



Effect of topdressed N fertilizer, available water, and soil conditions on dryland winter wheat (*Triticum aestivum* L.) production  
by Gordon Edgar Warrington

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:**

Field trials at 23 locations in central Montana were used to evaluate response of dryland winter wheat to spring topdressed N fertilizer, available moisture, and other soil and environmental properties. Plots were located only on soils classified as Danvers clay loam or. Sipple silt loam which helped to keep soil variability at a minimum. Ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) fertilizer was applied to the test plots using 0, 20, 40, 60, and 80,1b N/A. All locations were evaluated for stored moisture and growing season precipitation. The results were evaluated using simple linear and multiple linear correlation and regression.

Locations with 2.0 inches available spring soil moisture showed no response to N topdressing. With 2.0 inches or more of available spring soil moisture, response to N fertilizer increased with increasing soil moisture. Locations with 4.29 to 5.07 inches of available spring soil moisture responded the most to N fertilizer. Growing season precipitation had a nonsignificant relationship for most plant and grain factors measured. Soil- $\text{NO}_3\text{-N}$  at topdressing was positively correlated with % grain protein, and total grain N, and was negative correlated with kernel weight and test weight. Depth to the lime zone was positively correlated with grain yield, total grain N, and kernel weight. Percent organic matter was negatively correlated with kernel weight and test weight. Available soil P was positively correlated with these two characteristics.

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144

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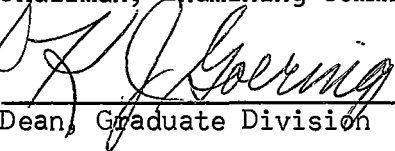
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Approved:

  
Head, Major Department

  
Chairman, Examining Committee

  
Dean, Graduate Division

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ABSTRACT

Field trials at 23 locations in central Montana were used to evaluate response of dryland winter wheat to spring topdressed N fertilizer, available moisture, and other soil and environmental properties. Plots were located only on soils classified as Danvers clay loam or Sipple silt loam which helped to keep soil variability at a minimum. Ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) fertilizer was applied to the test plots using 0, 20, 40, 60, and 80 lb N/A. All locations were evaluated for stored moisture and growing season precipitation. The results were evaluated using simple linear and multiple linear correlation and regression.

Locations with 2.0 inches available spring soil moisture showed no response to N topdressing. With 2.0 inches or more of available spring soil moisture, response to N fertilizer increased with increasing soil moisture. Locations with 4.29 to 5.07 inches of available spring soil moisture responded the most to N fertilizer. Growing season precipitation had a nonsignificant relationship for most plant and grain factors measured. Soil  $\text{NO}_3\text{-N}$  at topdressing was positively correlated with % grain protein, and total grain N, and was negative correlated with kernel weight and test weight. Depth to the lime zone was positively correlated with grain yield, total grain N, and kernel weight. Percent organic matter was negatively correlated with kernel weight and test weight. Available soil P was positively correlated with these two characteristics.

## INTRODUCTION

Under dryland conditions, wheat production is often limited by the water supply. However, there are periods of favorable moisture conditions during which the nutrient level in the soil is the factor limiting production. Therefore, it may be desirable to use fertilizers to supply the nutrient(s) in which the soil is deficient.

The use of fertilizer may increase the total amount of water used by a crop which may or may not be desirable. Viets (36) summarized the situation as follows: "Whether fertilizers increase consumptive use [of water] not at all or only slightly, all evidence indicates that water-use efficiency, or dry matter produced per unit of water used, can be greatly increased if fertilizers increase yield. So fertilization for the adequate nutrition of all crops plays a major role in the efficient use and conservation of water resources."

With present knowledge it is difficult to predict the fertilizer needs for a given area. A successful program to determine economical levels of fertilization for increased yields requires field studies of several variables. At the same time, measuring uncontrolled factors may help provide a basis for making future fertilizer recommendations.

Montana currently ranks 4th<sup>a/</sup> in total wheat yield among the major wheat producing states. With most of the wheat grown under dryland conditions, it is necessary to know how and at what times water and fertilizer will interact to promote maximum yields. In many of the extensively cropped areas of the state, N is the principle nutrient lacking for crop

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a/ Agricultural Statistics 1966, USDA

production.

Attempts have been made to relate amounts of available water and N to the yield and quality of wheat (8, 10, 13, 17, 29). Some of the studies have been done in the greenhouse and others in the field with only one variable receiving attention. Other workers (3, 9, 30, 40) have tried to elucidate the interaction of N and water on wheat.

Since Montana soil and climatic conditions are different from other areas, experimental work is needed to relate N-moisture interactions with winter wheat production. A fertilization experiment was designed to study various levels of available moisture and spring applied N on wheat production in the Judith Basin area of Montana.

## LITERATURE REVIEW

### Soil Water:

The distribution of water within soils depends mainly on the properties of individual soils such as texture, structure, and soluble salts. Texture influences the water holding capacity by the number and size of pores which will retain water at various tensions (20, 21). Aggregation and structural development will reduce water storage capacity and improve aeration by increasing macropore space and reducing the micropore volume (20). An increase in the salt content of a soil will result in an increase in the soil moisture content at the permanent wilting point of a soil (14, 20). The water content of a soil is related to other physical properties of soil and water such as hydraulic conductivity, matric suction, and vapor pressure (14). Measuring the adsorption and desorption of soil water results in a smooth continuous function from field capacity to permanent wilting point of a soil. The absence of discontinuities indicates that there is no sharp distinction between the forces involved at successive stages of wetting. Therefore, the energy required to remove a given amount of water from a soil is dependent on the combined soil and water properties.

### Plant Water:

Water is needed by plants for transpiration, as a solvent, and for some biochemical reactions. In terms of the amount of water used for the various function, transpiration requires the most. When water is not limiting, the rate of transpiration is determined by  $\text{CO}_2$  concentration, light intensity, temperature, and plant turgidity (21). Plants adapt to

a condition of moisture stress by reducing transpiration through turgor induced changes in the stomatal aperture (21, 34). When the stomata close, resistance to  $\text{CO}_2$  diffusion increases with a reduction in the rate of photosynthesis (22). As photosynthesis decreases, respiration increases and continues until the hydrolysis of starch has depleted the food reserves of the plant (21). A moisture stress of short duration will reduce the growth of a plant (16, 21). Over a long period of time, various hardening processes occur such as reduced cell size, increased protoplasmic viscosity, and decreased epidermal permeability thereby conserving the available water.

#### Plant-Soil Water:

The water in a soil is not equally available to plants over the range from field capacity to the permanent wilting point. Gingrich and Russell (16) found that growth of corn seedlings was reduced as soil moisture tension increased from 1 to 3 bars. However, in mannitol solutions of similar tensions the plants grew normally. From this they concluded that the growth reduction in the soil system was the result of reduced water conductivity. Soil temperature affects both plant growth and the amount of available water in the soil. A decrease in soil temperature results in slightly more water being retained at a given tension due to an increase in the viscosity of water (20, 21). The decrease in root ramification and rate of water uptake by plants probably has a significant effect on the water budget at low temperatures. Other factors affecting plant-soil moisture relationships are growth stage, rooting

characteristics, and drought resistance. Climatic factors such as wind velocity, humidity, and temperature influence the water requirements of plants (21).

Various workers (10, 13, 17) have observed that depth of soil moisture in the spring is a reliable guide for predicting the grain yield of wheat with the assumption that growing season precipitation will be approximately normal. Brengle (8) reported that if a moisture deficit occurred during tillering stage of wheat growth, the crop would not recover its full potential even if moisture was adequate during the remainder of the growing season. He also found a significant negative correlation between spring soil moisture and grain protein. Limited moisture may cause a reduction in test weight with an increase in protein due to shriveling of the grain (9, 29).

#### Plant Nitrogen:

Viets (37) states that, "worldwide, more crops are deficient in N than in any other chemical element." With insufficient N, plants cannot adequately synthesize the proteins and enzymes needed for growth and reproduction.

Nitrogen metabolism may be considered as follows: a) Assimilation of N; b) formation of and conversion of amino acids; c) synthesis of amines, peptides and other simple nitrogenous compounds; and d) formation and degradation of proteins and nucleic acids (39). Naftel (28), using nutrient solutions, found that  $\text{NH}_4\text{-N}$  was used in larger amounts than  $\text{NO}_3\text{-N}$  during early growth stages of cotton, wheat, and corn. As the

plants matured, the situation was reversed. Total N absorption was highest when both forms of N were present at about pH 6. When plants absorb N as  $\text{NO}_3^-$ , it is reduced to  $\text{NH}_4^+$  before being synthesized into metabolic compounds (11). Nitrogen is a constituent of chlorophyll, therefore a deficiency limits chlorophyll production. Because the yellow pigments are more prominent the plants become light green or yellow depending on the severity of the N deficiency (23).

Normally, mineralization of soil N must occur in order for organic N to become available for plant use. Ammonia is produced by soil microflora when more N is available than can be assimilated into their protoplasm (32). The oxidation of ammonia to nitrates is a two step microbial process (26, 31). First, ammonia is oxidized by the general group of organisms, Nitrosomonas, to produce nitrite. The nitrite is then oxidized to nitrate by the Nitrobacter group of organisms.

The rate of N mineralization is dependent on soil aeration, moisture, temperature, and pH conditions (1, 2). Russel (32) reports that if the soil is too wet, aerobic microbiological activity is restricted by poor aeration. Under normal conditions, microbial activity does not change much until the wilting point range is reached; then it drops off rapidly. Alexander (1) indicates that the optimum temperature for nitrification occurs between  $30^\circ$  and  $35^\circ$  C. He also gives the optimum pH range as 7 to 9 for most soils.

Bauer et al. (3) report that climatic conditions in North Dakota limit the accumulation of available N on nonfallow soils. Limited summer rainfall leaves the soil dry after harvest and winter temperatures are

are too low for mineralization of N from organic matter. When climatic conditions are favorable for ammonification and nitrification, the processes usually do not proceed rapidly enough to meet the demands of a growing crop. Most of the winter wheat in Montana is grown on fallow ground which has accumulated some nitrate. However, if large amounts of straw residues are incorporated into the soil, N may be unavailable to plants until decomposition of the straw nears completion (2).

#### Winter Wheat:

When N fertilizer is applied to wheat, an increase in grain yield and percent grain protein usually occurs (4, 29). However, there may be a slight decrease in test weight because the grain has a lower percentage of more dense carbohydrate materials. The addition of N to wheat during later growth stages has been observed to increase grain protein but not necessarily yield or test weight (15, 33).

Boatwright and Haas (6) found the N content of the grain was derived mainly by translocation of N from the leaves, stems, and chaff. Samples of above ground tissue taken at six times during plant development showed that the plants contained maximum N at heading. The total amount of N in the plant decreased slightly from heading until maturity while grain N increased with a decrease of N in the leaves, stems and chaff. They concluded that little or no N was absorbed from the soil between heading and maturity if N and P are adequate throughout the season.

The N fertilizer source which will produce the best yields is dependent on the crop and environmental conditions (37). However, ammonium

nitrate seems to be a good source of N when topdressed on dryland winter wheat in the spring. Brengle and Greb (9) found that spring applications of ammonium nitrate on winter wheat in eastern Colorado produced slightly higher yields than ammonium sulfate or urea applications. In Nebraska studies, ammonium nitrate and urea were found by Lowrey et al. (25) to be more effective as spring topdressings than ammonium sulfate. The difference was most pronounced when the soil surface was dry at and following the time of application, but no explanation was given for this effect. According to Brengle et al. (9), spring applications of N should be made before the jointing stage of plant growth. This agrees with N-uptake results presented by Boatwright et al. (6) and Carpenter et al. (12). A greenhouse study with spring wheat showed that N applied at tillering resulted in higher yields than did an equal amount of N applied at planting.<sup>a/</sup>

For the applied N to be most effective, P and the other essential elements should be adequate. Boatwright and Viets (7) used solution cultures to study P absorption during various growth stages of spring wheat. They found plant development was retarded when P was withheld for the first two weeks of growth. Maximum root development was achieved when P was available during the first four weeks of growth. In a field study with spring wheat, Boatwright and Haas (6) found that when P is limiting, N uptake may continue until the soft dough stage of grain development.

