Effect of topdressed N fertilizer, availabale 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
Montana State University

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 (NH4NO3) 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-NO3-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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Approved:

Erhardt R. Hehn
Head, Major Department

James R. Sims
Chairman, Examining Committee

R. J. Goering
Dean, Graduate Division

MONTANA STATE UNIVERSITY
Bozeman, Montana

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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 (NH_4NO_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 NO_3-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[a] 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 CO_2 concentration, light intensity, temperature, and plant turgidity (21). Plants adapt to a condition of moisture stress by reducing transpiration through turgor indiced changes in the stomatal aperature (21, 34). When the stomata close, resistance to 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 NH_4-N was used in larger amounts than NO_3-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 NO_3^-, it is reduced to 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 Nitrobactor 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° and 35° 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.[a/]

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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a/ 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_3-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[a/]	Legal Description	Variety of Grain	Planting Date Mo	Day	Yr	Row Spacing Inches	Fertilizer With Seed[b/] Lb N	Lb P	Last Crop[c/]
1	Bert Algers	JB	NW¼S 5T17NR12E	Cheyenne	9	25	65	10	NA	8.9	WWht
2	Bert Algers	JB	NW¼S33T18NR12E	Cheyenne	9	25	65	10	NA	8.9	WWht
3	John Barber	JB	SW¼S 2T17NR13E	Cheyenne	9	24	65	10	NA	7.3	WWht
4	Gordon Borcherding	F	NE¼S33T14NR16E	Winalta	10	5	65	10	4.4	8.5	Bar
5	I. L. Charmical	F	NW¼S 6T15NR18E	--	--	--	65	10	NA	A	--
6	Bill Cervenka	JB	SW¼S 5T15NR14E	Winalta	10	7	65	10	NA	7.9	Bar
7	Duane Donaldson	F	NW¼S29T18NR15E	--	--	--	65	7	NA	NA	--
8	Duane Donaldson	F	NW¼S 7T18NR15E	--	--	--	65	7	NA	NA	--
9	Howard Donaldson	F	SE¼S27T17NR15E	Cheyenne	10	3	65	10	NA	7.6	WWht
10	Myron Haker	JB	SW¼S 6T17NR12E	--	--	--	65	10	NA	NA	--
11	Cliford Heck	F	SW¼S28T15NR18E	Cheyenne	10	3	65	10	NA	7.6	WWht
12	Max Hertel	F	NE¼S11T13NR16E	--	--	--	65	10	NA	NA	--
13	John Janicek	F	SE¼S29T14NR17E	Cheyenne	9	30	65	7	NA	7.6	SWht
14	Orvie Lemond	JB	NE¼S12T17NR12E	Cheyenne	9	10	65	10	NA	9.0	WWht
15	Leon Linehart	JB	NW¼S 3T16NR15E	Cheyenne	9	10	65	7	NA	8.9	WWht
16	John Metcalf	JB	SE¼S23T17NR12E	Cheyenne	10	1	65	10	NA	8.9	WWht
17	Wilson Metcalf	JB	SE¼S26T16NR14E	Winalta	10	15	65	10	NA	9.9	SWht
18	Tom Moe	F	NW¼S 5T14NR18E	Cheyenne	10	3	65	7	NA	8.9	Bar
19	Henry Nemec	F	NE¼S 6T18NR12E	Warrior	10	4	65	10	NA	NA	Bar
20	Bill D. Snapp	F	NE¼S 4T17NR16E	--	--	--	65	10	NA	NA	--
21	Anton Tesarek	F	NE¼S 5T18NR13E	Warrior	9	30	65	7	5.5	9.9	Bar
22	Vern Valentine	JB	NW¼S13T15NR13E	Cheyenne	9	29	65	7	NA	NA	DFal
23	Jack VanKuiken	F	SW¼S32T18NR13E	Winalta	9	15	65	14	NA	9.9	WWht
24	John Wickens	F	SW¼S34T20NR18E	Cheyenne	9	20	65	7	NA	NA	WWht
25	John Wickens	F	SE¼S27T20NR18E	Cheyenne	9	20	65	7	NA	NA	Bar
26	John Wickens	F	SE¼S22T20NR18E	Cheyenne	9	20	65	7	NA	NA	WWht
27	Herb Zuemke	JB	NE¼S 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.

