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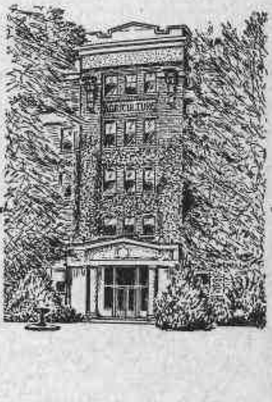

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Fertilizer Needs of Wheat in the Columbia Basin Dryland Area of Oregon[1]

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W. E. HALL, H. E. CUSHMAN, AND R. G. PETERSEN[2]

This bulletin summarizes data and conclusions from fertilizer experiments completed on 173 sites in the Columbia Basin dryland wheat area of Oregon during 1953-57.

Objectives of this research were:

1. To determine general fertility status of soils of the area with regard to nitrogen, phosphorus, sulfur, and certain micro nutrient elements.
2. To determine relationships between indigeneous levels of several forms of soil nitrogen, soil moisture and rainfall, and yield responses to nitrogen fertilizer.
3. To obtain information to improve generalized recommendations for use of fertilizer for wheat in the area.
4. To determine relative effectiveness of fall and spring applications of nitrogen fertilizer in increasing wheat yields.
5. To determine relationships between protein contents and yields of wheat as influenced by nitrogen fertilizer.

Extensive research in the Columbia Basin has established that available soil moisture and nitrogen are the most important factors limiting wheat production in the area. Consequently, major emphasis was on determination of quantitative relationships of these factors to wheat yields.

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[1] Joint contribution from Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, and the Oregon Agricultural Experiment Station.

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Materials and Methods

Description of area

The Columbia Basin dryland wheat area of Oregon includes all nonirrigated wheatlands of Umatilla, Morrow, Gilliam, Sherman, and Wasco counties. The area is roughly 150 miles long and 60 miles wide, extending from the Cascade Mountains on the west to the Blue Mountains on the east and southeast, and lying south of the Columbia River and the Oregon-Washington border. It contains approximately 1½ million acres of cropland.

Wide variations occur in elevation, soil depth, and precipitation. Elevations start at about 600 feet just south of the Columbia River and increase with distance and with proximity to the mountains to nearly 3,000 feet. In general, soil depths decrease with increase in elevation and distance from the Columbia River, ranging from 16 to 20 feet near the river to as little as 1½ feet on some sites in the southern reaches of the area. Average annual precipitation ranges from less than 10 to more than 20 inches. Higher rainfall occurs relatively close to the two mountain ranges. Most of the precipitation occurs between October and April.

Summaries of precipitation during the crop years (September 1 to August 31) pertinent to this study, and the average annual precipitation, are presented in Table 1 for the 16 official U. S. Department of Commerce Weather Bureau stations in the area.

In a relatively narrow belt of Prairie, Chernozem, and Chestnut soils along the face of the Blue Mountains, where annual rainfall averages around 15 inches or more, the land is usually cropped each year, often alternately with wheat and canning peas. In the much larger area of Brown and Chestnut soils, where average rainfall is from 10 to 15 inches, nearly all the farm land is alternately cropped and summer fallowed.

Distribution of experiments and selection of sites

Experimental sites were selected to sample fertilizer responses of wheat under the major variations of soil, climate, and management present in the dryland wheat area of the Columbia Basin counties. The number of experiments to be conducted in any year was estimated from time, manpower, and facilities available and then distributed among the counties roughly in accordance with wheat acreage. Within counties, experiments were further allocated among geographical subareas defined by variation in estimated precipitation, soil depth and texture, and management practices. Within subareas individual sites were selected on the basis of apparent suitability of land for experimental purposes and willingness of the farmer to cooperate.

Table 1. Summary of annual rainfall and precipitation during crop years for 16 official Weather Bureau stations in the Columbia Basin

Weather station	Average annual rainfall[1]	Precipitation for crop year— September 1-August 31				
		1952-53	1953-54	1954-55	1955-56	1956-57
Umatilla County						
Echo	9.8	11.8	8.9	7.1	13.0	10.4
Hermiston	8.2	10.0	6.9	6.5	11.5	9.9
Pendleton	14.3	14.5	10.5	9.4	17.1	11.9
Pendleton Expt. Station	16.0	17.3	14.4	12.9	22.2	15.5
Pilot Rock	13.2	15.0	12.2	11.0	19.5	13.4
Morrow County						
Heppner	12.3	15.4	13.8	11.1	16.9	13.0
Ione	13.4	14.6	11.9	9.8	17.9	13.0
Gilliam County						
Arlington	9.1	11.1	8.5	6.1	13.0	8.0
Condon	12.2	15.2	11.8	10.3	19.9	13.9
Mikkalo	9.3	13.6	8.8	7.4	16.0	10.5
Sherman County						
Kent	10.3	12.2	10.3	8.4	14.7	11.4
Moro	11.2	15.5	12.2	8.6	17.0	10.3
Wasco	11.8	13.1	11.5	8.0	15.7	9.4
Wasco County						
Antelope	11.6	15.8	11.8	10.0	19.2	13.3
Dufur	12.5	15.0	12.9	8.6	18.2	11.5
Friend	14.8	16.2	15.2	10.4	23.3	15.1

[1] Compiled from published records of the U. S. Department of Commerce Weather Bureau.

Finally, selection of specific sites was made on the basis of apparent uniformity of soil and past management, degree of slope, and proximity to roads. In general, slopes of more than 15% were avoided because of the difficulty of operating fertilizer application and plot harvesting equipment on steeper slopes. In most cases slopes were 5% or less. No attempt was made to select sites with any particular slope exposure. Table 2 lists the number of experiments completed in each of the Columbia Basin counties during the 4 years.

Soil series and types

Soils of all experimental sites were examined by soil scientists of the Division of Soil Survey, Soil Conservation Service, U. S. Department of Agriculture, and classified by series and type. The number of experiments on each soil is listed in Table 3.

A brief description of each of the soils follows (11):

Walla Walla soils occupy large areas of Umatilla, Sherman, and Wasco counties but are less extensive in Morrow and Gilliam counties.

Table 2. Number of experiments in each county for each year in both low (below 15 inches) and high (15 inches and over) rainfall areas

County	Number of experiments				
	1953-54	1954-55	1955-56	1956-57	Total
Umatilla					
Low rainfall	11	12	8	5	36
High rainfall	5	5	3	2	15
*Morrow**	9	7	5	5	26
Gilliam					
Low rainfall	6	7	7	4	24
High rainfall	1	0	0	0	1
*Sherman**	10	10	10	11	41
Wasco					
Low rainfall	4	5	9	7	25
High rainfall	3	2	0	0	5
Total	49	48	42	34	173

* All sites in Morrow and Sherman counties were in low rainfall areas.

These soils are found on semi-arid upland plains. They were developed from loess (wind-deposited material) under a cover largely of bunch grass. Except for the surface these soils have remarkably uniform textures throughout their profile. They are located in a 14 to 18 inch annual rainfall area. There is very little, if any, concentration of lime within the top 5 feet of the profile. The normal, moist, coarse-textured and dry phases of Walla Walla silt loam were included in the study.

Morrow is a fairly narrow belt of soils on undulating to gently rolling uplands on the north footslopes of the Blue Mountains in Gilliam, Morrow, and Umatilla counties. The surface is a silt loam but the texture becomes heavier with depth. The soils are all shallow, being only 2 to 2½ feet deep over the underlying bedrock of basalt. The annual rainfall ranges from 12 to 15 inches and is usually sufficient to wet the profile each winter.

Condon are friable, shallow soils developed from loess overlying bedrock stretching across Wasco, Sherman, Gilliam, and Morrow counties. They are shallower to free lime and basalt bedrock than Walla Walla soils and are distinguished from Morrow soils by their more friable and coarser textured subsoils. They lie in a belt having an average annual rainfall of from 10 to 14 inches. Condon silt loam is the predominant soil type.