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<sup>a/</sup> Warrington, G. E. 1967. A greenhouse study of the response of spring wheat to the time and rate of nitrogen application. Special problem report on file Dept. of Plant and Soil Sci., Montana State University.

Water-Nitrogen Effects:

Stored soil moisture and growing season precipitation have shown various degrees of correlation with wheat yields. In North Dakota Bauer et al. (3) found that as available stored moisture at seeding increased, the amount of rainfall needed to produce a profitable response to N decreased for spring wheat. In this case, the total moisture accounted for 40.3% of the yield response to N. Young et al. (40) reported on the effects of other factors related to the same experiment. Temperature as degree days above 21° C, and NO<sub>3</sub>-N to a depth of 61 cm at seeding and the total soil moisture accounted for 49.7% of the yield response; an improvement significant at the 1% level.

Brengle (8) and Brengle and Greb (9) report that winter wheat response in Colorado was associated with stored soil moisture in the spring. Yield response to N was confined mainly to sandy soils in their trials. On heavier soils, increases in yields were rare, but test weights remained high and were accompanied by an increase in protein. Olson et al. (30) explain that if yield reductions occur from N fertilization in dry farming, they may be due to unnecessary transpiration resulting from the over stimulation of growth. Excess transpiration during early growth could result in limited moisture before maturity. They did find an increase in dryland winter wheat yields occurring as a result of N fertilization on both wet and dry sites in Nebraska.

## MATERIALS AND METHODS

### Location of Test Plots:

Twenty-seven sets of test plots were selected in the wheat growing region of Judith basin and Fergus counties. The criteria for determining the suitability of a site for the experiment were: 1) The soil had to be classified by a standard soil survey as a Danvers clay loam or a Sipple silt loam. 2) The wheat crop had to appear to be of a uniform stand and weed free. 3) The land had to have less than 2.5% slope. 4) The locations would represent the varying rainfall and stored moisture conditions of the area.

Table I gives the names of the cooperators, the legal description of the location of the experimental sites, and other management information obtained from the cooperators. The map (Figure 1) shows the approximate geographic location of the sites.

### Soil Type:

Twenty-two of the experimental units were located on Danvers clay loam and five were located on Sipple silt loam (Table II). The Sipple soil series is found in the Lewistown - Moore area with about 18 inches mean annual precipitation as compared to the Danvers series with 16 inches mean annual precipitation. A few of the experimental units were on a gravelly phase of one or the other soil series. The moisture storage capacity of the gravelly phase was less than the typical soils of these series.

A technical description of the Danvers series is given in Table III. The description of the Sipple series has not been completely determined

Table I. Cooperator, county, legal description, crop variety, planting date, row spacing, fertilizer with seed, and last crop for winter wheat fertilizer experiments, Judith Basin - Fergus counties. 1966.

Loc.	Name	County <sup>a/</sup>	Legal Description	Variety of Grain	Planting Date			Row Spacing Inches	Fertilizer With Seed <sup>b/</sup>		Last Crop <sup>c/</sup>
					Mo	Day	Yr		Lb N	Lb P	
1	Bert Algers	JB	NW $\frac{1}{4}$ S 5T17NR12E	Cheyenne	9	25	65	10	NA	8.9	WWht
2	Bert Algers	JB	NW $\frac{1}{4}$ S33T18NR12E	Cheyenne	9	25	65	10	NA	8.9	WWht
3	John Barber	JB	SW $\frac{1}{4}$ S 2T17NR13E	Cheyenne	9	24	65	10	NA	7.3	WWht
4	Gordon Borcharding	F	NE $\frac{1}{4}$ S33T14NR16E	Winalta	10	5	65	10	4.4	8.5	Bar
5	I. L. Charmical	F	NW $\frac{1}{4}$ S 6T15NR18E	--	--	--	65	10	NA	A	--
6	Bill Cervenka	JB	SW $\frac{1}{4}$ S 5T15NR14E	Winalta	10	7	65	10	NA	7.9	Bar
7	Duane Donaldson	F	NW $\frac{1}{4}$ S29T18NR15E	--	--	--	65	7	NA	NA	--
8	Duane Donaldson	F	NW $\frac{1}{4}$ S 7T18NR15E	--	--	--	65	7	NA	NA	--
9	Howard Donaldson	F	SE $\frac{1}{4}$ S27T17NR15E	Cheyenne	10	3	65	10	NA	7.6	WWht
10	Myron Haker	JB	SW $\frac{1}{4}$ S 6T17NR12E	--	--	--	65	10	NA	NA	--
11	Cliford Heck	F	SW $\frac{1}{4}$ S28T15NR18E	Cheyenne	10	3	65	10	NA	7.6	WWht
12	Max Hertel	F	NE $\frac{1}{4}$ S11T13NR16E	--	--	--	65	10	NA	NA	--
13	John Janicek	F	SE $\frac{1}{4}$ S29T14NR17E	Cheyenne	9	30	65	7	NA	7.6	SWht
14	Orvie Lemond	JB	NE $\frac{1}{4}$ S12T17NR12E	Cheyenne	9	10	65	10	NA	9.0	WWht
15	Leon Linehart	JB	NW $\frac{1}{4}$ S 3T16NR15E	Cheyenne	9	10	65	7	NA	8.9	WWht
16	John Metcalf	JB	SE $\frac{1}{4}$ S23T17NR12E	Cheyenne	10	1	65	10	NA	8.9	WWht
17	Wilson Metcalf	JB	SE $\frac{1}{4}$ S26T16NR14E	Winalta	10	15	65	10	NA	9.9	SWht
18	Tom Moe	F	NW $\frac{1}{4}$ S 5T14NR18E	Cheyenne	10	3	65	7	NA	8.9	Bar
19	Henry Nemec	F	NE $\frac{1}{4}$ S 6T18NR12E	Warrior	10	4	65	10	NA	NA	Bar
20	Bill D. Snapp	F	NE $\frac{1}{4}$ S 4T17NR16E	--	--	--	65	10	NA	NA	--
21	Anton Tesarek	F	NE $\frac{1}{4}$ S 5T18NR13E	Warrior	9	30	65	7	5.5	9.9	Bar
22	Vern Valentine	JB	NW $\frac{1}{4}$ S13T15NR13E	Cheyenne	9	29	65	7	NA	NA	DFal
23	Jack VanKuiken	F	SW $\frac{1}{4}$ S32T18NR13E	Winalta	9	15	65	14	NA	9.9	WWht
24	John Wickens	F	SW $\frac{1}{4}$ S34T20NR18E	Cheyenne	9	20	65	7	NA	NA	WWht
25	John Wickens	F	SE $\frac{1}{4}$ S27T20NR18E	Cheyenne	9	20	65	7	NA	NA	Bar
26	John Wickens	F	SE $\frac{1}{4}$ S22T20NR18E	Cheyenne	9	20	65	7	NA	NA	WWht
27	Herb Zuemke	JB	NE $\frac{1}{4}$ S 2T15NR15E	Winalta	10	5	65	14	4.4	8.4	WWht

a/ JB - Judith Basin county; F - Fergus county. b/ NA - Not applied with seed; A - P applied with seed but amount is missing. c/ WWht - Winter Wheat, Bar - Barley, DFal - Double Fallow, SWht - Spring Wheat.

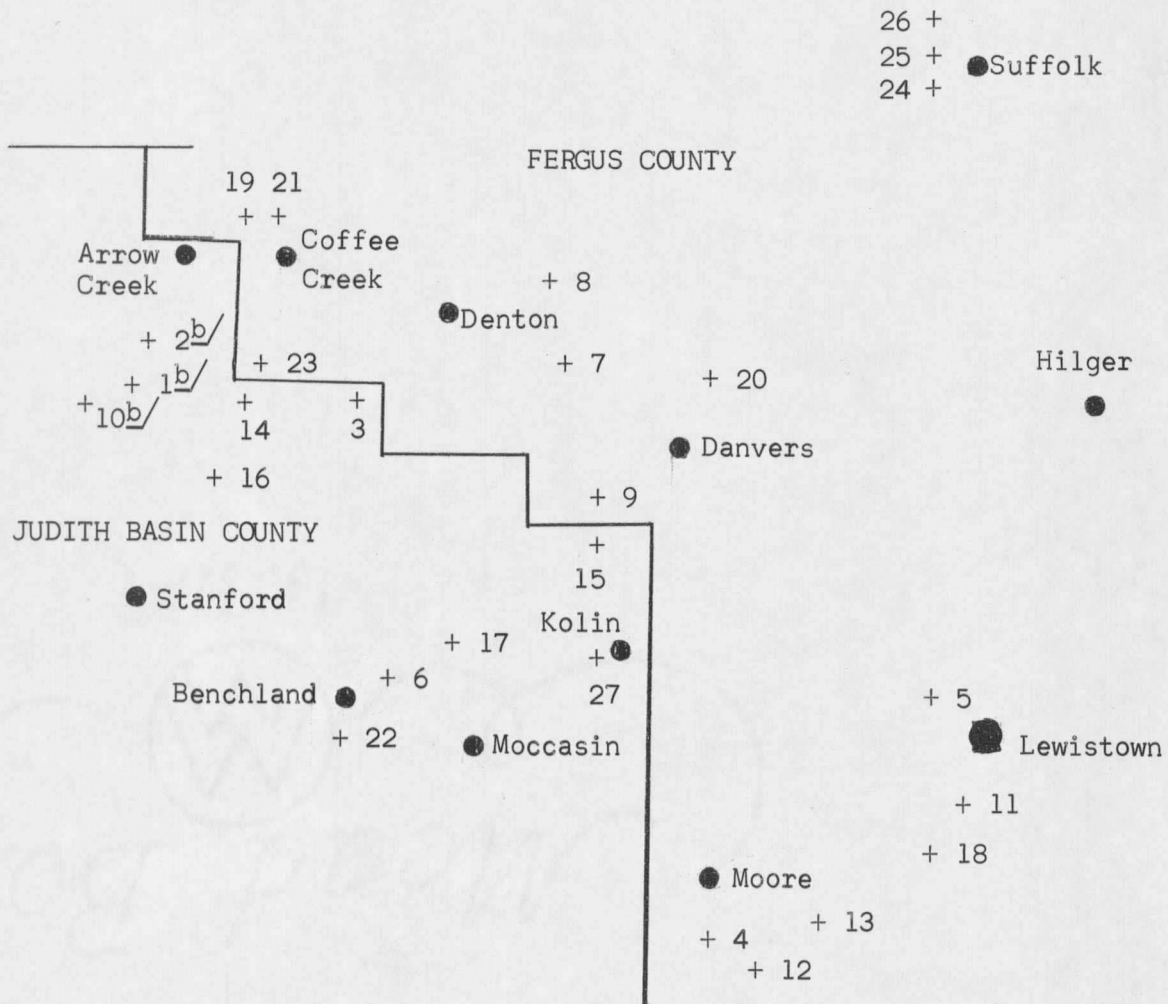


Figure 1. Map showing the approximate locations of the test plots with nitrogen topdressing in the spring of 1966.<sup>a/</sup>

<sup>a/</sup> The numbers refer to the locations indicated in the other tables.

<sup>b/</sup> Locations 1, 2, 10, and 12 were not harvested because of hail damage and weeds.

Table II. Soil physical properties for winter wheat fertilizer experiments, Judith Basin - Fergus counties, 1966.