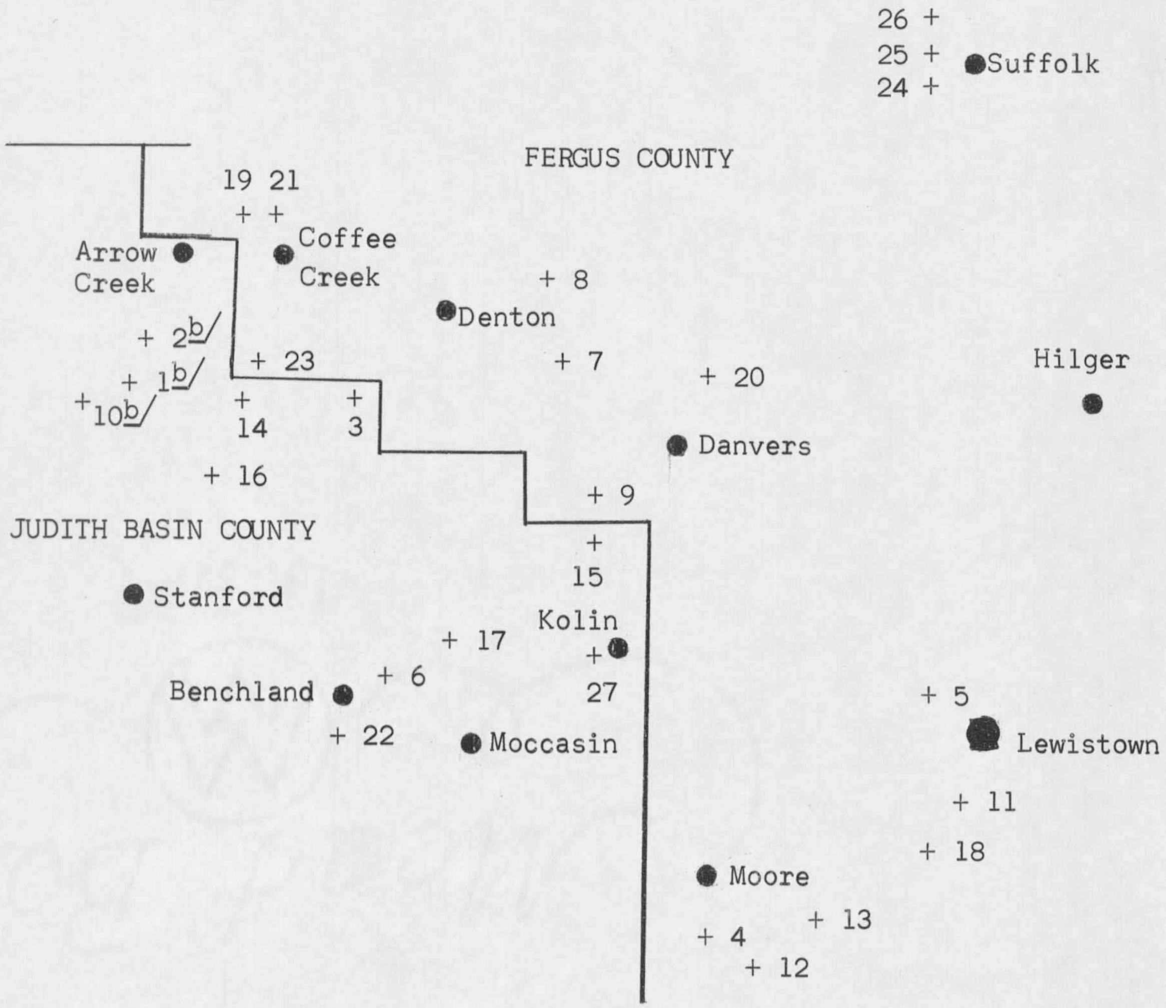

Figure 1. Map showing the approximate locations of the test plots with nitrogen topdressing in the spring of 1966.a/

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

b/ 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 April 24	May 19	June 15	July 18	Inches Available Soil Water
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).a/

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.

a/ 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).[a]

Physiography: High Bench upland

Relief: Level <1% Slope

Elevation: 5500 feet

Climate:[b] 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)(%) Sand	Silt	Clay	>2	Text. Class	pH Sat. Paste	Organic Matter O. C. %	N %	C/N	$CaCO_3$ Equiv. %
0-3	A1p	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

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

b/ MAP = Mean Annual Precipitation; MAT = Mean Annual Temperature