Ritzville soils occupy a wide zone of smooth to rolling uplands extending south from the Columbia River about 30 miles and reaching from the John Day River on the west nearly to Pendleton on the east. They are light-colored soils developed from fine floury loess and somewhat coarser wind-laid materials. They are underlain for the most part by basalt bedrock but in places by lime-cemented gravels. They range in depth from approximately 3 feet to over 6 feet. The two soil series in this study were Ritzville silt loam and Ritzville very fine sandy loam.

Table 3. Number of experimental sites on each soil type for each year

Soil type	Symbol	Number of experiments				
		1953-54	1954-55	1955-56	1956-57	Total
Athena silt loam	At	3	4	1	1	9
Walla Walla silt loam	Wl	8	4	3	4	19
Walla Walla silt loam, moist phase	Wm	2	1	3	2	8
Walla Walla silt loam, dry phase	Wd	3	3	4	3	13
Walla Walla coarse silt loam	Wc	1	2	2	4	9
Walla Walla very fine sandy loam	Wv	0	2	0	0	2
Ritzville silt loam	Rs	6	8	4	3	21
Ritzville very fine sandy loam	Ri	3	3	5	3	14
Condon silt loam	Co	8	7	8	10	33
Shaniko silt loam	Sh	0	1	1	0	2
Dufur silt loam	Du	1	1	1	1	4
Morrow silt loam	Mo	6	3	4	0	13
McKay silt loam	Mc	1	2	1	0	4
Pilot Rock silt loam, shallow phase	Pi	2	1	0	1	4
Tub silty clay loam	Tu	2	1	1	1	5
Waha silt loam	Wh	1	1	1	0	3
Wamic very fine sandy loam	Wa	0	0	0	1	1
New Series "A" very fine sandy loam	NA	2	0	0	0	2
New Series "A" silt loam	NS	0	1	2	0	3
New Series "B" very fine sandy loam	NB	0	1	0	0	1
New Series "C" silt loam	NC	0	1	0	0	1
New Series "E" silt loam	NE	0	0	1	0	1
Unnamed series very fine sandy loam	UN	0	1	0	0	1
		49	48	42	34	173

Athena silt loam soil occupies an extensive belt in the higher part of the plains and lower foothills northeast of Pendleton. It is a dark-colored, fine-textured soil, and is in a higher rainfall area than Walla Walla.

Other soils: Pilot rock silt loam occurs in the vicinity of Pilot Rock in Umatilla County. It is similar to Walla Walla but is quite shallow, underlain by a firmly cemented hardpan over beds of lime-cemented gravels. The parent material is a rather thin mantle of fine floury loess.

McKay silt loam lies on old alluvial fans and terraces northeast of Pilot Rick. The surface soil is quite friable and granular but becomes extremely platy down to 15 or 20 inches. Below this the soil becomes columnar in appearance and alkaline in reaction.

Waha silty clay loam occurs in the foothills in the eastern part of Umatilla County. It is a fairly shallow soil (21 to 38 inches) and because it is in an area of higher rainfall is moderately well developed.

Tub silt loam is very shallow soil overlying a clayey material derived from tuff. This soil occurs around the town of Antelope in southeastern Wasco County.

Farmer operations on experimental sites

In all cases the cooperating farmers, in accordance with their own schedules, prepared seedbeds, planted wheat, sprayed weeds, and performed other necessary field operations on experimental sites except application of fertilizer treatments and harvest of plots. When they applied fertilizer to surrounding areas they avoided experimental sites. With few exceptions wheat was seeded at right angles to plot lengths.

Application of fertilizers

Required quantities of fertilizers were applied with a tractor-mounted, belt-type applicator having four belt-hoppers each supplying two bands of fertilizer spaced a foot apart. Fertilizers applied in fall, on loose seedbeds, were placed on or slightly below soil surfaces. Subsequent stirring of the soil by rod-weeders and grain drills mixed the fertilizer with the soil. In the spring, nitrogen fertilizer was applied to the soil surface in bands a foot apart. In all cases a considerable amount of rainfall occurred after spring application of fertilizers.

Experimental treatments and design

Fertilizer treatments varied somewhat with areas and years (Table 4). Nitrogen rates employed in lower rainfall areas varied by 20-pound increments from 0 to 80 pounds N per acre in 1953-54 and from 0 to 100 pounds in later years. In the higher rainfall areas

Table 4. Fertilizers applied to wheat in the lower rainfall area[1]

Fertilizer treatments for crop year		
1953-54	1954-55 and 1956-57	1955-56
N-P_2O_5-S	N-P_2O_5-S	N-P_2O_5-S
	Fall-applied fertilizer, pounds per acre	
0-0-0	0-0-0	0-0-0
0-50-50		
20-50-50	20-0-0	20-0-0
40-50-50	40-0-0	40-0-0
60-50-50	60-0-0	60-0-0
80-50-50	80-0-0	80-0-0
	100-0-0	100-0-0
0-50-0		
40-50-0	40-50-0	
0-0-50		
40-0-50	40-0-50	
40-0-0		
	40-50-50	
	40-50-50-MN[2]	40-50-50-MN
	Spring-applied fertilizer, pounds per acre	
20-50-50[3]	20-0-0	20-0-0
40-50-50	40-0-0	40-0-0
60-50-50	60-0-0	60-0-0
80-50-50	80-0-0	80-0-0
	100-0-0	100-0-0

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[1] On sites in the higher rainfall area, rates of nitrogen were 50% higher than those listed here.

[2] MN = Micro nutrients (25 lbs. each of borax and sulfates of copper and manganese, and 50 lbs. of zinc sulfate per acre).

[3] P_2O_5 and S applied in fall.

rates of nitrogen were 50% greater. These rates of nitrogen were applied in the fall at seeding time (September or October) and in the spring shortly after growth started (March or early April) for fall-seeded wheat.

In lower rainfall areas where circumstances required wheat to be sown in spring, both fall and spring nitrogen treatments were applied. In higher rainfall areas nitrogen was applied only in spring for spring wheat.

To insure that responses to nitrogen were not limited by deficiencies of phosphorus or sulfur, these two nutrients were applied with all rates of nitrogen in 1953-54. In succeeding years phosphorus and sulfur were employed only in certain treatments designed to provide qualitative information on the need for these elements. A micro nutrient mixture containing boron, copper, manganese, and zinc was combined with nitrogen, phosphorus, and sulfur in one treatment for each of the three crop years 1955 to 1957.

Ammonium nitrate, Tennessee Valley Authority concentrated superphosphate (essentially sulfur-free), gypsum, borax, and sulfates of copper, manganese, and zinc were employed as fertilizer sources in all experiments.

Soil sampling

At the time of fall and spring fertilizer application soils of all experimental sites were sampled by 1-foot increments to a depth of 6 feet, or to bedrock or other restrictive layer if the usable soil depth was less than 6 feet. Four composite samples for each depth were taken from each experimental site. The fall sampling unit was the 50 x 120 foot area of one replication or block (50 x 96 foot in 1955-56). In spring the check plots (0 lb. N/A) in each replication were the sampling units. Samples from the first and second foot were composites of approximately 10 cores taken with a 1-inch sampling tube; samples from greater depths were composites of 5 cores.

Dates of fertilizer application and soil sampling

Mean dates of application of fertilizer and sampling of soils for determination of moisture and nitrogen and standard deviations from these dates are given in Table 5.

Inevitably, in a research program of this scale a considerable spread occurred in dates of fertilizer application. A general tendency existed for dates of application and sampling to be a few days later in Umatilla and Morrow than in the other three counties. Applications within a given county were usually completed within one to two weeks.