Loc.	Soil Series Name	Texture	Elevation Ft. MSL.	% Slope	Aspect	Depth to Lime Inches	Soil Temp ° C at 20 inches				Inches Available Soil Water
							April 24	May 19	June 15	July 18	
1	Danvers	SiCL	4000	1.0	S	11	7	10	16	23	2.69
2	Danvers	SiCL	4000	0.0		14	--	12	16	24	4.64
3	Danvers	SiCL	3950	0.0		10	8	--	17	23	1.76
4	Sipple	SiCL	4300	1.0	W	10	7	8	14	26	4.29
5	Danvers	SiL	3900	1.0		16	7	9	15	25	4.47
6	Danvers	SiCL	4250	--	--	9	--	12	15	24	1.21
7	Danvers	SiL	3600	0.5	W	7	10	--	20	24	3.68
8	Danvers	SiCL	3600	2.0	N	10	--	--	18	25	4.87
9	Danvers	SiCL	3900	1.0	W	10	9	9	--	26	3.64
10	Danvers	SiCL	3950	2.5	N	7	7	12	18	25	2.74
11	Sipple	SiL	4200	1.0	E	10	7	9	13	25	3.69
12	Sipple	SiL	4400	0.0		13	9	10	14	24	3.23
13	Sipple	SiCL	4500	1.0	W	12	8	9	15	26	2.02
14	Danvers	SiCL	3800	0.5	N	7	--	11	16	25	3.20
15	Danvers	SiCL	3850	--	--	9	8	10	--	27	3.21
16	Danvers	SiCL	4000	0.5	S	7	8	10	16	25	3.27
17	Danvers	SiCL	4150	0.0		7	9	11	13	24	2.45
18	Sipple	SiCL	4300	0.0		10	--	9	--	--	3.44
19	Danvers	SiL	3700	0.5	N	9	8	11	18	23	2.83
20	Danvers	SiL	3550	0.0		20	9	10	--	24	4.66
21	Danvers	SiCL	3700	1.0	E	14	8	14	17	24	1.31
22	Danvers	SiCL	4300	1.0	N	15	--	12	14	23	2.00
23	Danvers	SiCL	3800	1.5	N	7	--	11	18	25	2.03
24	Danvers	SiCL	3650	1.0	E	20	8	9	16	25	5.07
25	Danvers	SiCL	3600	0.0		14	8	9	20	28	1.28
26	Danvers	SiL	3550	0.5	E	20	8	8	20	29	3.31
27	Danvers	SiCL	4000	0.0		10	10	10	--	29	2.56

Table III. Typical profile of Danvers clay loam (190 feet south and 125 feet west of the NE. corner of sec. 1, T. 18 N., R. 12 E.; in a summer-fallowed strip on a slope of less than 1 percent at an elevation of 3750 feet).<sup>a/</sup>

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Ap	0 to 4 inches, gray (10YR 5/1) clay loam, very dark brown (10YR 2/2) when moist; moderate, medium, granular structure; slightly hard when dry; firm when moist, sticky and plastic when wet; abrupt boundary.
B2t	4 to 10 inches, grayish-brown (2.5Y 5/2) heavy clay loam, very dark grayish brown (10YR 3/2) when moist; compound structure in which moderate, medium prisms separate to medium and fine, subangular blocks; hard when dry, firm when moist, very sticky and very plastic when wet; continuous, distinct clay films on all ped faces; plentiful roots; clear boundary.
B3	10 to 14 inches, gray (10YR 5/1) clay loam that has a moderate amount of fine gravel and is dark grayish brown (10YR 4/2) when moist; moderate, medium, subangular blocky structure; hard when dry, firm when moist, very sticky and very plastic when wet; continuous, distinct clay films on vertical faces and patches of clay films on horizontal faces; slight effervescence; plentiful roots; gradual boundary.
C1ca	14 to 23 inches, gray (10YR 6/1) light clay, grayish brown (10R 5/2) when moist; moderate, medium and fine, subangular blocky structure; hard when dry, firm when moist, very sticky and very plastic when wet; patches of clay films on vertical faces; violent effervescence; few roots; gradual boundary.
C2ca	23 to 34 inches, light-gray (5Y 7/2) light clay, olive gray (5Y 5/2) when moist; massive; slightly hard when dry, friable when moist, very sticky and plastic when wet; violent effervescence; few roots; clear boundary.
IIC3ca	34 to 39 inches, light-gray (5Y 7/2) gravelly sandy clay loam, olive gray (5Y 7/2) when moist; massive; hard when dry, friable when moist, sticky and plastic when wet; violent effervescence; few roots; clear boundary.
IIC4	39 to 50 inches, light-gray (5Y 7/2) very gravelly sandy loam, olive gray (5Y 5/2) when moist; massive; loose when dry, very friable when moist, nonsticky and nonplastic when wet; violent effervescence.

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<sup>a/</sup> Soil Survey, Judith Basin Area, Montana. Series 1959, No. 42, issued January 1967.

for the Judith Basin area but a tentative description of the soil is given in Table IV. Both soils have developed from a combination of alluvium and windblown material overlaying limestone gravels.

Varieties and Cultural Practices:

Three varieties of wheat were used in the experiment. Fourteen locations were planted to Cheyenne, which has fair winter hardiness, but is susceptible to stem rust and shattering. Five locations were planted to Winalta, a winter hardy wheat with excellent milling and baking qualities. It is susceptible to bunt, and leaf and stem rusts. Warrior was grown at two locations and is slightly superior to Cheyenne in winter hardiness (27).

The plots were set out on established stands. Seedling rates, determined by the cooperators, were about 60 lbs/A. Variety, planting date, and row spacing are given in Table I. The variety and planting date were unavailable for six locations.

Experimental Design:

A randomized complete block design with two replications and five treatments was used at each location. This design was chosen to maximize the number of locations and to ensure a wide variation in available moisture. Individual plot size was 16 X 16 feet.

Fertilizer Treatments:

Over half of the cooperators used a fertilizer source of phosphorus (P) at the time of seeding. P was topdressed on the locations not

Table IV. Characteristics of Sipple silt loam (40 feet south and 30 feet west of the NW corner of sec. 26, T. 14 N., R. 16 E.; Fergus county, Montana).<sup>a/</sup>

Physiography: High Bench upland  
 Relief: Level <1% Slope  
 Elevation: 5500 feet  
 Climate:<sup>b/</sup> MAP 18"; MAT 42°F, MEAN July 65°F, MEAN Jan. 20°F.  
 Parent Material: Old Alluvium over limestone gravels

Depth (Inches)	Hor.	Particle Size (MM)(%)				Text. Class	pH Sat. Paste	Organic Matter			CaCO <sub>3</sub> Equiv. %
		Sand	Silt	Clay	>2			O. C. %	N %	C/N	
0-3	Alp	12	52	36	--	SiCL	6.7	4.4	.37	11	--
3-5	A12	15	50	35	--	SiCL	6.5	4.9	.40	12	--
5-7	B1	34	39	27	Tr.	CL	6.4	2.9	.23	12	--
7-13	B21	35	31	34	Tr.	CL	6.6	1.5	.14	11	--
13-15	B22	45	26	29	4	SCL	7.4	1.3	.13	10	2
15-20	B3	56	20	24	6	SCL	8.0	1.1	.10	11	20
20-31	Cca	60	19	21	11	SCL	8.3	0.4	.04	10	20
31-55	Dca	45	28	27	70	CL	8.3	0.2	--	--	57

<sup>a/</sup> Compiled by A. R. Southard. Chemical and Physical Properties of Soil Series in Montana. (1965).

<sup>b/</sup> MAP = Mean Annual Precipitation; MAT = Mean Annual Temperature

receiving P at seeding time. The P was applied as monocalcium phosphate ( $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ ) at the rate of 22 lbs/A concurrently with the N treatment. Potassium fertilizer was not applied due to the high level of available K (Table VI).

The following N rates were used at each location with ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) as the source.

Treatment	Lbs N/A
1	0
2	20
3	40
4	60
5	80

The fertilizer materials were topdressed between March 29 and April 15, 1966. A "Barber" spreader,<sup>a/</sup> which uses a ground driven auger as a metering device, provided a uniform distribution of the fertilizer materials. The spreader was calibrated for the intended rates prior to the time of topdressing.

#### Soil Sampling:

Soil samples for a standard soil analysis were taken from the 0 - 6 inch depth using a Hoeffler tube. The sampling was done between the rows around the outside of the plots at about the same time the fertilizer was applied. Two sets of samples were taken with a King tube in one foot increments for the determination of soil moisture and soil nitrates ( $\text{NO}_3\text{-N}$ ). King tube sampling was limited to the upper two to six feet of the profile because all locations were underlain by gravel at various depths. The

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<sup>a/</sup> Barber Mfg. Corp., Spokane, Washington

samples used for moisture determination were placed in tightly closed cans. The  $\text{NO}_3\text{-N}$  samples were frozen in plastic bags until they could be dried.

During the summer, samples were taken at eleven locations for bulk density (BD) determinations. A hole was opened near the experimental plots and intact units of soil were removed from six inch increments to a depth of 18 or 24 inches. The amount of coarse material at depths greater than 18 inches made it difficult to obtain intact samples.

#### Soil Chemical Properties:

The Soil Testing Laboratory at Montana State University<sup>a/</sup> did the standard soil analyses. The procedures that were used are given in Table V and the results of the analyses are in Table VI. Exchangeable cations were determined for the soils from ten of the locations.

The samples used for  $\text{NO}_3\text{-N}$  determination were dried in a forced draft oven at  $60^\circ\text{C}$ , ground in a porcelain mortar and screened through a 2mm sieve. The nitrate analysis described by Jackson (19) was modified to use 20 gms. of soil and 100 ml. of extracting solution.

The distance to the lime or carbonate in the soil was measured on a sample obtained with a Hoeffler tube. A small amount of 10% HCl solution was placed on the soil, and the presence of lime was determined by noting where strong effervescence occurred (Table II). The boundary between no or weak effervescence and strong effervescence was well defined in most cases.

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<sup>a/</sup> Bozeman, Montana

Table V. Soil analysis procedures used for soil samples

Name of Analysis	Reference of Procedure
i) Conductivity	Montana Agricultural Experiment Station, Plant and Soil Science Department, Mimeographed Circular No. 50, July 1963. Bozeman, Montana
ii) pH	Montana Agricultural Experiment Station, Plant and Soil Science Department, Mimeographed Circular No. 50, July 1963. Bozeman, Montana
iii) Organic Matter	Adapted from: Jackson, M. L., Soil Chemical Analysis. pp. 219-221, Prentice-Hall, Inc. 1958
iv) Available Phosphorus	Smith, F. W. et al., Soil Sci. Soc. Amer. Proc. 21:400-404, 1957
v) Available Potassium	Methods of Soil and Plant Analysis, Oregon State College, November 1954, S-34
vi) Exchangeable Cations	Diagnosis and Improvement of Saline and Alkali Soils, USDA Agriculture Handbook No. 60. 1954
a) K	Method 11a
b) Na	Method 10a
c) Ca + Mg	Method 7

Table VI. Soil chemical properties for winter wheat fertilizer experiments, Judith Basin-Fergus counties, 1966.

Loc	Conduc-		% Organic Matter	Avail-	Avail-	Exchangeable			Total
	M	Mhos		able P	able K	Na	K	Ca+Mg	
		pH		Lb/A	Lb/A	Cations me/100 gms. <sup>a/</sup>			
1	.56	6.6	3.1	52	830				
2	.44	6.2	3.3	70	920	0.2	1.3	22.2	23.7
3	.48	7.3	3.8	60	830				
4	.08	6.5	3.1	42	425	0.2	0.7	22.2	23.1
5	.56	6.7	3.5	65	870				
6	.44	6.0	3.9	60	760	0.1	1.2	24.0	25.3
7	.52	6.1	2.3	50	720				
8	.44	6.4	2.6	48	760				
9	.52	5.9	2.8	60	840	0.1	1.2	20.0	21.3
10	.48	6.4	3.6	46	920				
11	.76	7.5	4.3	46	485	0.1	0.8	b/	
12	.12	5.9	3.4	36	345	0.1	0.6	19.0	19.7
13	.60	6.7	3.6	50	515				
14	.56	7.2	3.4	48	720	0.1	1.0	26.6	27.7
15	.68	7.0	2.8	28	600				
16	.76	7.2	3.0	40	465				
17	.48	6.4	3.5	46	770				
18	.56	6.5	4.0	85	630				
19	.92	7.0	2.6	42	660	0.1	1.0	b/	
20	.60	6.6	2.8	75	999				
21	.44	7.0	2.4	77	790				
22	.60	7.4	3.7	52	850	0.1	1.2	24.6	25.9
23	.68	7.0	3.6	80	980				
24	.72	7.7	2.8	55	615	0.2	0.9	b/	
25	.48	6.1	2.4	60	950				
26	.52	6.2	2.8	72	870				
27	.60	7.0	3.3	34	690				

a/ Determined only for locations given.

b/ Free lime in soil.

