May and June
^{4/} Calculated for the month of July
^{5/} Calculated for the months of June and July

Table 23. Total winter wheat yield for the various fertilizer treatments at the seven locations used in this study.

Trt lb N/A	Location							Mean
	1*	2*	3	4	5**	6	7	
	lb/A							
0.0	7135	6081	7787	8748	3611	8373	10071	1401
6.7	8016	7117	8166	9347	3559	7122	10005	7619
13.3	6893	6789	7959	8821	3559	8171	10693	7555
20.0	6530	8171	8244	9384	5147	7727	10156	7908
26.7	7705	7842	8763	10381	4975	7425	10193	8183
33.3	7895	8309	8089	9220	5683	9180	10935	8473
40.0	8031	8033	7726	10255	6081	8938	10676	8534
46.7	7670	8171	8372	10600	6668	9242	10141	8695
Mean	7484	7564	8138	9595	4910	8272	10359	

* Significant difference between treatments $p = .05$.

** Significant difference between treatments $p = .01$.

Table 24. Test weight for the various fertilizer treatments at the seven locations used in this study.

Trt lb N/A	Location							Mean
	1	2	3	4	5	6	7	
	lbs/bu							
0.0	64.0	62.8	63.6	63.3	60.6	62.4	62.4	62.7
6.7	63.9	63.4	63.5	63.8	61.4	62.2	62.2	62.9
13.3	64.3	63.5	63.5	62.8	61.1	62.5	62.1	62.8
20.0	64.0	63.3	63.6	63.3	61.1	62.2	62.2	62.8
26.7	64.1	63.4	63.5	62.9	61.1	62.1	62.2	62.8
33.3	64.0	63.3	63.4	63.3	61.2	62.5	62.2	62.8
40.0	64.0	63.3	63.4	63.1	61.6	62.2	62.2	62.8
46.7	64.0	63.0	63.4	63.0	61.9	62.4	62.1	62.8
Mean	64.0	63.3	63.5	63.2	61.3	62.3	62.0	

Table 25. Percent N in the straw for the various fertilizer treatments at the seven locations used in this study.

Trt lb N/A	Location							Mean
	1	2	3	4	5	6*	7	
	% N ^{1/}							
0.0	0.17	0.15	0.17	0.14	0.13	0.23	0.14	0.16
6.7	0.16	0.15	0.19	0.14	0.14	0.31	0.14	0.18
13.3	0.18	0.15	0.16	0.13	0.10	0.28	0.14	0.16
20.0	0.20	0.17	0.18	0.13	0.13	0.25	0.16	0.17
26.7	0.18	0.17	0.17	0.16	0.11	0.27	0.16	0.17
33.3	0.19	0.13	0.21	0.15	0.13	0.28	0.15	0.18
40.0	0.18	0.16	0.19	0.17	0.14	0.31	0.14	0.18
46.7	0.20	0.17	0.22	0.17	0.14	0.29	0.15	0.19
Mean	0.18	0.16	0.19	0.15	0.13	0.28	0.15	

* Significant difference between treatments $p = .05$.

^{1/} Dry weight basis

Table 26. Percent protein in the grain for the various fertilizer treatments at the seven locations used in this study.

Trt lb N/A	Location							Mean
	1*	2*	3*	4**	5	6*	7**	
	% protein $\frac{1}{5}$							
0.0	11.7	10.0	12.3	10.2	8.1	14.1	10.6	11.0
6.7	11.6	10.5	12.5	10.3	8.0	14.6	11.1	11.20
13.3	12.4	10.1	11.4	10.7	8.0	15.0	10.7	11.2
20.0	12.5	10.5	12.1	10.5	8.8	14.6	11.1	11.4
26.7	12.4	10.3	12.1	11.4	8.3	15.1	11.3	11.6
33.3	13.3	10.8	12.9	10.1	8.0	14.7	11.5	11.6
40.0	12.7	10.8	12.3	11.6	8.2	15.0	11.3	11.7
46.7	13.1	11.1	13.4	11.6	8.5	14.9	11.5	12.0
Mean	12.5	10.5	12.4	10.8	8.2	14.7	11.1	

* Significant difference between treatments $p = .05$

** Significant difference between treatments $p = .01$

$\frac{1}{5}$ % N $\times$ 5.7 = protein (dry weight basis)

Table 27. Available soil water at the seven locations used in this study as determined at harvest time.