Determination of available soil moisture

All soil samples were dried for 48 hours at 55° C. for determination of moisture content and subsequently crushed and screened for further laboratory determinations. Soil samples to determine moisture

Table 5. Mean dates of application of fertilizer and sampling of soil

Crop year	Fall application and sampling	Spring application and sampling
	Mean Date ± S.D.	Mean Date ± S.D.
1953-54	Oct. 1 ± 7 days	Mar. 18 ± 12 days
1954-55	Oct. 5 ± 14 days	Mar. 23 ± 12 days
1955-56	Sept. 31 ± 9 days	Mar. 28 ± 15 days
1956-57	Sept. 24 ± 12 days	April 2 ± 12 days

retention at 15 atmospheres tension were prepared for each site by compositing equal portions of soil from the four replicate samples of each depth sampled. Fifteen-atmosphere percentages were determined by Richards' method (9). Duplicate samples for determination of bulk density were taken with a modified Lutz sampler (8). Samples were taken from each foot of soil to 6 feet or to rock on 78 experimental sites during 1953-54 and 1954-55. Mean values were calculated for each foot of depth of each soil series and type sampled. These values were employed for similar soils in 1955-56 and 1956-57. An assumed value of 1.30 was used for soils on which the bulk density was not determined. The 15-atmosphere percentage and bulk density values are presented in Table 6.

Percentage of available soil moisture at time of sampling was calculated by subtracting the 15-atmosphere percentage from the moisture percentage found in the soil. The total available soil moisture, in inches per foot of soil, was calculated as follows: available moisture (percent) x bulk density x 12.

Analyses of soil for nitrogen

All samples of soil were analyzed for nitrate, ammonium, and nitrifiable nitrogen by procedures outlined by Stanford and Hanway (10). Values for each soil depth were converted from parts per million to pounds per acre by this formula: 0.2718 x bulk density x parts N per million.

Rainfall records

From 1954-55 to 1956-57, 35 cooperators in Morrow, Gilliam, Sherman, and Wasco counties were supplied with rain gauges to measure precipitation at points as near experimental sites as practical. Some gauges were a mile or two from the experimental site and in certain instances were as far as 5 or 6 miles away. Precipitation records for Umatilla County were obtained from approximately 15 rain gauges located in as many communities within the county and serviced by Pendleton Grain Growers, Inc., and their cooperators.[3] Precipitation records were also obtained from all official Weather Bureau observation stations in the area. Precipitation occurring between spring fertilizer application and harvest was added to available moisture in the soil at date of application. Since runoff of spring rainfall often is negligible, the sum of these two was considered the amount of

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[3] These records were made available by B. A. Gassett, Research Laboratory, Pendleton Grain Growers, Inc.

moisture available to the crop after spring fertilizing. Precipitation at a given experimental site was estimated from the nearest gauging station or stations.

Table 6. Mean bulk densities and 15-atmosphere moisture percentages for some soils of the Columbia Basin[1]

Soil type	Number of sites	Mean bulk density and 15-atmosphere moisture percentage at depths (feet) of						
		0-1	1-2	2-3	3-4	4-5	5-6	Mean
		Bulk density, grams per cubic centimeter						
Athena silt loam	1	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Walla Walla silt loam[2]	24	1.38	1.35	1.38	1.41	1.41	1.39	1.39
Walla Walla coarse silt loam[3]	9	1.38	1.38	1.35	1.42	1.44	1.40	1.35
Ritzville Silt loam	15	1.33	1.30	1.32	1.31	1.32	1.32	1.32
Ritzville very fine sandy loam	16	1.33	1.31	1.33	1.35	1.32	1.33	1.33
Condon silt loam	25	1.26	1.26	1.34	1.33	....	....	1.30
Morrow silt loam	9	1.23	1.23	1.26	1.30	....	....	1.26
McKay silt loam	2	1.30	1.46	1.39	....	....	....	1.38
Pilot Rock silt loam	3	1.30	1.31	1.31	1.31	....	....	1.31
Tub silty clay loam	1	1.30	1.30	....	....	....	....	1.30
Waha silt loam	3	1.22	1.33	1.22	....	....	....	1.26
New Series "A" silt loam	2	1.47	1.55	1.56	1.41	1.50	1.52	1.50
New Series "B" very fine sandy loam	1	1.29	1.33	1.38	1.40	1.44	1.44	1.38
		15-atmosphere moisture, percent						
Athena silt loam	9	10.69	10.87	9.47	10.14	10.29	11.73	10.53
Walla Walla silt loam[2]	30	6.87	6.99	6.45	6.40	6.46	6.42	6.60
Walla Walla coarse silt loam [3]	13	6.97	6.77	6.52	5.88	5.83	5.71	6.28
Ritzville silt loam	20	6.29	6.48	6.36	6.20	6.03	6.13	6.15
Ritzville very fine sandy loam	17	7.15	7.22	7.02	6.72	6.22	6.43	6.79
Condon silt loam	37	8.94	9.25	8.86	8.83	9.22	9.61	9.12
Morrow silt loam	12	11.43	12.62	11.07	....	....	....	11.71
McKay silt loam	4	11.58	15.06	13.50	....	....	....	13.38
Pilot Rock silt loam	3	9.97	10.09	10.34	9.37	....	....	9.94
Tub silt loam	4	19.81	21.94	....	....	....	....	20.88
Waha silt loam	2	10.80	11.10	10.00	10.00	8.70	8.80	9.90
New Series "A" silt loam	4	6.68	6.75	7.53	9.15	10.60	10.44	8.53
New Series "B" very fine sandy loam	1	8.56	8.31	8.67	8.56	6.78	6.24	7.85

[1] The number of values averaged for each depth may differ owing to variability in site depth within soil types.

[2] Includes moist phase.

[3] Includes dry phase.

Wheat varieties

Table 7 lists varieties of wheat grown in these experiments and the number of sites on which each was grown.

The varieties Elmar, Rex, Golden, Brevor, Federation, Elgin, and Omar are white wheats, used chiefly for pastry flours. Orfed, Requa, Baart, and Burt are white wheats used for either pastry or bread flours, depending upon their protein content. Turkey Red is a hard red winter bread wheat.

Table 7. Varieties of wheat and number of sites on which each was grown

Wheat variety	Number of sites				
	1953-54	1954-55	1955-56	1956-57	Total
Elmar	29	22	22	19	92
Rex	9	7	2	....	18
Golden	5	7	4	4	20
Brevor	2	5	2	....	9
Federation, spring	2	....	8	....	10
Federation, fall	....	1	....	....	1
Elgin	1	3	1	1	6
Orfed	....	2	1	2	5
Requa	....	....	1	....	1
Baart	....	....	1	....	1
Burt	....	....	....	2	2
Turkey Red	1	1	....	1	3
Omar	....	....	....	5	5
Total	49	48	42	34	173

Harvesting methods

Self-propelled portable plot combines were used to harvest all plots except a few in the higher rainfall area of Umatilla County, where a larger combine was used. Small plot combines cut and threshed wheat from a strip 41½ inches wide and 40 feet long in the central portion of the 8 x 50 foot plots. Larger combines harvested strips 7 by 100 feet from plots 120 feet long and 12 feet wide.

Wheat from each individual plot was re-cleaned and weighed. Yields were calculated at 60-pound bushels per acre. Subsamples were analyzed for protein by the Kjeldahl procedure. Protein values were corrected to 14% moisture in the wheat as suggested by the Western Wheat Quality Laboratory, Pullman, Washington. For 1953-54 and 1954-55 crops, wheat samples from individual plots were analyzed while for 1955-56 and 1956-57, samples from the four replicate plots of each treatment on each site were composited prior to analysis. Test weights were determined by normal procedures.