Soil Physical Properties:

Soil samples for moisture determination were weighed as soon as possible after being obtained. They were dried in a forced draft oven at 110 C for 24 hours, reweighed, ground and passed through a 2mm sieve. The material larger than 2mm was weighed and the amount of soil determined. The ground samples were used for the 15 bar moisture determination. Plant available water was calculated from the difference between the initial and 15 bar moisture content of the soil (Table II). It was assumed that the gravels would not retain any water at 15 bars tension.

The BD samples were air dried for several weeks in the laboratory and then subsampled. A fine thread was tied to a piece of soil and the unit weighed. Next, the soil was immersed in hot paraffin for several seconds, removed and allowed to cool. The volume of the soil was found from the displacement of the paraffin coated piece as it was suspended in water. Calculations were based on an average BD of 1.60 for all locations at all depths.

Soil Temperature:

Soil temperature was measured at a depth of 20 inches at monthly intervals. A sample of soil was removed using a Hoeffler tube, and a centigrade thermometer placed into the sample (Table II).

Precipitation:

Two types of rain gages were used to measure precipitation at all locations. One type of rain gage consisted of an 8 inch plastic funnel sealed in an 8 inch plastic flower pot. Dow Corning 780 building sealant

with one part silicone rubber was used as the sealing compound. A  $\frac{1}{4}$  inch copper tube transferred the water to a 1 liter plastic bottle for storage. With the exception of the transfer tube and a small air vent, the storage bottle was sealed to minimize evaporation losses. The entire unit was attached to a steel fence post with the top of the collection funnel 40 inches above the surface of the ground. This type of gage was used at locations 1, 5, 7, 9, 10, 11, 12, 13, 16, 17, 19, 20, 21, 24, 25, 26, and 27. The water collected was measured at approximately weekly intervals.

The other type of rain gage was a Tru-Check,<sup>a/</sup> made of heavy plastic with a wedge shaped well. The calibration is in hundredths for the first inch and tenths for the remainder of the six inch capacity. The opening at the top is rectangular, measuring 2.3 X 2.5 inches. A bracket is provided with the gage for mounting on a wooden post. This gage was used at the locations where a homestead was close to the experimental plots. At these places, the cooperators recorded the rainfall when it occurred.

#### Plant Samples:

At approximately the boot and flowering stage of plant growth, plant samples were taken from every treatment at all locations. The samples were obtained by cutting a 3 foot length of row at ground level. At the same time, the growth stage of the plant was determined according to the Feekes scale (24).

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<sup>a/</sup> Edwards Mfg. Co., Alberta Lea, Minn.

The plant samples were oven dried at 60 C, weighed and ground. Nitrogen analyses were done by the Grain Laboratory, Montana State University,<sup>a/</sup> using the macro Kjeldahl method.

Plant samples were taken at harvest by cutting 40 to 50 plants at random around the perimeter of each harvested plot. This permitted the harvest of the central portion for yield. Total nitrogen was determined for the whole plant by the Grain Laboratory.

#### Harvesting the Crop:

The crop was cut at ground level from an area of approximately 50 or 100 square feet in the center of each plot. Part of the cutting was done by using an electric hedge trimmer with power supplied by a portable generator. However, hand sickles were used to cut most of the plots. The length of each harvest row was measured by laying a 10-foot length of conduit alongside the row. The number of rows harvested were determined from the row spacing used in planting the crop.

After cutting, the heads and as much straw as possible were placed in quarter barrel paper sacks. The sacking was done with the aid of a sacker which funneled the bundles into the sack. Each bundle was tied and identified with a tag before it was removed from the plot where it was cut. The bundles were stored in a shed until threshing time.

Two separate bundles were cut from each location and used to determine the moisture content when the crop was threshed. The moisture samples were

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<sup>a/</sup> Bozeman, Montana

handled and stored in the same manner as the bundles from the experimental plots. All bundles were weighed just prior to being threshed and the moisture samples had an extra paper sack placed over the straw to prevent the loss of straw or grain. The moisture samples were dried in a forced draft oven for 24 hours at 60 C and reweighed. Total dry matter harvested was then computed using the average moisture values of the respective locations.

Locations 1, 2, and 10 were not harvested because of hail damage. Location 12 was not harvested because of weeds.

#### Grain Samples:

A small thresher<sup>a/</sup> designed for experimental work with small grains was used to thresh the grain from the straw. The grain was collected in 10 lb heavy duty paper sacks and identified by the tag which had been on the bundle that was just threshed. Next the grain was left in the laboratory for several weeks until it had reached a uniform moisture content.

The small amount of chaff remaining with the grain was removed using a Carter dockage tester.<sup>b/</sup> If any unthreshed heads were present, they were rethreshed in a small head thresher. Following the cleaning operation, the grain was weighed for the yield determination. Test weight was determined using a standard volume measurement and weighing the grain.

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<sup>a/</sup> Allen Machine Co., Ames, Iowa

<sup>b/</sup> Carter-Day Co., Minneapolis, Minnesota

Subsamples of the grain were taken and ground prior to the protein analysis by the Montana State University Grain Laboratory. A second set of subsamples were taken for the kernel weight determination. The samples were carefully cleaned to remove any cracked grain and the number of kernels counted. Afterward the same samples were weighed and the weight per 100 kernels calculated.

Statistical Procedures:

The data collected in this project were analyzed statistically using methods described by Steele and Tory (35). Randomized complete block design, A X B factorial, analysis of covariance, simple and multiple linear regression were the statistical procedures applied to the project. All computational work was processed by the IBM 1620 model II computer at the Montana State University computing center.

## RESULTS AND DISCUSSION

All dependent variables (grain yield, percent grain protein, total grain N, kernel weight, test weight, total dry matter harvested, percent plant protein, and total N uptake) were analyzed using a treatment X location factorial analysis of variance. In all cases a significant difference ( $p=0.01$ ) was found between locations for all dependent variables. With the exception of grain yield, significant differences ( $p=0.01$ ) were found between N fertilizer treatments for all variables. Grain yield produced a significant difference between treatments at the 5% level. No treatment X location interaction occurred for any of the variables, implying that the magnitude of variation at an individual location was due to N fertilizer treatments.

The significance of all statistical analyses reported in this thesis has been determined at the 5% level unless otherwise stated.

### Growth Characteristics:

Differences in plant height (Table VII), not related to N treatments, were observed at locations with less than 2.0 inches available spring soil moisture. At some locations with less than 3.69 inches of available moisture plant height was also erratic. The random pattern of fluctuating plant heights in the plots was continuous with similar conditions in the surrounding field. These growth differences may be attributed to fluctuations in soil depth causing changes in the amount of available moisture. Plant height differences were nonsignificant between N treatments at each location.

Table VII. Plant height at harvest, measured to the base of the heads.

Location	Height Inches				
	N fertilizer treatment lb/A				
	0	20	40	60	80
3	24	27	23	22	24
4	29	28	28	29	30
5	29	30	31	31	33
6	29	27	28	29	29
7	24	24	25	25	24
8	29	27	30	28	31
9	26	25	25	25	26
11	26	29	30	30	29
13	27	30	28	27	31
14	24	24	22	25	24
15	26	26	28	26	28
16	18	22	21	21	22
17	25	27	25	28	24
18	29	28	27	26	29
19	26	25	23	24	25
20	28	28	28	28	28
21	25	25	26	25	27
22	25	25	29	26	26
23	22	23	21	24	20
24	32	35	34	34	35
25	29	26	24	23	25
26	30	29	27	26	27
27	28	29	28	28	28

Grain Yield:

Average yields of all treatments at each location are presented in Table VIII. Figure 2 shows the relationship of yield response to N fertilizer and total growing season moisture. Predicted linear response to total moisture is shown for the check and 80 lb/A N treatments. A further breakdown indicates that the amount of spring soil moisture is more important than growing season precipitation for predicting yields. All locations with  $\leq 2.0$  inches of available soil moisture responded little or not at all to applied N. Solving the regression equations for their common intercept shows that  $\leq 2.0$  inches of spring moisture will produce yield depressions with N fertilization. The regression equation predicts that locations with 4.29 to 5.07 inches of spring moisture would respond most favorably to N fertilization. Locations with 2.02 to 3.69 inches of spring soil moisture should show an increasing response to N fertilization as the soil moisture increases.

Depth to lime is positively correlated with yield for all N fertilizer treatments, Table IX. This is probably due to several factors but it has been observed that inadequate P or a dry soil with sufficient P will reduce grain yield of spring wheat (5, 18). Formation of relatively insoluble calcium phosphates reduces the amount of available P, thus, effectively reducing yields. This factor would have increasing importance with low levels of growing season precipitation where the soil above the lime zone is dry for long periods of time.

Soil  $\text{NO}_3\text{-N}$  had a significant positive correlation with yield on only the check plot. This would be expected because the primary source of N

Table VIII. Grain yield response to N fertilizer treatments.

Location	Gms. harvested/50 ft. <sup>2</sup> <u>a/</u> N fertilizer treatment lb/A				
	0	20	40	60	80
3*	876.	831.	789.	682.	815.
4	1080.	1033.	1093.	1039.	1128.
5	917.	1186.	1257.	1263.	1235.
6	1067.	951.	1079.	918.	959.
7	1270.	1209.	1300.	1352.	1361.
8	1234.	1214.	1367.	1357.	1371.
9	745.	708.	766.	786.	775.
11	822.	890.	1077.	972.	933.
13	939.	1088.	1082.	1104.	1100.
14	823.	825.	811.	948.	892.
15	865.	852.	982.	778.	1001.
16	754.	951.	841.	905.	984.
17	854.	915.	916.	1014.	1031.
18	919.	1057.	1060.	1053.	1177.
19	972.	1045.	944.	1023.	1092.
20	1458.	1428.	1459.	1447.	1480.
21	865.	914.	986.	1025.	1052.
22	1233.	1144.	1313.	1312.	1188.
23	859.	887.	872.	1025.	850.
24*	1536.	1735.	1906.	1826.	1802.
25	1384.	1295.	1293.	1102.	1259.
26	1115.	1147.	1115.	905.	1092.
27	907.	1027.	914.	926.	624.

a/ (0.032)(gms/50 ft<sup>2</sup>) = bu./A.

\* Significant difference between treatments p = .05.

Table IX. Multiple regression equations and correlation of response by grain factors to soil and climatic variables for each N fertilizer treatment.