0.0 lb N/A Trt Depth ft	Location						
	1	2	3	4	5	6	7
	Inches of water						
0-1	0.03	0.12	---	---	0.64	0.13	-
1-2	0.09	-	-	-	0.61	0.03	-
2-3	0.01	0.27	-	-	1.83	-	0.07
3-4	0.59	0.66	-	-	0.22	-	0.46
4-5	-	0.87	0.37	-	0.50	0.53	0.61
5-6	0.98	1.13	0.40	0.20	0.71	0.84	1.03
Total	1.70	3.05	0.77	0.20	4.51	1.53	2.17
<u>46.7 lb N/A Trt</u>							
0-1	-	0.10	-	-	0.41	-	-
1-2	-	-	-	-	0.05	-	-
2-3	-	0.06	-	-	0.16	-	-
3-4	0.31	0.44	-	-	0.19	-	0.06
4-5	0.82	0.76	1.89	-	0.41	0.34	1.15
5-6	0.89	1.08	1.76	1.40	0.62	0.86	1.11
Total	2.02	2.44	3.65	1.40	1.84	1.20	2.32

Table 28. Soil NO₃-N content at the seven locations used in this study as determined at harvest time.^{1/}

0.0 lb N/A Trt	Location						
Depth	1	2	3	4	5	6	7
	lb. N/A						
0-6"	2	2	5	0	3	2	1
6-12"	0	1	6	0	2	0	0
1-2'	2	0	6	0	4	0	0
2-3'	2	0	6	2	0	0	0
3-4'	0	0	4	2	0	0	0
4-5'	0	0	8	6	2	0	0
5-6'	4	4	6	4	4	0	4
6-7'	2	2	4	0	4	0	4
7-8'	2	2	-	0	4	0	4
8-9'	2	4	-	0	6	0	6

46.7 lb N/A	Trt						
	1	2	3	4	5	6	7
0-6"	1	2	17	2	3	5	3
6-12"	0	0	5	0	2	1	1
1-2'	0	0	6	2	0	1	2
2-3'	4	0	2	2	0	16	4
3-4'	0	2	0	4	0	4	4
4-5'	2	2	2	2	0	0	4
5-6'	6	4	4	2	4	0	6
6-7'	4	4	4	2	4	0	6
7-8'	0	4	-	2	0	0	8
8-9'	0	4	-	2	0	0	16

- Indicates data unavailable

^{1/} Phenoldisulfonic acid method

LITERATURE CITED

1. American Association of Cereal Chemists. 1962. Cereal Laboratory methods. (7th Edition). The Association, St. Paul, Minn.
2. Baier, W. and G. W. Robertson. 1967. Estimating yield components of wheat from calculated soil moisture. Can. J. Plant Sci. 47:617-630.
3. Bremner, J. M. 1965. Total nitrogen. p. 1149-1178. In C. A. Black (ed). Methods of Soil Analysis. Part II. American Society of Agronomy, Inc., Madison, Wisconsin.
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, Wisconsin.
5. Burleigh, J. R., R. E. Allan and O. A. Vogel. 1964. Effect of temperature on coleoptile elongation in eight wheat varieties and selections. Agron. J. 56:523-524.
6. 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.
7. Dreier, A. F., D. J. Sander. P. H. Grabouski and L. A. Daigger. 1969. Winter wheat and rye fertilizer experiments in Nebraska 1968. Nebraska Agr. Exp. Sta. Dut-state Testing Circular, 133.
8. Eastoe, J. E. and A. G. Pollard. 1950. A modified phenoldisulfonic acid method for determining nitrates in soil extracts. J. Sci. Food Ag. 1:266-269.
9. Eck, H. V. and B. B. Tucker. 1968. Winter wheat response to nitrogen as affected by soil and climatic factors. Agron. J. 60:663-666.
10. Fisher, F. L., E. R. Ibert and H. F. Beckman. 1958. Inorganic nitrate, nitrite or nitrate-nitrite. Rapid colorimetric determination of microgram quantities in aqueous solution. Anal. Chem. 30:1972-1974.
11. Geist, J. M., J. O. Reuss and D. D. Johnson. 1970. Prediction of nitrogen fertilizer requirements of field crops. II. Appli-