Determination of residual effects

To determine residual effects of nitrogen fertilizer applied to the preceding crop, original plots on certain sites were re-located and wheat was harvested with a plot combine in the usual manner. Each year there were some plots where no residual effects of nitrogen were observed when the experimental sites were examined in May. No attempt was made to measure residual effects where none were apparent upon observation. Estimations of residual effects were not made where a high degree of variability was exhibited in the initial crop year.

Determination of "maximum" yield

Maximum yield was determined by (1) subtracting the L.S.D. from the highest yield of the experiment and (2) selecting the yield which was equal to or larger than the subtracted figure starting from the lowest rate of applied nitrogen.

Experimental Results and Discussion

Yield responses from added nitrogen

Average yields of wheat obtained from each of the rates of nitrogen applied, in fall and spring, on 152 experimental sites in the lower rainfall areas are summarized in Table 8. Data are grouped by magnitude of nitrogen response obtained. Data from certain sites deviated considerably from the average of that group. Yield responses on individual sites and averages for counties are presented elsewhere (1, 2).

Statistically significant wheat yield increases were observed on 109 and 112 sites from fall- and spring-applied nitrogen, respectively. Highest average yields were obtained in the 1956-57 crop, lowest in the 1954-55 crop.

Average yield increases from the several rates of fall-applied nitrogen were: 20 pounds, 6.4 bushels; 40 pounds, 10.2 bushels; and 60 pounds, 12.2 bushels. Average yields were not further increased by larger amounts of nitrogen. Yield increases from spring-applied nitrogen were 4.9, 8.8, 11.2, 11.9, and 12.8 bushels, respectively, for 20, 40, 60, 80, and 100 pounds of nitrogen.

During the four years there were 24 sites (15.8% of the total in the low rainfall area) on which effects of fall nitrogen applications on wheat yields were too small to be statistically significant. Similar results were observed from spring-applied nitrogen on 29 sites (19.1% of the total).

Table 8. Summary of average yields of wheat as affected by nitrogen fertilizer, low rainfall area, 1953-57

Time of application	Number of sites	Average yields of wheat fertilized with nitrogen at indicated rates, pounds per acre					
		0	20	40	60	80	100[1]
		Bushels per acre					
(Sites on which one or more rates of nitrogen produced significant[2] yield increases.)							
Fall 1953	28	25.3	32.1	35.9	37.8	38.4	......
Fall 1954	22	21.2	29.0	31.7	33.5	33.2	31.9
Fall 1955	36	19.9	25.4	29.9	32.3	33.5	35.3
Fall 1956	23	30.9	37.1	40.9	42.5	40.8	41.5
4-year average	109	23.9	30.3	34.1	36.1	36.1	36.1
Spring 1954	34	26.2	30.2	33.1	35.4	36.3	......
Spring 1955	25	21.0	26.6	30.3	32.3	33.1	32.8
Spring 1956	31	20.1	25.8	30.1	33.2	34.1	36.1
Spring 1957	22	31.0	36.6	40.3	42.2	42.6	43.3
4-year average	112	24.3	29.2	33.1	35.5	36.2	37.1
(Sites on which effects of nitrogen on yields were too small to be significant.)							
Fall 1953	8	28.0	29.7	30.3	28.6	28.2	......
Fall 1954	10	18.9	20.9	21.2	21.3	19.8	19.9
Fall 1955	3	22.9	23.7	23.3	23.4	21.6	24.9
Fall 1956	3	29.6	29.3	29.0	28.8	29.0	30.0
4-year average	24	23.8	25.2	25.5	24.9	23.1	22.7
Spring 1954	6	22.9	22.9	21.5	22.9	22.2	......
Spring 1955	10	20.7	22.1	22.5	23.2	22.1	21.8
Spring 1956	8	20.4	21.5	21.5	23.1	21.5	23.0
Spring 1957	5	26.8	26.4	29.2	28.8	29.0	29.5
4-year average	29	22.1	22.9	23.2	24.1	23.1	23.9
(Sites on which one or more rates of nitrogen produced significant yield decreases and no significant increases occurred.)							
Fall 1953	4	24.0	21.4	19.9	16.3	15.7	......
Fall 1954	9	22.7	22.2	20.3	16.8	15.1	14.2
Fall 1955	0	......	......	......	......	......	......
Fall 1956	6	27.1	26.2	22.8	22.0	20.2	18.2
4-year average	19	24.4	23.3	21.0	18.4	16.8	15.8
Spring 1954	0	......	......	......	......	......	......
Spring 1955	6	21.2	20.8	19.6	18.2	15.9	14.9
Spring 1956	0	......	......	......	......	......	......
Spring 1957	5	29.7	28.4	27.2	25.8	24.8	27.1
4-year average	11	24.7	23.9	22.8	21.4	19.6	20.0

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[1] The 100-pound rate of nitrogen was not employed in 1953-54.

[2] In comparison with 0 pounds nitrogen per acre, at $P = 0.05$.

Table 8. Summary of average yields of wheat as affected by nitrogen fertilizer, low rainfall area, 1953-57 (Continued)

Time of application	Number of sites	Average yields of wheat fertilized with nitrogen at indicated rates, pounds per acre					
		0	20	40	60	80	100[1]
		Bushels per acre					
(Weighted average yields for all sites regardless of type of nitrogen response.)							
Fall 1953	40	25.7	30.5	33.2	33.8	34.0	......
Fall 1954	41	20.4	25.5	26.6	26.8	25.9	25.1
Fall 1955	39	20.1	25.3	29.4	31.6	32.6	34.5
Fall 1956	32	30.1	34.3	36.4	37.4	35.8	36.1
4-year average	152	23.8	28.6	31.1	32.1	31.8	31.5
Spring 1954	40	25.7	29.1	31.4	33.5	34.2	......
Spring 1955	41	21.0	24.5	26.6	27.7	27.4	27.1
Spring 1956	39	20.1	24.9	28.3	31.1	31.5	33.4
Spring 1957	32	30.1	33.7	36.5	37.5	37.7	38.6
4-year average	152	23.9	27.8	30.4	32.2	32.4	32.6

[1] The 100-pound rate of nitrogen was not employed in 1953-54.

[2] In comparison with 0 pounds nitrogen per acre, at $P = 0.05$.

There were 19 sites (12.5%) on which one or more rates of fall-applied nitrogen resulted in statistically significant yield depressions and no increases. No yield depressions were observed in the 1955-56 crop. Yield depressions from spring-applied nitrogen occurred on 11 sites (7.2%) and in only 2 of the 4 years.

The overall average yields of wheat grown without nitrogen were similar on all sites regardless of magnitude of nitrogen fertilizer response.

For all experimental sites in the lower rainfall area average yield increases from 20, 40, 60, 80, and 100 pounds of fall-applied nitrogen were 4.8, 7.3, 8.3, 8.0, and 7.7 bushels, respectively. For the same rates of spring-applied nitrogen the yield increases were 3.9, 6.5, 8.3, 8.5, and 8.7 bushels, respectively.

Average yields obtained in higher rainfall areas are presented in Table 9. During the 4 years, nitrogen was applied both fall and spring on 19 sites and in spring only on 2 additional sites. Fall-applied nitrogen increased yields significantly on 16 sites and decreased yields on 3 sites. Spring-applied nitrogen increased yields on 16 sites, had no significant effect on yields on 2 sites, and decreased yields on 3 sites.

On 16 sites where significant yield increases occurred, 30, 60, 90, and 120 pounds of fall-applied nitrogen produced average yield increases of 10.2, 14.5, 15.8, and 13.2 bushels, respectively. Nitrogen applied in the spring at the same rates caused yield increases of 10.9, 15.9, 17.9, and 19.0 bushels.