N Treatment (lb/A)	Regression equation <sup>a/</sup>	R	R <sup>2</sup>
0	Gy = 162.2 + 121.2 <sup>⊗</sup> SM - 13.1Pr + 31.0**L + 9.9*N	.730	.533
20	Gy = 399.4 + 77.0**SM + 7.1Pr + 33.3**L	.750	.562
40	Gy = 353.0 + 112.8**SM - 3.7Pr + 36.8**L	.756	.556
60	Gy = 476.9 + 131.3**SM - 15.4Pr + 25.3* L	.658	.433
80	Gy = 398.7 + 102.4**SM + 9.5Pr + 28.7* L	.698	.487
0	Gp = 8.38 + 0.83* SM - 0.32Pr + 0.11**N	.702	.492
20	Gp = 9.53 + 0.28* SM - 0.20Pr + 0.13**N	.759	.576
40	Gp = 11.05 + 0.21**SM - 0.20Pr + 0.12**N	.781	.609
60	Gp = 13.30 - 0.29**SM - 0.09Pr + 0.11**N	.797	.636
80	Gp = 13.09 + 0.44**SM - 0.28Pr + 0.09**N	.823	.777
0	Gn = -2.51 + 3.80 SM - 0.72Pr + 0.51**L + 0.37**N	.782	.612
20	Gn = 3.31 + 1.84 SM - 0.22Pr + 0.52**L + 0.31**N	.759	.576
40	Gn = 0.98 + 3.47 SM - 0.49Pr + 0.63**L + 0.32**N	.768	.590
60	Gn = 4.20 + 3.77 <sup>⊗</sup> SM - 0.51Pr + 0.50* L + 0.27* N	.688	.474
80	Gn = 6.49 + 2.86 <sup>⊗</sup> SM - 0.28Pr + 0.64**L + 0.22* N	.697	.485
0	KW = -11.02 + 0.45**SM + 1.41 <sup>⊗</sup> Pr + 0.40**L - 0.23**OM + 0.01**Pa	.866	.750
20	KW = -10.00 + 0.43**SM + 1.30 Pr + 0.38**L - 0.21**OM + 0.01* Pa	.858	.736
40	KW = -8.77 + 0.42**SM + 1.15 Pr + 0.33**L - 0.19* OM + 0.01* Pa	.868	.753
60	KW = -10.28 + 0.44**SM + 1.29 Pr + 0.38**L - 0.21* OM + 0.01**Pa	.841	.707
80	KW = -10.78 + 0.45**SM + 1.36 Pr + 0.39**L - 0.23**OM + 0.01**Pa	.883	.779
0	TW = 68.53 + 2.13 SM - 0.79Pr - 0.25N - 0.80*OM + 0.02 Pa	.664	.441
20	TW = 67.18 + 2.25 <sup>⊗</sup> SM - 0.82Pr - 0.22N - 0.71 <sup>⊗</sup> OM + 0.02 Pa	.647	.418
40	TW = 67.66 + 2.22 SM - 0.82Pr - 0.24N - 0.75 <sup>⊗</sup> OM + 0.02 Pa	.637	.406
60	TW = 67.59 + 2.29 SM - 0.84Pr - 0.28N - 0.90 <sup>⊗</sup> OM + 0.03*Pa	.667	.445
80	TW = 67.48 + 2.35 SM - 0.88Pr - 0.26N - 0.91*OM + 0.03 <sup>⊗</sup> Pa	.607	.368

a/ Gy = Grain yield (gms/50ft<sup>2</sup>); Gp = % grain protein (% = N x 6.25); Gn = total N in grain (gms/50ft<sup>2</sup>); KW = kernel weight (gms/100 kernels); TW = test weight (lb/bu); SM = available soil moisture at topdressing time (inches); Pr = rainfall from April 10 to July 16 (inches); L = depth to lime in soil (inches); N = NO<sub>3</sub>-N in soil at topdressing (lb/A); OM = % organic matter in soil at topdressing to a depth of 6 in.; Pa = available P in soil at topdressing to a depth of 6 in.

⊗ = Significant correlation p = 0.10; \* = significant correlation p = 0.05;  
 \*\* = Significant correlation p = 0.01.

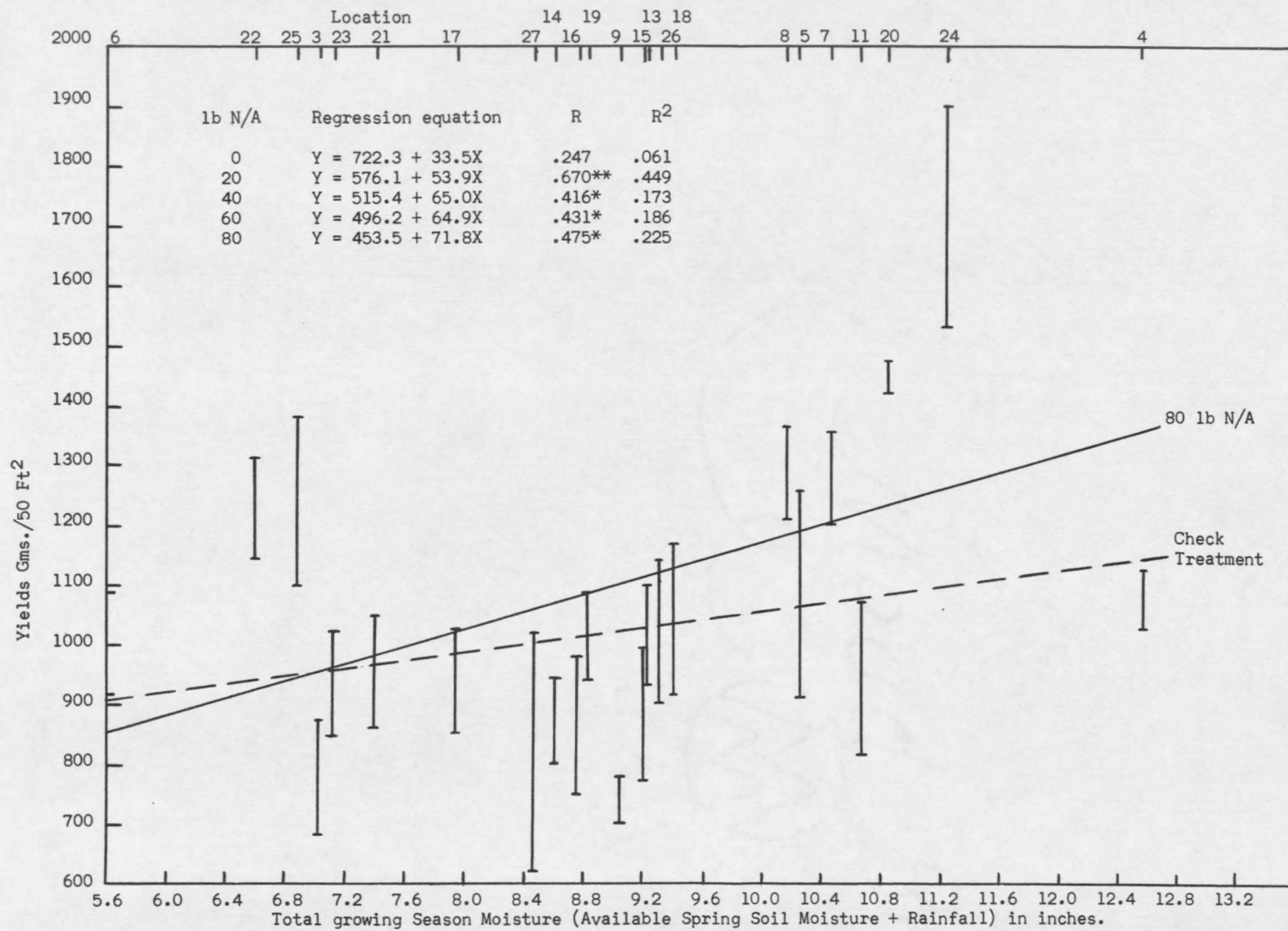


Figure 2. Grain yield response to N fertilizer treatments and total growing season moisture. Regression lines show theoretical yields of check and 80 lb N/A treatments for total growing season moisture. a/

a/ Bars show range of N response at each location; \*\* = Significant Correlation p=0.01; \* = Significant Correlation p=0.05.

would be from accumulated forms of plant available N.

Grain Protein:

Increasing amounts of fertilizer N produced a very definite increase in the percent protein of the grain when all locations are considered together, Table X. Percent grain protein was negatively correlated at all N treatment levels with spring soil moisture plus rainfall. When these were the only factors considered, available spring soil moisture had a significant negative effect on grain protein at 40, 60, and 80 lbs N applied. An increase in soil moisture may result in an increase in grain carbohydrates and a decrease in percent protein. Rainfall showed no significant contribution to grain protein for any of the N treatments. An improvement in the correlation ( $p=0.01$ ) occurred by including the amount of soil  $\text{NO}_3\text{-N}$  at the time of topdressing, Table IX. This addition caused a positive relationship with spring soil moisture for all but the 60 lb N treatment. These data indicate when sub-soil moisture was available to the crop during grain development, soil  $\text{NO}_3\text{-N}$  was taken up and translocated into the grain, whereas fertilizer N remained relatively unavailable. Boatwright and Ferguson (5), growing spring wheat under greenhouse conditions, developed a technique for growing plants in soil with either a complete root system, a primary root system, or an adventitious root system. They found that higher amounts of N were translocated into the grain, when complete root systems developed, than when plants developed incomplete root systems. Plants with only adventitious roots translocated more N into the grain than plants with

Table X. Effect of N fertilizer treatments on percent grain protein.

Location	% grain protein <u>a/</u> N fertilizer treatment lb/A				
	0	20	40	60	80
3**	12.95	13.55	15.30	16.65	16.55
4*	13.50	14.40	15.00	16.15	15.90
5	9.75	9.00	10.85	11.95	12.85
6*	14.25	14.95	15.80	16.45	17.10
7**	10.30	11.15	12.05	13.05	13.50
8	10.75	12.80	12.95	13.35	14.20
9**	11.25	12.30	13.30	14.15	15.25
11**	9.65	10.55	11.15	12.80	13.25
13**	9.25	10.75	11.90	13.15	14.10
14*	10.95	11.40	12.45	13.35	14.50
15*	11.35	12.00	12.95	14.75	14.45
16*	10.15	10.35	11.90	14.25	13.95
17**	12.30	12.80	13.95	14.70	15.30
18**	9.55	10.20	11.25	12.25	12.35
19*	11.15	12.10	12.70	13.90	14.45
20**	12.50	13.60	14.55	15.30	15.45
21**	11.40	12.45	12.95	14.30	15.00
22*	13.60	14.10	13.80	15.90	16.50
23*	11.50	12.50	14.25	14.55	15.95
24**	9.60	10.25	10.75	11.55	12.80
25	10.50	12.00	13.60	14.75	15.35
26*	10.25	9.90	11.40	13.50	13.95
27**	14.10	14.95	15.85	16.80	16.75

a/ % = N x 6.25

\* Significant difference between treatments p = .05.

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

primary roots. Therefore, during grain development, adventitious roots may be more active in providing N that can be translocated into the grain. Several workers (15, 18, 38) have shown that N applied after boot growth stage would result in an increase in percent grain protein. It is possible that small amounts of soil  $\text{NO}_3\text{-N}$  could have an influence on percent grain protein. An initial 300 lb/A rate of N applied at seeding to spring wheat under greenhouse conditions was found to increase grain protein over the check treatment. However, a significant increase in percent grain protein over the 300 lb N/A rate occurred when only 100 lbs N/A was applied at either boot or soft dough stage of plant development.<sup>a/</sup>

Although growing season precipitation was not a significant factor when related to percent grain protein, the regression equation shows it to have a negative effect. This would be possible assuming that the surface soil contains most of the essential nutrients for plant development. Under these conditions, the formation of carbohydrates may increase as rainfall increases.

#### Total Grain N:

Multiple regression, Table IX, shows a positive correlation for available spring soil moisture, depth to lime, and soil  $\text{NO}_3\text{-N}$ , with growing season precipitation negative in relation to the grain uptake of N,

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<sup>a/</sup> Warrington, G. E. 1967. A greenhouse study of the response of spring wheat to the time and rate of nitrogen application. Special problem report on file Dept. of Plant and Soil Sci., Mont. State Univ.

Table XI. Total N content of the grain was related to crop yield and percent grain protein. The discussion of factors influencing percent grain protein may be used to explain all of the relationships except depth to lime. Any factor which will increase yield will result in some increase in the total grain N provided a proportional decrease in percent protein does not occur. The positive influence due to depth of lime would therefore result from factors similar to those discussed for grain yield. Although available soil moisture did not contribute significantly, its effect was probably divided between increasing grain yield and percent protein.

Kernel Weight:

Increasing amounts of fertilizer N resulted in corresponding decreases in the weight of 100 kernels of grain, Table XII. Positive correlation with kernel weight occurred for available soil moisture, growing season precipitation, depth to lime, and available P for a N fertilizer treatment. Significant negative correlation was obtained from percent organic matter in the upper 6 inches of soil, Table IX. Because kernel weight is one of the yield components, its response to factors which will increase yield is expected. Adequate soil moisture is needed during grain development for translocation of carbohydrates and proteins into the grain. Growing season precipitation would be expected to enhance plant availability of applied fertilizer and other nutrients in the surface 6-12 inches of soil. Depth to lime could have an influence on P as discussed in respect to grain yield. Response to available P, although

Table XI. Effect of N fertilizer treatments on the amount of N in the grain at maturity.