- cation of theoretical models to malting barley. Agron. J. 62:385-389.
12. Kittams, H. A., C. M. Smith and R. T. Choriki. 1966. Nitrogen for dryland wheat consistently boosts yield in all parts of the state. Montana Farmer-Stockman, March 3, 1966, p. 17.
 13. Leggett, G. E. 1959. Relationships between wheat yields, available moisture, and available nitrogen in eastern Washington dryland areas. Washington Agr. Exp. Sta. Bul. 609.
 14. Lehane, J. J. and W. J. Staple. 1962. Effects of soil moisture tensions on growth of wheat. Can. J. Soil. Sci. 42:180-188.
 15. Lehane, J. J. and W. J. Staple. 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.
 16. Lewis, D. G. 1961. Determination of inorganic nitrogen in soil. J. Sci. Food Ag. 12:735-742.
 17. Lowe, R. H. and J. L. Hamilton. 1967. Rapid method for determination of nitrate in plant and soil extracts. J. Ag. Food Chem. 15:359-361.
 18. Middleton, K. R. 1959. The use of the orange I method for determining soil nitrates and a comparison with phenoldisulfonic acid method for certain soils of northern Nigeria. J. Sci. Food Ag. 10:218-224.
 19. Montana Agricultural Experiment Station. 1963. Procedures used in the soil testing laboratory. Mimeographed Circular No. 50. Bozeman, Montana.
 20. Myers, R. J. K. and E. A. Paul. 1968. Nitrite ion electrode method for soil nitrate nitrogen. Can. J. Soil. Sci. 48:369-391.
 21. Nelson, J. L., L. T. Kurt and R. H. Bray. 1954. Rapid determination of nitrates and nitrites. Anal. Chem. 26:1081-1082.
 22. Pelton, W. L. 1967. The effect of a windbreak on wind travel, evaporation and wheat yield. Can. J. Plant Sci. 47:209-214.
 23. Schlehuber, A. M. and B. B. Tucker. 1967. Culture of wheat. p. 117-176. In K. S. Quisenberry and L. P. Reitz (ed). Wheat

and wheat improvement. American Society of Agronomy, Madison, Wisconsin.

24. 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.* 61:785-787.
25. Smith, J. A. 1966. An evaluation of nitrogen soil test methods for Ontario soils. *Can. J. Soil Sci.* 46:185-194.
26. Staple, S. J. and J. J. Lehane. 1965. The influence of field shelter belts on wind velocity, evaporation, soil moisture and crop yield. *Can. J. Ag. Res.* 35:440-453.
27. Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc. New York.
28. Stewart, B. A. and C. J. Whitfield. 1965. Effects of crop residue, soil temperature and sulfur on the growth of winter wheat. *Soil Sci. Soc. Am. Proc.* 29:752-755.
29. Thompson, L. M. 1969. Weather and technology in the production of wheat in the United States. *J. Soil and Water Cons.* 24:214-224.
30. Wantabe, F. S. and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorous in water and NaHCO_3 extracts in soil. *Soil Sci. Soc. Am. Proc.* 29:677-678.
31. West, P. W. and G. T. Tyler. 1960. A new method for the determination of nitrates. *Anal. Chem. Acta.* 23:227-232.
32. Williams, G. D. V. and G. W. Robertson. 1965. Estimating most profitable prairie wheat production from precipitation data. *Can. J. Plant Sci.* 45:34-39.
33. Woolley, D. G. 1963. Effects of nutrition, osmotic pressure, and temperature of the nutrient solution on plant growth and chemical composition. *Can. J. Plant Sci.* 43:44-49.
34. Young, R. A., J. L. Ozburn, A. Bauer and E. J. 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.

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