Table 9. Summary of average yields of wheat as affected by nitrogen fertilizer, high rainfall area, 1953-57

Time of application	Number of sites	Average yields of wheat fertilized with nitrogen at indicated rates, pounds per acre					
		0	30	60	90	120	150[1]
		Bushels per acre					
(Sites on which one or more rates of nitrogen produced significant[2] yield increases.)							
Fall 1953	8	28.7	38.7	43.2	44.3	42.8	......
Fall 1954	3	20.6	31.1	34.4	32.0	27.0	26.1
Fall 1955	3	31.4	43.2	49.9	54.3	50.9	52.1
Fall 1956	2	47.5	55.5	56.4	59.8	57.4	57.6
4-year average	16	30.0	40.2	44.5	45.8	43.2	43.7
Spring 1954	9	26.5	38.0	41.9	45.0	46.7	......
Spring 1955	2	26.9	36.8	43.9	42.2	39.1	44.3
Spring 1956	3	31.4	42.4	50.8	55.2	56.8	56.9
Spring 1957	2	47.7	56.4	59.1	56.6	59.1	57.0
4-year average	16	30.1	41.0	46.0	48.0	49.1	53.3
(Sites on which effects of nitrogen on yields were too small to be significant.)							
Fall 1953	0						
Fall 1954	0						
Fall 1955	0						
Fall 1956	0						
4-year average	0						
Spring 1954	0	......	......	......	......	......	......
Spring 1955	2	11.0	12.6	......	13.3	......	11.0
Spring 1956	0	......	......	......	......	......	......
Spring 1957	0	......	......	......	......	......	......
4-year average	2	11.0	12.6	......	13.3	......	11.0
(Sites on which one or more rates of nitrogen produced significant yield decreases and no significant increases occurred.)							
Fall 1953	0	......	......	......	......	......	......
Fall 1954	3	23.3	23.8	17.0	13.9	13.9	9.3
Fall 1955	0	......	......	......	......	......	......
Fall 1956	0	......	......	......	......	......	......
4-year average	3	23.3	23.8	17.0	13.9	13.9	9.3
Spring 1954	0	......	......	......	......	......	......
Spring 1955	3	27.7	28.7	......	21.9	......	17.7
Spring 1956	0	......	......	......	......	......	......
Spring 1957	0	......	......	......	......	......	......
4-year average	3	27.7	28.7	......	21.9	......	17.7

[1] The 150 pound rate of nitrogen was not employed in 1953-54.

[2] In comparison with 0 pounds nitrogen per acre, at P = 0.05.

Table 9. Summary of average yields of wheat as affected by nitrogen fertilizer, high rainfall area, 1953-57 (Continued)

Time of application	Number of sites	Average yields of wheat fertilized with nitrogen at indicated rates, pounds per acre					
		0	30	60	90	120	150[1]
		Bushels per acre					
(Weighted average yields of all sites regardless of type of nitrogen response.)							
Fall 1953	8	28.7	38.7	43.2	44.3	42.8	......
Fall 1954	6	21.9	27.4	25.7	22.9	20.4	17.7
Fall 1955	3	31.4	43.2	49.9	54.3	50.9	52.1
Fall 1956	2	47.5	55.5	56.4	59.8	57.4	57.6
4-year average	19	28.9	37.6	40.1	40.8	38.5	34.3
Spring 1954	9	26.5	38.0	41.9	45.0	46.7	......
Spring 1955	7	22.7	26.4	......	25.2	......	23.4
Spring 1956	3	31.4	42.4	......	55.2	......	56.9
Spring 1957	2	47.7	56.4	......	56.6	......	57.0
4-year average	21	28.0	36.5	41.9	41.0	46.7	37.4

[1] The 150 pound rate of nitrogen was not employed in 1953-54.

[2] In comparison with 0 pounds nitrogen per acre, at P = 0.05.

When all sites were considered, average yield increases for 30, 60, 90, and 120 pounds of nitrogen applied in the fall were 8.7, 11.2, 11.9, and 9.6 bushels, respectively. Returns from 30, 90, and 150 pounds of nitrogen applied in the spring were 8.5, 13.0, and 9.4 bushels, respectively.

Yield responses to sulfur, phosphorus, and micro nutrients

Sulfur and phosphorus variables (Table 3) were included in the experiments each year. The micro nutrients boron, copper, manganese, and zinc were employed in one treatment each year except 1953-54. In 1955-56 a single treatment included sulfur, phosphorus, and the micro nutrients.

There were statistically significant yield responses to sulfur on 1 experimental site in 1953-54, 2 sites in 1954-55, and no sites in 1956-57. Significant yield responses to phosphorus were noted on 2, 5, and 0 sites, respectively in these years. In 1955-56 there were 4 significant responses to the combination of sulfur, phosphorus, and the micro nutrients; the nutrient responsible could not be identified but sulfur is suspected.

It is probable that some or all of the indicated yield increases from sulfur and phosphorus are real. However, where significance is calculated at a probability of 0.05, and 173 experiments are involved, chance alone could be responsible for 8 or 9 apparently significant yield increases. Additional research will be necessary to more precisely define sulfur and phosphorus deficiencies in the area.

Effects of time of application of nitrogen

Summaries of the average yields of wheat produced by similar rates of nitrogen applied in fall or spring are shown in Table 10. During the 4 years there were 38 sites on which fall-applied was superior to spring-applied nitrogen, 42 sites on which spring-applied nitrogen was superior, and 91 sites on which time of application had no significant effect on yields. Fall-applied nitrogen in the low rainfall area was more effective than spring-applied in increasing yields under conditions of adequate moisture and also more effective in reducing yields where moisture was seriously limited during the latter part of the growing season.

Table 10. Summary of effects of time of application of nitrogen fertilizer on wheat yields for all experimental sites

Year	Number of sites	Average yield from nitrogen applied	
		Fall	Spring
		Bushels per acre	
(Sites on which fall-applied was superior to spring-applied nitrogen.)			
1953-54	15	37.5	32.8
1954-55	5	36.1	34.5
1955-56	14	28.8	25.1
1956-57	4	39.2	35.0
Average	38	34.3	30.4
(Sites on which spring-applied was superior to fall-applied nitrogen.)			
1953-54	12	26.5	30.4
1954-55	13	20.5	23.1
1955-56	4	32.3	38.5
1956-57	13	29.9	32.6
Average	42	26.2	29.6
(Sites on which differences between fall- and spring-applied nitrogen were not significant.)			
1953-54	21	32.9	33.4
1954-55	29	24.6	24.6
1955-56	24	30.7	30.5
1956-57	17	40.2	40.3
Average	91	31.1	31.1
(All sites.)			
1953-54	48	32.7	32.4
1954-55	47	24.7	25.3
1955-56	42	30.2	29.5
1956-57	34	36.1	36.7
Average	171	30.6	30.6

Table 11. Relative efficiencies of fall- and spring-applied nitrogen as related to depth of soil

Soil depth	Fall-applied nitrogen superior	Spring-applied nitrogen superior	No significant difference	Average total
	No. sites	*No. sites*	*No. sites*	*No. sites*
Less than 3 feet	0	14	24	38
3 to 5 feet....	8	23	27	58
Over 5 feet ..	30	5	40	75
Total	38	42	91	171

Sufficient soil moisture was available consistently in early spring to allow plants to utilize some of the nitrogen applied in the fall. It was thought that where moisture supply was insufficient to carry the crop to maturity, tillering and foliage production stimulated by the fall-applied nitrogen resulted in exhaustion of available moisture early in the physiological development of the plants. Consequent "burning" of foliage and shriveling of grain resulted in yield reductions. This was reflected in the test weight of the grain. Nitrogen applied in spring had less effect on tillering and foliage and thereby contributed less to rapid exhaustion of available moisture, resulting in fewer yield depressions than fall-applied nitrogen.