Location	Gms. N/50 ft. <sup>2</sup> a/ N fertilizer treatment lb/A				
	0	20	40	60	80
3*	18.16	18.03	19.33	18.18	21.58
4*	23.32	23.81	26.20	26.85	28.68
5*	14.21	16.99	21.84	24.17	25.38
6	24.35	22.70	27.27	24.14	26.25
7**	20.93	21.57	25.07	28.23	29.40
8	21.25	24.72	28.33	29.02	31.17
9**	13.41	13.96	16.30	17.77	18.90
11	12.68	14.98	19.21	19.91	19.66
13*	13.90	18.70	20.62	23.22	24.76
14	14.46	15.04	16.20	20.17	20.66
15*	15.67	16.30	20.34	18.35	23.06
16**	12.25	15.65	16.01	20.52	21.96
17**	16.77	18.76	20.43	23.85	25.23
18**	14.04	17.18	19.08	20.61	23.24
19	17.32	20.27	19.19	22.73	25.30
20	29.16	31.07	33.96	35.41	36.59
21**	15.80	18.25	20.49	23.46	25.25
22	26.79	25.82	28.99	33.41	31.23
23*	15.82	17.65	19.87	23.72	21.66
24*	23.62	28.45	32.83	33.76	36.90
25**	23.31	24.92	28.21	25.65	30.73
26	18.29	18.18	20.33	19.73	24.35
27	20.47	24.57	23.20	24.90	16.52

a/ (1.921)(gms/50 ft.<sup>2</sup>) = lbs./A

\* Significant difference between treatments p = .05.

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

Table XII. Effect of N fertilizer treatments on kernel weight of the grain.

Location	Gms./100 kernels				
	N fertilizer treatment lb/A				
	0	20	40	60	80
3*	2.76	2.67	2.54	2.46	2.54
4	2.97	2.85	2.85	2.76	2.83
5	3.00	2.83	2.94	2.79	2.76
6	2.44	2.44	2.42	2.38	2.35
7	3.34	3.23	3.16	3.18	3.14
8	3.12	3.03	3.11	2.97	2.91
9	2.91	2.86	2.82	2.80	2.75
11**	2.78	2.72	2.72	2.58	2.55
13*	3.13	3.04	2.93	2.85	2.80
14*	2.98	2.82	2.71	2.74	2.66
15	2.96	2.94	2.89	2.75	2.81
16	2.75	2.79	2.65	2.60	2.65
17*	2.64	2.53	2.44	2.48	2.43
18*	3.10	2.97	2.95	2.89	2.82
19	3.03	2.83	2.74	2.66	2.68
20	3.57	3.53	3.52	3.49	3.51
21	3.22	3.08	3.05	3.05	2.95
22	2.74	2.76	2.76	2.66	2.59
23	3.05	2.98	2.82	2.87	2.75
24	3.50	3.55	3.53	3.40	3.20
25**	3.14	3.05	2.93	2.84	2.86
26	3.04	3.08	2.85	2.72	2.82
27*	2.58	2.62	2.53	2.40	2.37

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

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

small, was significant for all N treatments. This correlation may have resulted from insufficient fertilizer P being applied, or a reflection of the distribution of natural soil P as compared to banded or topdressed fertilizer P. The influence of soil organic matter may have been due to N released during decomposition. Plant uptake of N during grain development probably stimulated formation of proteins as indicated by percent grain protein. An increase in percent protein with a decrease in kernel weight suggests that most of the kernel weight comes from carbohydrates.

Test Weight:

Test weight (Table XIII) decreased as increasing amounts of N were applied. Available spring soil moisture shows a significant ( $p=0.10$ ) positive correlation for only the 20 lb N/A treatment, Table IX. Growing season precipitation and soil  $\text{NO}_3\text{-N}$  have a nonsignificant negative relationship with test weight. Rainfall was included in those correlations because all sources of water should be evaluated for their potential contribution if one source shows some significance. Soil  $\text{NO}_3\text{-N}$  showed a large influence on the correlation coefficient when it was included with other factors. Percent organic matter was found to have a negative significant ( $p=0.10$ ) correlation with test weight. Soil P resulted in a positive relationship with test weight for all N treatments, with significance ( $p=0.05$ ) for 60 lb N/A and ( $p=0.10$ ) for 80 lb N/A.

Test weight is a density measurement, therefore, factors promoting carbohydrate formation should have a positive correlation with test weight. Factors promoting protein synthesis will tend to decrease test

Table XIII. Test weight of grain at maturity in response to N fertilizer treatments.

Location	Lb/bu.				
	N fertilizer treatment lb/A				
	0	20	40	60	80
3*	63.10	62.90	62.30	61.80	62.30
4	62.50	61.75	61.50	61.50	61.50
5	63.00	63.00	62.75	61.75	61.25
6	61.70	61.70	61.20	61.10	60.60
7	65.20	65.20	65.10	65.00	64.90
8	64.90	64.70	64.40	63.80	63.70
9	64.10	63.70	63.50	63.00	63.80
11	63.50	63.50	63.25	62.25	62.50
13**	64.00	63.50	63.50	62.75	61.75
14	64.20	64.15	64.10	63.50	62.75
15	63.75	63.50	63.00	62.25	62.50
16	64.50	64.00	63.70	62.60	62.60
17*	62.25	61.75	61.50	61.00	61.00
18	64.25	64.00	64.00	63.75	63.50
19**	63.75	63.25	63.00	62.50	61.75
20	64.50	64.60	64.00	63.90	63.50
21	64.70	63.80	64.30	64.50	63.90
22	63.20	62.80	63.20	62.00	62.60
23*	65.20	64.80	64.20	64.20	63.50
24	65.20	64.70	64.80	64.70	63.90
25	64.25	64.20	63.90	63.00	63.40
26**	63.25	63.00	62.50	61.25	61.25
27*	62.25	62.00	62.00	60.75	61.00

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

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

weight producing a negative correlation with test weight. Available soil moisture is needed for translocation of carbohydrate and protein constituents into the grain during dry periods after boot stage. Growing season precipitation would be expected to have a negative effect because it may promote plant uptake of fertilizer and soil sources of N.  $\text{NO}_3\text{-N}$  and organic matter probably contribute to grain protein synthesis thereby resulting in a negative effect on test weight. The positive relationship of P with test weight indicates that it may be more important in carbohydrate formation than protein synthesis.

#### Preharvest Plant Development:

A treatment X location analysis of variance was used to determine if significant differences occurred for the dependent variables [plant maturity (determined by the Feekes scale), dry weight, and total N uptake] at two sampling times (Tables XIV, XV, XVI, XVII, XVIII, XIX). In all cases, significant ( $p=0.01$ ) differences were found between locations for all dependent variables. However, multiple regression analysis showed little consistent correlation with the independent variables measured at each location. At about boot stage, significant ( $p=0.01$ ) differences occurred between treatments for all dependent variables. A significant treatment X location interaction occurred for plant maturity and dry weight of the first samples taken. This implies that various factors at a location influenced plant response to N fertilizer.

No treatment X location interactions occurred for dependent variables associated with the second set of plant samples. No significant treatment

Table XIV. Growth stage of preharvest plant samples obtained June 22 and 23, 1966.

Location	Growth stage Feekes scale a/ N fertilizer treatment lb/A				
	0	20	40	60	80
3	10.35	10.25	10.15	10.20	10.05
4	10.05	10.05	10.00	10.00	10.00
5	9.25	9.00	9.50	9.25	9.00
6	9.25	9.00	9.00	9.00	8.50
7	10.50	10.45	10.45	10.45	10.45
8	10.15	10.10	10.15	10.10	10.15
9	10.00	10.00	10.00	10.00	10.00
11*	10.00	9.50	9.00	9.25	9.25
13	10.05	10.00	10.00	10.00	10.00
14	10.05	10.05	10.05	10.05	10.05
15	9.00	9.00	9.00	8.50	8.50
16	10.00	10.00	10.00	10.00	9.75
17	9.50	9.50	9.25	9.25	9.00
18	10.00	10.00	10.00	10.00	10.00
19	10.25	10.05	10.25	10.10	10.00
20	10.35	10.30	10.10	10.45	10.30
21	10.50	10.50	10.45	10.50	10.45
22	10.00	10.00	9.50	9.50	9.75
23	10.30	10.35	10.25	10.10	10.25
24	10.10	10.00	10.00	10.05	10.00
25	10.10	10.05	10.15	10.10	10.05
26	10.25	10.15	10.20	10.15	10.05
27	10.05	10.05	10.00	10.05	10.05

a/ Large, E. C. 1954. Growth stages in cereals, illustration of the Feekes scale. Plant Pathology, 4:128-129.

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

Table XV. Dry weight of plant samples obtained June 22 and 23, 1966.

Location	Dry weight gms/50 ft <sup>2</sup> a/ N fertilizer treatment lb/A				
	0	20	40	60	80
3	1710.	1761.	1726.	1876.	1924.
4	1083.	1651.	1428.	1621.	1875.
5	1031.	1172.	1340.	1257.	1145.
6	938.	1343.	1219.	1101.	1405.
7	1651.	1949.	1834.	1944.	1927.
8	1659.	1791.	2059.	1881.	1766.
9	1070.	1113.	1248.	1206.	1222.
11	1007.	1134.	1313.	971.	1233.
13	1133.	1340.	1329.	1607.	1923.
14	1696.	2080.	1857.	2374.	1843.
15	614.	587.	584.	671.	627.
16*	773.	1000.	1552.	1887.	1555.
17	1368.	1335.	1606.	1473.	1317.
18	1230.	1269.	1510.	2154.	1874.
19	1273.	1153.	1598.	1342.	1037.
20	1703.	1647.	1389.	1771.	1399.
21	1590.	1686.	2514.	2379.	2451.
22	2037.	2270.	1734.	1756.	2143.
23	1840.	991.	1896.	1928.	1883.
24	1417.	2391.	2479.	2536.	2154.
25	2190.	1746.	2574.	1897.	1962.
26	1819.	1953.	2269.	1807.	1489.
27	1824.	1824.	1724.	1989.	2189.

a/ (1.921)(gms/50 ft.<sup>2</sup>) = lb./A.

\* Significant difference between treatments p = .05.

Table XVI. Preharvest N uptake by plants in response to N fertilizer treatments. Plant samples obtained June 22 and 23, 1966.

Location	Gms N/50 ft. <sup>2</sup> in plants. <sup>a</sup> / N fertilizer treatment lb/A				
	0	20	40	60	80
3*	21.29	23.11	25.14	30.25	31.86
4	16.16	25.36	24.06	27.70	32.22
5	15.40	19.41	23.62	22.54	27.84
6	25.98	41.80	28.95	33.62	39.38
7	22.39	27.79	27.34	30.94	33.20
8	21.24	23.80	29.37	30.06	28.99
9*	15.19	15.71	19.50	21.89	21.44
11*	13.88	19.07	22.35	20.06	24.91
13*	14.62	21.96	21.78	29.17	35.47
14	20.66	25.51	23.47	32.70	29.09
15	13.98	13.77	15.04	18.92	17.38
16*	11.17	15.46	24.71	31.06	27.36
17	22.55	25.88	28.86	32.31	28.47
18*	15.69	17.53	23.18	34.84	30.58
19	15.77	19.00	25.42	25.53	21.14
20	30.14	31.76	30.40	34.82	32.03
21*	17.29	20.23	33.21	33.40	34.26
22	33.91	34.07	30.68	33.79	39.32
23	23.29	12.57	26.91	30.60	27.66
24	19.84	36.35	38.20	38.66	40.13
25	31.76	26.22	38.32	32.70	30.95
26	24.04	26.14	33.32	31.63	25.58
27	24.62	26.56	27.19	31.38	35.64

<sup>a</sup>/ (1.921)(gms/50 ft.<sup>2</sup>) = lb./A.

\* Significant difference between treatments p = .05.

Table XVII. Growth stage of preharvest plant samples obtained July 5, 6 and 7, 1966.

Location	Growth stage Feekes scale a/ N fertilizer treatment lb/A				
	0	20	40	60	80
3	11.10	11.10	11.05	11.10	11.05
4	10.54	10.54	10.54	10.53	10.54
5	10.53	10.52	10.52	10.52	10.52
6	10.52	10.52	10.52	10.52	10.51
7	11.15	11.12	11.12	11.15	11.12
8	11.05	11.10	11.05	10.84	11.05
9	11.10	11.12	11.12	11.10	11.10
11	10.52	10.52	10.52	10.52	10.51
13	10.82	10.54	10.54	10.54	10.54
14	10.54	10.82	10.82	10.54	10.32
15	10.52	10.53	10.52	10.52	10.52
16	11.10	10.82	10.54	10.82	10.54
17	10.54	10.54	10.54	10.54	10.54
18	10.54	10.54	10.54	10.77	10.54
19	11.10	10.54	11.10	10.82	10.82
20	11.10	11.15	11.12	11.10	11.12
21	11.12	11.12	11.10	11.10	11.10
22	10.54	10.79	10.54	10.54	10.77
23	11.05	11.10	11.05	11.10	11.10
24	10.82	10.54	10.82	11.10	11.10
25	11.10	11.10	11.10	11.10	11.10
26	11.10	11.10	11.10	11.10	10.82
27	11.10	11.10	11.10	11.10	11.10

a/ Large, E. C. 1954. Growth stages in cereals, illustration of the Feekes scale. Plant Pathology, 4:128-129.

Table XVIII. Dry weight of plant samples obtained July 5, 6, and 7, 1966.

Location	Dry weight gms/50 ft. <sup>2</sup> a/ N fertilizer treatment lb/A				
	0	20	40	60	80
3	1998.	2052.	2081.	2432.	2252.
4	2028.	1978.	2271.	2287.	2527.
5	1901.	2130.	2632.	2265.	2825.
6	2611.	2758.	2618.	2900.	2631.
7**	2173.	2897.	2780.	2944.	2503.
8	2253.	2237.	2539.	2296.	2333.
9	1659.	1387.	1647.	1417.	1636.
11	1562.	2071.	2407.	2138.	2368.
13	1826.	2651.	2156.	2866.	2329.
14	2400.	2223.	2479.	2805.	5450.
15	1287.	1339.	1626.	1489.	1734.
16	1846.	1626.	1872.	2537.	2639.
17	2550.	2748.	2851.	2623.	2702.
18	2116.	2044.	2171.	2483.	2277.
19	1986.	1990.	1873.	1883.	1758.
20	2934.	2981.	2225.	2508.	2270.
21*	1513.	2303.	2369.	2677.	3463.
22	2974.	2867.	3299.	2779.	3716.
23	2048.	2114.	2094.	2078.	1946.
24	2407.	4501.	3706.	4076.	4703.
25	3233.	2381.	2917.	2267.	2463.
26	1997.	2356.	2304.	2540.	2510.
27	1906.	2366.	2534.	2264.	2385.

a/ (1.921)(gms/50 ft.<sup>2</sup>) = lb./A.

\* Significant difference between treatments p = .05.

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

Table XIX. Preharvest N uptake by plants in response to N fertilizer treatments. Plant samples obtained July 5, 6, and 7, 1966.

Location	Gms N/50 ft. <sup>2</sup> in plants a/ N fertilizer treatment lb/A				
	0	20	40	60	80
3*	21.89	23.99	25.80	33.85	31.35
4	21.69	21.95	27.24	29.06	32.24
5	19.29	22.82	30.80	27.07	37.72
6	42.43	47.20	42.76	48.39	39.48
7*	22.96	34.08	35.21	41.04	36.62
8	24.70	25.38	30.16	31.23	29.97
9	18.04	16.28	20.15	20.00	23.50
11	14.93	22.13	27.38	27.15	29.93
13	16.96	26.72	24.44	36.97	28.03
14	20.46	23.86	25.12	30.06	65.35
15	17.39	17.93	23.21	24.86	27.06
16*	20.23	19.18	23.12	33.41	36.39
17	28.66	32.56	33.16	33.21	38.17
18	19.51	20.34	23.54	27.00	27.32
19	21.20	23.89	22.53	25.47	26.71
20	37.52	42.81	35.94	38.65	40.26
21**	14.37	25.27	26.69	31.71	43.15
22*	36.15	35.59	43.37	37.34	51.24
23*	20.23	19.72	27.15	25.30	28.12
24*	21.76	45.35	38.72	46.24	51.69
25	33.88	26.58	40.63	29.17	33.15
26	22.87	24.72	23.07	33.58	29.46
27	25.33	27.05	28.06	28.98	31.25

a/ (1.921)(gms/50 ft.<sup>2</sup>) = lb./A.

\* Significant difference between treatments p = .05.

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

effect was found for plant maturity. However, dry weight and total N uptake did continue to show significant ( $p=0.01$ ) differences associated with N fertilizer treatments.

A significant negative correlation was found between total dry matter and soil (2:1 water-soil) solution electrical conductivity. This occurred at both sampling times for the 80 lb/A N treatment. It may be that high rates of spring topdressed ammonium nitrate will cause some salt injury to winter wheat, but no symptoms of salt burn were observed for the N treatments used.

#### Response of Grain Plus Straw:

Production of total dry matter (TDM) increased with increasing rates of N at most locations (Table XX). At a few locations, a depression in TDM production occurred for 60 and 80 lb N/A as compared to the other treatments. A positive correlation with TDM was found for available spring soil moisture, growing season precipitation, depth to lime, and soil  $\text{NO}_3\text{-N}$  (Table XXI). Of these factors only growing season precipitation was nonsignificant for all N treatments. Soil moisture did not have a significant relationship with TDM for the check treatment. Precipitation occurring before a large amount of vegetative cover developed would be more effective in wetting the soil as compared to equal amounts occurring later. However, all sources of water could contribute to nutrient uptake and plant growth. Depth to lime may have an influence on P availability as discussed for grain yield. Only the check treatment showed a significant relationship of soil  $\text{NO}_3\text{-N}$  with TDM. In this case,

Table XX. Effect of N fertilizer treatments on the production of total dry matter (grain + straw).

Location	Gms. harvested/50 ft. <sup>2</sup> <u>a/</u> N fertilizer treatment lb/A				
	0	20	40	60	80
3	2296.	2229.	2118.	1940.	2029.
4	3032.	2907.	3120.	3103.	3369.
5**	2531.	2805.	3143.	3270.	3312.
6	2779.	2448.	3060.	2602.	2728.
7**	2446.	2614.	2816.	2917.	2883.
8	2964.	3264.	3424.	3374.	3496.
9	1741.	1658.	1787.	1848.	1855.
11	2048.	2402.	2816.	2737.	2441.
13	2390.	2877.	2966.	2899.	3121.
14	2166.	2188.	2188.	2534.	2448.
15	1908.	1886.	2136.	1908.	2341.
16	1759.	2242.	2045.	2242.	2396.
17	2086.	2516.	2373.	2639.	2822.
18	2250.	2629.	2629.	2629.	2941.
19	2159.	2373.	2052.	2287.	2587.
20	3038.	2985.	3164.	3207.	3260.
21	2399.	2539.	2853.	2951.	2926.
22	2870.	2618.	3104.	3278.	2948.
23	2235.	2371.	2381.	2641.	2537.
24*	3400.	3896.	4245.	4076.	4171.
25	3213.	2889.	2959.	2519.	2958.
26	2579.	2625.	2578.	2485.	2602.
27	2359.	2922.	2662.	2748.	2705.

a/ (1.921)(gms/50 ft.<sup>2</sup>) = lbs./A.

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

Table XXI. Multiple regression equations and correlation of response by plant factors to soil and climatic variables for each N fertilizer treatment.

N Treatment (lb/A)	Regression equation <sup>a/</sup>	R	R <sup>2</sup>
0	TDM = 1121 + 0.3 SM + 14.4Pr + 65.6**L + 23.6*N	.758	.575
20	TDM = 1365 + 36.9 <del>0</del> SM + 87.3Pr + 53.6* L	.621	.386
40	TDM = 1271 + 75.3 <del>0</del> SM + 69.7Pr + 70.9**L	.632	.399
60	TDM = 1428 + 134.2*SM + 47.6Pr + 53.7* L	.609	.371
80	TDM = 1431 + 58.6*SM + 104.8Pr + 51.9* L	.630	.397
0	Pp = 2.55 + 1.62 SM - 0.46*Pr + 0.05* N	.676	.456
20	Pp = 4.36 + 0.85*SM - 0.29 Pr + 0.05**N	.714	.509
40	Pp = 4.07 + 1.23*SM - 0.39*Pr + 0.06**N	.749	.561
60	Pp = 5.82 + 0.48*SM - 0.21 Pr + 0.06**N	.724	.525
80	Pp = 5.61 + 0.92*SM - 0.32 Pr + 0.05* N	.653	.426
0	Pn = 12.02 + 0.39 <del>0</del> L + 0.31* N	.610	.372
20	Pn = 16.44 + 0.31 <del>0</del> L + 0.30**N	.624	.390
40	Pn = 17.49 + 0.39 <del>0</del> L + 0.34**N	.612	.375
60	Pn = 19.68 + 0.40 <del>0</del> L + 0.36**N	.620	.385
80	Pn = 23.18 + 0.34 <del>0</del> L + 0.33**N	.627	.393

<sup>a/</sup> TDM = total dry matter, grain + straw (gms/50 ft<sup>2</sup>); Pp = % plant protein (% = N x 6.25); Pn = total N used by grain and straw (gms/50 ft<sup>2</sup>); SM = available soil moisture at top-dressing time (inches); Pr = rainfall from April 10 to July 16 (inches); L = depth to lime in soil (inches); N = NO<sub>3</sub>-N in soil at topdressing (lb/A).

⊙ = Significant correlation p = 0.10; \* = Significant correlation p = 0.05;  
 \*\* = Significant correlation p = 0.01.

soil  $\text{NO}_3\text{-N}$  was probably the main source of N for plant development.

Percent plant protein increased through the 60 lb N/A treatment. A few locations had no further increase with the 80 lb/A rate of N (Table XXII). Available soil moisture, growing season precipitation, and soil  $\text{NO}_3\text{-N}$  correlate with percent plant protein for some N treatments (Table XXI). These factors influenced response in the same direction as occurred for percent grain protein. Although the magnitude of response is somewhat different, it seems that each factor's influence on plant protein is similar to its influence on grain protein.

Total N uptake was related to TDM production and percent N in the plant. Most locations had an increase in total N uptake as increasing amounts of N were applied (Table XXIII). Only depth to lime and soil  $\text{NO}_3\text{-N}$  provided good correlations with total N uptake (Table XXI). As occurred with TDM, depth to lime may influence P availability, particularly when the surface soil is dry. If P is available in a moist soil zone, above the lime, increased growth will probably occur. Sub-soil  $\text{NO}_3\text{-N}$  may be the main source of plant N when the surface soil is dry. Under these conditions, N in the dry surface soil may not be utilized by the plant.

#### Growing Season Precipitation:

Precipitation data for April 10 to July 16 (Table XXIV) was analyzed with preharvest plant development and mature plant factors using multiple regression. Dry weight at boot stage had a significant positive correlation with the first general rainfall. This first general precipitation came the second week after N topdressing, April 17-23. All other

Table XXII. Effect of N fertilizer treatments on the percent protein in the total dry matter.

Location	% dry matter protein <u>a/</u> N fertilizer treatment lb/A				
	0	20	40	60	80
3*	6.75	6.85	7.55	8.30	8.85
4**	6.50	6.85	7.10	7.75	7.85
5	5.50	5.40	5.35	5.70	5.70
6	7.95	8.20	8.55	9.05	9.05
7**	5.60	6.50	6.85	7.60	8.10
8*	5.80	6.15	6.90	7.20	7.15
9	6.05	6.70	7.30	6.25	7.75
11*	4.45	5.20	5.55	6.55	7.05
13	4.20	5.40	5.65	6.60	5.65
14**	5.20	5.95	6.40	7.05	7.65
15	6.25	6.65	6.50	7.65	7.50
16	5.85	5.90	7.10	8.25	7.75
17	6.35	6.80	7.15	7.50	7.90
18**	5.00	4.85	5.80	6.45	6.50
19**	6.20	7.05	7.05	7.85	8.50
20**	6.25	7.00	7.40	8.40	8.50
21**	5.25	5.90	6.25	6.90	7.25
22	7.10	7.70	7.80	8.80	8.45
23*	5.85	6.60	7.20	7.45	8.20
24*	5.25	5.35	5.40	5.90	6.30
25	5.30	6.75	6.60	7.40	8.00
26*	5.40	5.55	6.25	7.35	7.60
27*	6.85	7.45	8.05	8.10	8.30

a/ % = N x 6.25

\* Significant difference between treatments p = .05.