In Table 11 the number of experimental sites on which fall-applied nitrogen was superior to, inferior to, or not significantly different from spring-applied nitrogen in effect on yields are tabulated by soil depth. Fall-applied was not superior to spring-applied nitrogen on any soil depth less than 3 feet; 30 of the 38 sites on which fall-applied nitrogen was superior had a soil depth of over 5 feet. One-third of the 42 sites on which spring-applied was superior to fall-applied nitrogen had soil depth of less than 3 feet; over three-quarters had soil depth less than 5 feet. Only 5 of 42 sites in this class had soil depth of over 5 feet. Soil depths on sites where fall- and spring-applied nitrogen had similar effects on yields were distributed throughout the range; nearly one-half had depth of 5 feet or more.

Nitrogen required to produce one bushel of wheat

In the intermediate rainfall areas of eastern Washington, Jacquot (5) reported that from 2.3 to 5.7 pounds of nitrogen were required to produce 1 bushel of wheat under the wheat-fallow system of farming. The average was 3.2 pounds of nitrogen per bushel whether 30 or 60 pounds of nitrogen per acre were used. Under annual cropping conditions the amount of nitrogen required over a 4-year period to produce a bushel of wheat was 2.6 and 2.7 pounds, respectively, for 30- and 60-pound applications, with a range from 1.9 pounds in 1948 to 3.5 pounds in 1950. The report did not contain the ranges that were averaged to obtain the applied values given.

The average number of pounds of fall-applied nitrogen required to increase wheat yield by 1 bushel per acre in the Columbia Basin of Oregon is given in Table 12 for each year and county. Calculations

Table 12. Average amount of nitrogen required to increase wheat yield by 1 bushel per acre on sites in low rainfall area on which *fall-applied* nitrogen produced significant yield increases

Year	County[1]	Number of sites	Nitrogen required for maximum yield	Yield			Amount of nitrogen per bushel increase
				Check	Maximum	Increase	
			Lbs./A.	*Bushels per acre*			*Pounds*
1953–54....	U	9	37.8	23.1	34.8	11.7	3.2
	M	3	20.0	24.0	28.8	4.8	4.2
	G	4	55.0	24.3	32.9	8.6	6.4
	S	8	55.0	30.7	48.2	17.5	3.1
	W	4	35.0	19.2	30.0	10.8	3.2
	All	28	42.9	25.0	37.0	12.0	3.6
1954–55....	U	9	42.2	18.2	30.3	12.1	3.5
	M	4	25.0	16.5	22.5	6.0	4.2
	G	4	40.0	25.1	34.9	9.8	4.1
	S	3	53.3	29.1	47.6	18.5	2.9
	W	2	50.0	24.1	41.9	17.8	2.8
	All	22	40.9	21.2	33.1	11.9	3.4
1955–56....	U	8	52.5	23.3	37.7	14.4	3.7
	M	5	52.0	21.4	35.2	13.8	3.8
	G	5	48.0	16.5	28.5	12.0	4.0
	S	9	51.1	21.4	34.5	13.1	3.9
	W	9	66.7	16.6	30.4	13.8	4.8
	All	36	55.0	15.8	33.4	17.6	4.1
1956–57....	U	4	45.0	30.7	45.2	14.5	3.1
	M	2	20.0	29.4	34.7	5.3	3.8
	G	2	60.0	28.0	37.5	9.5	6.3
	S	9	26.7	33.7	40.7	7.0	3.8
	W	6	36.7	28.5	40.9	12.4	3.0
	All	23	34.8	30.9	40.7	9.8	3.6
4 years....	U	30	44.0	22.7	35.6	12.9	3.4
	M	14	32.9	21.7	30.1	8.4	3.9
	G	15	49.3	22.4	32.6	10.2	4.8
	S	29	44.8	28.6	41.5	12.9	3.5
	W	21	50.5	21.2	34.4	13.2	3.8
4 years, 5 counties		109	44.8	23.8	35.8	12.0	3.7

[1] Counties: U = Umatilla, M = Morrow, G = Gilliam, S = Sherman, and W = Wasco.

Table 13. Average amount of nitrogen required to increase wheat yield by 1 bushel per acre on sites in low rainfall area on which *spring-applied* nitrogen produced significant yield increases

Year	County[1]	Number of sites	Nitrogen required for maximum yield	Yield			Amount of nitrogen per bushel increase
				Check	Maximum	Increase	
			Lbs./A.	*Bushels per acre*			*Pounds*
1953–54....	U	9	51.1	24.0	35.4	11.4	4.5
	M	6	36.7	25.8	34.1	8.3	4.4
	G	5	40.0	35.7	34.1	8.4	4.8
	S	10	44.0	31.4	38.8	7.4	5.9
	W	4	45.0	19.2	28.1	8.9	5.1
	All	34	44.1	26.2	35.1	8.9	4.9
1954–55....	U	11	41.8	18.6	30.2	11.6	3.6
	M	4	40.0	14.0	20.6	6.6	6.0
	G	5	40.0	24.0	32.0	8.0	5.0
	S	3	73.3	29.1	47.8	18.7	3.9
	W	2	70.0	24.1	46.0	21.9	3.2
	All	25	47.2	20.6	32.4	11.8	4.0
1955–56....	U	6	53.5	23.6	37.8	14.2	3.7
	M	5	44.0	21.4	34.2	12.8	3.4
	G	5	56.0	16.5	29.0	12.5	4.5
	S	7	60.0	22.9	36.1	13.2	4.6
	W	8	67.5	16.5	32.2	15.7	4.3
	All	31	57.4	20.1	34.0	13.9	4.1
1956–57....	U	5	48.0	30.3	42.0	13.4	4.1
	M	2	20.0	29.4	33.3	3.9	5.2
	G	2	50.0	28.0	37.8	9.8	5.1
	S	8	37.5	34.0	43.7	9.7	3.9
	W	5	48.0	29.5	41.6	12.1	3.6
	All	22	41.8	31.2	41.3	10.6	4.1
4 years....	U	31	48.4	23.0	35.1	12.1	4.0
	M	17	37.6	22.1	30.9	8.7	4.3
	G	17	45.9	22.8	32.4	9.6	4.8
	S	28	49.3	29.8	40.5	10.7	4.6
	W	20	56.0	21.7	35.6	13.9	4.1
4 years, 5 counties		112	48.0	24.2	35.4	11.3	4.3

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[1] Counties: C—Umatilla, M—Morrow, G—Gilliam, S—Sherman, and W—Wasco.

are based on increased yield, over the check, from that rate of nitrogen which produced maximum yield on each site.

Average amounts of spring-applied nitrogen required to produce a one-bushel wheat yield increase are summarized in Table 13. In general, nitrogen applied in spring was less efficient in increasing yield than nitrogen applied in fall, as is indicated by comparison of the average values for the same year in Tables 12 and 13.

Table 14. Amount of fertilizer nitrogen required to produce 1 bushel of wheat, for the 20-pound increment less and 20-pound increment more than the rate per acre which produced the maximum yield, low rainfall area sites on which nitrogen increased yields
(All values are weighted averages.)

	One 20-pound increment less than rate giving the maximum yield		One 20-pound increment more than rate giving the maximum yield	
	Nitrogen applied		Nitrogen applied	
Year	Fall	Spring	Fall	Spring
	Pounds of nitrogen per bushel of wheat			
1953-54	3.9 (28)[1]	4.9 (34)	17.4 (25)	12.6 (32)
1954-55	4.4 (22)	4.4 (25)	22.6 (22)	23.2 (24)
1955-56	4.1 (36)	4.0 (31)	16.6 (33)	14.8 (26)
1956-57	4.1 (23)	4.6 (23)	12.4 (23)	15.3 (23)
All	4.1 (109)	4.5 (113)	16.4 (103)	15.4 (105)

[1] Numbers in parentheses indicate the number of experimental sites providing data.