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

Table XXIII. Effect of N fertilizer treatments on the amount of N in the grain and straw at maturity.

Location	Gms. N/50 ft. <sup>2</sup> a/ N fertilizer treatment lb/A				
	0	20	40	60	80
3	24.76	24.44	25.62	25.81	28.54
4*	31.53	31.85	35.43	38.49	42.30
5	22.33	24.27	26.89	29.79	30.12
6	35.39	31.98	42.08	37.67	39.41
7**	21.90	27.19	30.87	35.47	37.37
8	27.48	31.88	37.82	38.86	40.00
9	16.85	17.79	20.85	18.13	23.00
11*	14.56	19.98	25.01	28.49	27.29
13	16.01	24.85	26.89	30.61	28.65
14**	17.99	20.82	22.29	28.58	29.95
15*	19.04	19.88	22.27	23.30	27.85
16*	16.36	21.20	23.33	29.44	29.71
17*	21.08	27.44	27.13	31.59	35.59
18**	18.00	20.41	24.40	27.12	30.59
19*	21.42	26.76	23.15	28.71	35.15
20**	30.39	33.42	37.44	43.10	44.31
21**	20.22	24.07	28.60	32.57	33.90
22	32.55	32.27	38.73	46.15	39.57
23**	20.91	24.98	27.42	31.41	33.16
24*	28.53	33.35	36.67	38.50	42.04
25	27.24	31.24	31.24	28.66	37.80
26*	22.29	23.29	25.93	29.14	31.67
27*	25.91	34.82	34.31	35.62	35.87

a/ (1.921)(gms/50 ft.<sup>2</sup>) = lb./A.

\* Significant difference between treatments p = .05.

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

Table XXIV. Precipitation by weeks from April 10 to July 16, 1966.

Loc	April	April	April	May	May	May	May	May-	June	June	June	June	June-	July	July	Total
	10-16	17-23	24-30	1-7	8-14	15-21	22-28	29-4	5-11	12-18	19-25	26-2	3-9	10-16		
	Inches of precipitation															
3	.0	.5	.0	1.2	.0	.5	.5	.4	.0	.3	1.0	.0	.9	.0	5.3	
4	.0	.6	.0	1.2	.2	.7	1.1	.4	.0	1.2	2.1	.0	.0	.8	8.3	
5	.0	.5	.0	.8	.2	.5	1.3	.3	.0	.6	.6	.8	.1	.1	5.8	
6	.0	.6	.0	1.0	.0	.5	.9	.4	.0	.2	.6	.0	.1	.1	4.4	
7	.0	.4	.0	1.0	.5	.2	1.0	.2	.2	.7	.6	.8	1.2	.0	6.8	
8	.0	.3	.0	.8	.0	.6	1.4	.2	.1	.3	.5	.5	.6	.0	5.3	
9	.0	.8	.0	.9	.0	.6	1.0	.3	.0	.2	.4	.7	.1	.3	5.3	
11	.0	.3	.0	.8	.3	.5	1.3	.3	.1	.5	1.5	.9	.3	.1	6.9	
13	.1	.3	.0	.9	.3	.8	1.1	.4	.1	.9	1.4	.8	.0	.1	7.2	
14	.0	.4	.0	.0	1.0	.2	.4	.8	.4	.0	.3	1.0	.0	.9	5.4	
15	.0	.9	.0	1.1	.0	.0	1.1	.3	.0	.2	1.6	.4	.1	.3	6.0	
16	.0	.4	.0	1.0	.3	.5	.7	.3	.0	.3	.6	.6	.8	.0	5.5	
17	.0	.6	.0	1.0	.1	.8	.9	.5	.0	.3	.5	.5	.1	.2	5.5	
18	.0	.3	.0	.5	.1	.7	1.2	.3	.0	1.3	1.5	.0	.1	.0	6.0	
19	.0	.4	.0	.8	.3	.4	.8	.5	.0	.3	1.0	.8	.7	.0	6.0	
20	.0	.6	.0	.7	.3	.6	1.2	.1	.1	.2	.8	1.1	.4	.1	6.2	
21	.0	.3	.0	.8	.2	.4	.8	.6	.0	.3	1.1	.6	1.0	.0	6.1	
22	.0	.4	.0	1.2	.0	.7	.7	.5	.0	.2	.8	.1	.0	.0	4.6	
23	.0	.4	.0	1.2	.0	.5	.6	.0	.0	.3	1.1	.0	1.0	.0	5.1	
24	.0	.3	.0	.8	.2	.5	1.5	.2	.0	.2	.6	1.2	.7	.0	6.2	
25	.0	.3	.0	.6	.0	.5	1.6	.2	.0	.2	.7	1.0	.5	.0	5.6	
26	.0	.2	.0	.9	.1	.5	1.8	.3	.0	.1	.8	.9	.4	.0	6.0	
27	.0	.9	.0	.9	.0	.7	1.4	.2	.0	.4	.8	.6	.0	.0	5.9	

preharvest data show no significant correlation with precipitation.

The effect of an early rainfall on growth may be the result of N moving into the soil. During the second week, the applied fertilizer N probably moved into the soil in sufficient amounts to influence plant development. The amount of precipitation and resultant depth of wetting would determine how long N fertilizer remains in a moist soil zone. Precipitation for the first week occurred at only one location with 0.1 inch recorded. During the first week it is likely that the surface soil where active roots may be concentrated was dry. Regardless of N fertilizer application additional moisture at this time probably enhanced plant development. Increasing amounts of rainfall would result in moisture being available in the surface soil for longer periods of time.

Correlation of precipitation with test weight and percent grain protein was found for various weeks. Precipitation for the second week after N topdressing was significantly negatively correlated with test weight for 0, 20, and 40 lb N rates. A significant positive correlation occurred for the twelfth week for all but the 60 lb N rate. Percent grain protein was significantly positively correlated with precipitation occurring the second week.

The early negative effect of precipitation on test weight and positive effect on grain protein indicate that N taken up by the plant at about tillering stage had a direct effect on later grain development. The positive correlation between test weight and precipitation occurring at about flowering stage indicates that carbohydrate formation may be

promoted if enough rain falls to make nutrients in the surface soil available for plant uptake.

Analysis of weekly precipitation data, excluding 0.1 inch values resulted in a slight decrease in correlation with all dependent variables. This implies that a rainfall of 0.1 inch may have an important effect on overall plant development.

U. S. weather bureau records for stations in Judith Basin and Fergus counties show that precipitation occurring from April through July 1966 (Table XXV) was below the long time average. It is possible that in other years, other response patterns could result from different frequencies and amounts of precipitation.

Table XXV. Average rainfall and 1966 rainfall during April, May, June, and July reported by weather stations at Denton, Lewistown, Moccasin and Stanford.

	April		May		June		July		Total	
	<u>Avg.</u>	<u>1966</u>	<u>Avg.</u>	<u>1966</u>	<u>Avg.</u>	<u>1966</u>	<u>Avg.</u>	<u>1966</u>	<u>Avg.</u>	<u>1966</u>
Denton	.83	1.12	1.97	2.05	3.24	.47	1.37	1.14	7.41	4.78
Lewistown	1.03	.86	2.58	2.53	4.00	3.13	1.61	1.37	9.22	7.89
Moccasin	.96	1.57	2.18	1.99	3.50	2.27	1.43	.93	8.07	6.76
Stanford	.97	.91	2.40	2.53	3.55	1.69	1.78	1.06	8.70	6.19
Avg. of all stations									8.35	6.41

## SUMMARY AND CONCLUSION

Field trials conducted with dryland winter wheat were designed to provide information about N fertilization interaction with available spring soil moisture, growing season precipitation, and other soil and environmental factors. Soil samples taken at the time of N topdressing were used to evaluate the amount of stored soil moisture. Rain gages at or near each experimental site were used to determine precipitation by weekly intervals. An attempt was made to keep soil variability at a minimum by having the test plots only on Danvers clay loam or Sipple silt loam soils. Growing season precipitation showed little significant correlation with the various facets of plant and grain development. However, its effect was included in the regression equations when available spring soil moisture showed a significant correlation with some characteristic of plant or grain development.

The first regional precipitation occurred the second week after topdressing. Dry weight of plant samples taken at about boot stage, and percent grain protein had a significant positive correlation with this period of precipitation. Test weight responded with a significant negative correlation. The above is attributed to the movement of N fertilizer into the surface soil and the provision of surface moisture for the young plants. Plant uptake of N at this growth stage may have an important effect on the overall development of the crop. Because rainfall for April through July was below the regional average, future response might be somewhat different.

Grain yield response to N fertilizer was correlated with available spring soil moisture. With less than 2.0 inches of soil moisture, a

theoretical decrease in yields would occur with N fertilizer. Above 2.0 inches available soil moisture, some increase in yields would be predicted with N fertilization.

Soil properties had varying degrees and directions of correlation with components of plant and grain development. Depth to the lime zone was positively correlated with total dry weight (grain plus straw), total N uptake, grain yield, kernel weight, and total grain N. Phosphate chemistry predicts that much of the P in the lime zone will exist as calcium phosphates which are relatively unavailable for plant use. Also, wheat may not be able to utilize P from a dry soil, therefore, if the soil was dry to the lime zone, P would become a limiting factor in plant development.

A positive correlation of soil  $\text{NO}_3\text{-N}$  with percent plant protein, total N uptake, percent grain protein, and total grain N existed for all N treatments. A negative correlation between soil  $\text{NO}_3\text{-N}$  and test weight also occurred. Soil  $\text{NO}_3\text{-N}$  may be utilized by plants at times when a dry surface soil may reduce uptake of fertilizer N. If P is unavailable, an increase in protein synthesis may occur over carbohydrate production, thus, reducing test weight and increasing percent grain protein and total grain N. Variations in percent plant protein and total N uptake may also be related to P deficiencies. Without fertilizer N, soil  $\text{NO}_3\text{-N}$  is probably the main source of plant N. This would account for the correlation of the check treatment  $\text{NO}_3\text{-N}$  with grain yield and dry weight.

Percent organic matter was negatively correlated with kernel weight and test weight. Because organic matter is a source of N, it would have

some influence on protein synthesis. An increase in percent protein would cause a decrease in kernel weight. A reduction in kernel weight without a corresponding reduction in kernel size would result in a lower test weight.

Available soil P was positively correlated with kernel weight and test weight. This may reflect the better soil distribution of natural P as compared to topdressed or banded fertilizer P placed at or near the soil surface. The relatively immobile fertilizer P would become unavailable when the upper few inches of top soil dried.

Results of this experiment indicate that it might be beneficial to apply some N fertilizer to the crop at planting or possibly during a summer fallow operation. Precipitation could then move the N into the subsoil where it would be available during plant development when rainfall was lacking. Because precipitation patterns and soil moisture conditions vary annually, spring topdressing may be desirable to provide additional N as indicated by soil moisture conditions. If the depth of lime factor is related to P availability, then increasing the amount of P above the lime zone would help. Other approaches to increasing P availability such as using chelating agents, or bonding P with materials which would reduce the rate of P fixation, should be studied.

The greatest yield response from N topdressing can be expected when there is 4.29 to 5.07 inches or more of available spring soil moisture. However, further evaluation of soil  $\text{NO}_3\text{-N}$  is needed in order to make suitable N fertilizer recommendations based on existing soil conditions. The data indicates spring soil moisture to be more important than growing season precipitation for predicting yields. However, more information

is needed about the effects of growing season precipitation on the response of dryland winter wheat to N fertilization. The amount of rainfall and time of occurrence may be of value for predicting yields before harvest. The data indicates that depth to the lime zone can be a significant factor and should be considered when predicting grain yields and response to N topdressing.

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