Table 14 tabulates the average amounts of nitrogen required to produce 1 bushel of wheat at rates of 20 pounds less and 20 pounds more nitrogen than the rate which produced maximum yields. Values tabulated are weighted averages for all sites, in the low rainfall areas, on which yields were increased by nitrogen, and for which data were available. Calculations could not be made for "20 pounds less" for farms on which maximum yield was obtained from 20 pounds of nitrogen per acre, nor for "20 pounds more" for sites where maximum yield was produced by the highest rate of nitrogen applied.

These data emphasize the great variation in efficiency of nitrogen in wheat production, when applied at rates less and greater than required for maximum yield. Comparison of the data in Tables 12 and 14 shows relatively little difference in efficiency of nitrogen applied at the maximum yield rate (3.7 pounds of fall-applied nitrogen per bushel increase for all sites) or at 20 pounds per acre less than this rate (4.1 pounds per bushel). For the increment of applied nitrogen 20 pounds per acre greater than the rate giving maximum yield, the production efficiency of nitrogen was very markedly reduced, so that over four times as much was required (16.4 pounds per bushel) to produce one bushel increase in yield.

Table 15 summarizes the average amounts of nitrogen required to produce maximum yield on each of six most important soil types in the Columbia Basin dryland area of Oregon. The 106 sites for which data are tabulated represent all experimental sites on the indicated soil series on which nitrogen increased wheat yields. Differences in numbers of experiments on the several soils make it rather hazardous to make strict comparisons among soil types. It appears that somewhat less nitrogen is required to produce a bushel of wheat on Walla Walla silt loam than on other soil types. Observations on Morrow silt

Table 15. Average amount of nitrogen required to increase wheat yield by 1 bushel per acre on indicated soil types on sites where *fall-applied* nitrogen produced significant yield increases

Year	Number of sites	Nitrogen required for maximum yield	Yield			Amount of nitrogen per bushel increase
			Check	Maximum	Increase	
		Lbs./A.	*Bushels per acre*			*Pounds*
			Condon silt loam			
1953-54	3	47	23.7	33.0	9.3	5.0
1954-55	4	25	23.6	30.9	7.3	3.4
1955-56	7	54	24.4	39.9	15.5	3.5
1956-57	5	24	32.6	38.5	5.9	4.1
			Morrow silt loam			
1953-54	0	----	------	------	------	----
1954-55	1	20	24.4	27.8	3.4	5.9
1955-56	4	55	20.4	32.7	12.2	4.5
1956-57	0	----	------	------	------	----
			Ritzville silt loam			
1953-54	3	40	21.5	28.2	6.7	6.0
1954-55	5	44	14.6	24.4	9.8	4.5
1955-56	5	40	19.0	28.6	9.6	4.2
1956-57	1	20	36.8	42.0	5.2	3.8
			Ritzville very fine sandy loam			
1953-54	5	32	20.8	29.1	8.3	3.6
1954-55	1	40	14.1	24.8	10.7	3.7
1955-56	3	60	18.5	31.9	13.3	4.5
1956-57	3	40	26.8	37.5	10.7	3.7
			Walla Walla silt loam (all phases)			
1953-54	12	53	30.7	45.3	17.0	4.4
1954-55	7	51	25.1	40.9	15.8	3.2
1955-56	10	56	20.9	35.3	13.4	4.2
1956-57	12	35	31.1	42.2	13.3	2.6
			Athena silt loam			
1953-54	4	68	20.6	39.2	18.6	3.6
1954-55	1	30	8.0	12.6	4.6	6.5
1955-56	1	30	48.0	58.0	10.0	3.0
1956-57	1	60	57.8	74.9	17.1	3.5

loam are probably too few to conclude that less efficient use of nitrogen is made on that soil than on others, even though higher average values for pounds of nitrogen used per bushel of wheat are shown.

On each soil type there was much variation in efficiency of nitrogen from year to year.

Nitrogen content of different soil types

Average amounts of different forms of nitrogen in nonfertilized soil samples of the major soil types are given in Table 16. Results for both fall and spring soil samples are included. Dates of sampling are indicated in Table 4. For all soils the amount of ammonium nitrogen was greater than either nitrate or nitrifiable nitrogen. The low quantity of nitrifiable nitrogen may possibly be accounted for by the increase in microbial population upon incubation and, consequently, a decrease in water-soluble nitrate. All of these soils were oven-dried at 55° C. so the microbial population may have been low at the start of the incubation period.

There was a wider range of values between soil types for ammonium nitrogen than for the other forms. The differences between the four deeper and two shallower soils (Condon and Morrow) were greater than the differences within these two groups of soils for all three forms of nitrogen.

In many cases the difference in nitrogen values between years was very great. Years 1955-56 and 1956-57 appeared to have higher values for nitrate and ammonium nitrogen than did 1953-54 and 1954-55.

With only two exceptions values for the three forms of nitrogen from spring-sampled plots were lower for all soils than for the corresponding fall-sampled plots. Again there was considerable variation between years for the different soil types.

Wheat yields related to soil types

In these experiments 17 named and 6 unnamed soil types were involved. Average maximum yields of wheat on each of these soil types are given for each year in Table 17. Of the soil series represented by more than five sites, highest average maximum yields were obtained on Walla Walla silt loam, followed in order by Walla Walla coarse silt loam, Condon silt loam, Ritzville very fine sandy loam, Morrow silt loam and silty clay loam, and Ritzville silt loam. Response differences between years and unequal numbers of experimental sites on the given soil types allow only limited conclusions to be drawn from these data. The two Ritzville soils and the Morrow soils produced similar average yields despite the fact that the average Morrow soil depth is less than half that of the Ritzville soils.

Table 16. Average amounts of indicated forms of nitrogen found in sampled depth of six soil types

Soil series	Fall-sampled soil					Spring-sampled soil				
	1953-54	1954-55	1955-56	1956-57	Average all years	1953-54	1954-55	1955-56	1956-57	Average all years
					Pounds per acre					
					Nitrate nitrogen					
Walla Walla silt loam[1]	45.8	37.3	76.4	55.7	53.8	46.4	48.6	44.5	41.8	45.3
Walla Walla coarse silt loam[2]	57.0	38.0	76.5	42.2	53.4	53.0	47.7	55.5	39.3	48.9
Ritzville silt loam	55.3	25.8	64.7	72.0	54.5	40.5	26.8	38.2	81.0	46.6
Ritzville very fine sandy loam	40.9	34.4	59.0	43.8	44.5	32.0	28.5	34.5	42.8	34.5
Condon silt loam	47.5	41.0	40.9	56.3	46.4	28.1	40.5	28.3	50.8	36.9
Morrow silt loam	64.2	39.3	46.3	......	49.9	31.8	35.0	23.2	......	30.0
					Ammonium nitrogen					
Walla Walla silt loam[1]	86.4	76.3	100.8	182.2	111.4	92.8	74.0	154.8	101.5	105.8
Walla Walla coarse silt loam[2]	90.7	92.3	229.0	175.0	146.8	93.0	88.7	187.5	85.8	113.8
Ritzville silt loam	69.8	62.0	101.2	160.5	98.4	77.8	61.8	113.0	98.0	87.7
Ritzville very fine sandy loam	71.5	72.1	149.0	143.0	108.9	61.8	56.8	132.5	125.5	94.2
Condon silt loam	55.3	56.3	50.8	104.1	66.6	73.8	52.0	124.7	74.1	81.2
Morrow silt loam	53.0	49.3	59.7	......	54.0	66.6	67.0	107.5	......	80.4
					Nitrifiable nitrogen					
Walla Walla silt loam[1]	30.1	40.4	39.5	22.7	33.2	26.1	19.4	28.6	34.0	27.0
Walla Walla coarse silt loam[2]	44.3	45.0	57.0	27.5	43.5	22.7	35.3	53.5	26.3	34.5
Ritzville silt loam	36.0	27.5	67.8	18.0	37.3	19.3	35.8	27.0	21.0	25.8
Ritzville very fine sandy loam	29.3	37.6	62.0	22.0	38.0	16.3	31.8	21.0	24.0	23.3
Condon silt loam	25.8	18.8	45.5	26.3	29.1	19.0	20.9	16.6	23.5	20.0
Morrow silt loam	31.0	14.0	48.5	......	31.2	22.8	28.3	20.7	......	23.9

[1] Includes moist phase.

[2] Includes dry phase.

Table 17. Summary of average maximum yields of wheat for some major soils of the Columbia Basin with *fall-applied* nitrogen[1]

Soil type	Average soil depth sampled	Average maximum yields of wheat				
		1953-54	1954-55	1955-56	1956-57	Total
	Feet	*Bushels per acre*				
Athena silt loam	6.0	40.8	24.7	56.9	78.6	39.6
Walla Walla silt loam[2]	6.0	46.2	40.8	42.0	50.0	44.8
Walla Walla coarse silt loam[3]	5.5	47.1	37.8	27.2	36.0	37.0
Ritzville silt loam	5.0	27.6	22.0	28.6	21.7	25.0
Ritzville very fine sandy loam	4.0	28.4	19.5	28.3	37.5	28.4
Condon silt loam	3.0	33.0	27.2	38.6	35.0	33.5
Morrow silt loam	2.0	25.6	20.6	32.7	......	26.8
McKay silt loam	2.5	33.3	36.7	27.6	......	33.5
Pilot Rock silt loam	3.0	20.4	25.9	......	29.1	23.9
Tub silt loam	2.5	24.2	16.4	31.0	31.0	25.3
New Series "A", silt loam & very fine sandy loam	4.5	44.9	43.1	23.9	30.8	35.2
New Series "B", very fine sandy loam	4.5	......	40.0	31.4	......	37.1

[1] Number of experiments on each soil type for each year listed in Table 3.
[2] Includes moist phase.
[3] Includes dry phase.

A summary of the average yields of wheat produced by the several rates of nitrogen on each of six soil types is given in Table 18. These six soil types represent 120 of the 173 experimental sites. Average yields are presented for each of three classes of response to nitrogen within each soil type.

Test weights

Effects of nitrogen application on test weights of wheat are summarized in Table 19 for the 156 sites on which test weight data were obtained.

Effects of nitrogen fertilizer on test weights tended to parallel effects on yields. Generally, on sites where yields were increased by nitrogen, test weights were also increased. Test weights declined slightly with increasing nitrogen on sites where no significant effects on yields were produced. Largest decreases in test weights occurred on sites where increased nitrogen reduced yields. On these sites, reduced yields were often accompanied by "burning" of foliage and shriveling of grain resulting from too early exhaustion of the moisture supply.

In general, average test weights were low. However, weights were slightly higher for 1953-54 than for either of the other years.

Table 18. Summary of average effects of *fall-applied* nitrogen on yield of wheat for six soil types

Effect of nitrogen on yield	Number of sites	Average yield of wheat fertilized with nitrogen at indicated rates of pounds per acre					
		0	20	40	60	80	100
		Bushels per acre					
		Condon silt loam					
Increase	21	26.3	32.1	36.1	36.9	36.8	37.5
No effect	6	30.1	32.4	33.6	32.9	31.8	29.6
Decrease	6	24.8	23.4	19.9	16.7	15.4	12.1
All	33	27.3	30.6	32.7	32.5	32.0	31.7
		Morrow silt loam					
Increase	5	21.2	27.2	29.1	32.1	31.5	33.2
No effect	4	27.2	28.2	29.2	26.9	26.9	......
Decrease	4	24.5	21.3	19.8	16.8	15.1	......
All	13	24.0	25.7	26.3	25.8	25.0	......
		Ritzville very fine sandy loam					
Increase	14	19.9	26.6	29.4	30.6	30.3	31.0
No effect	2	20.4	22.1	22.1	19.9	19.4	15.4
Decrease	1	11.5	11.6	9.9	9.9	9.9	9.4
All	17	19.5	25.2	27.4	28.1	27.8	27.6
		Ritzville silt loam					
Increase	13	21.0	26.5	29.3	31.0	30.7	30.0
No effect	4	17.9	18.8	18.8	19.4	18.4	19.0
Decrease	0	......	......	......	......	......	......
All	17	20.3	24.7	26.8	28.3	27.8	26.6
		Walla Walla silt loam[1]					
Increase	26	28.8	36.0	40.8	43.3	43.7	41.9
No effect	1	24.3	24.7	25.4	24.0	21.4	26.6
Decrease	2	34.3	36.1	33.9	31.7	29.9	27.4
All	29	29.0	35.6	39.8	41.8	42.0	39.9
		Walla Walla coarse silt loam[2]					
Increase	8	26.9	33.7	40.5	41.3	41.8	......
No effect	2	18.5	22.4	21.9	19.9	20.1	19.6
Decrease	1	19.8	16.3	11.4	4.9	3.5	2.6
All	11	24.7	30.1	34.5	34.1	34.4	......

[1] Includes moist phase.
[2] Includes dry phase.

Table 19. Summary of average test weights of wheat as affected by nitrogen fertilizer, data from low and high rainfall areas combined

Time of application	Number of sites	Test weight of wheat fertilized with nitrogen at indicated rates of pounds per acre[1]					
		0	20	40	60	80	100
		Pounds per bushel					
(Sites on which one or more rates of nitrogen produced significant[2] yield increases.)							
Fall 1953	36	58.8	59.5	60.1	60.5	60.6	......
Fall 1954	24	58.6	59.2	59.5	59.6	59.5	58.9
Fall 1955	23	58.4	58.5	58.9	58.9	58.7	58.7
Fall 1956	24	58.3	58.9	59.5	59.6	59.6	59.3
Average	107	58.7	59.1	59.6	59.7	59.7	59.0
Spring 1954	43	59.0	60.0	60.4	60.6	60.8	......
Spring 1955	28	58.7	59.1	59.3	59.5	59.0	58.8
Spring 1956	20	58.5	58.6	58.9	59.0	58.9	59.1
Spring 1957	24	58.4	58.9	59.3	59.4	59.7	59.4
Average	115	58.7	59.3	59.6	59.8	59.8	59.1
(Sites on which the effects of nitrogen on yield were too small to be significant.)							
Fall 1953	8	60.4	60.8	60.5	60.4	60.2	......
Fall 1954	10	58.5	59.1	59.2	58.4	58.0	58.2
Fall 1955	3	59.6	59.1	58.7	57.7	57.2	57.7
Fall 1956	3	60.4	60.4	60.2	59.9	59.7	59.9
Average	24	59.5	59.8	59.7	59.2	58.8	58.4
Spring 1954	6	61.0	60.2	60.4	60.2	59.3	......
Spring 1955	9	58.2	58.3	57.9	57.9	57.9	57.7
Spring 1956	6	58.8	58.5	58.6	58.6	58.5	58.4
Spring 1957	4	59.6	59.7	59.5	59.0	58.8	58.6
Average	25	59.2	59.0	59.0	58.8	58.5	58.1
(Sites on which one or more rates of nitrogen produced significant yield decreases and no significant increases occurred.)							
Fall 1953	4	61.2	60.4	59.2	58.7	59.1	......
Fall 1954	12	59.6	59.6	59.3	58.4	58.1	57.8
Fall 1955	0	......	......	......	......	......	......
Fall 1956	6	57.6	56.3	55.5	54.9	55.2	55.1
Average	22	59.3	58.8	58.2	57.5	57.5	56.9
Spring 1954	0						
Spring 1955	11	59.6	59.9	59.4	58.8	58.7	58.5
Spring 1956	0	......	......	......	......	......	......
Spring 1957	5	57.3	55.5	55.0	55.1	53.8	53.5
Average	16	58.9	58.5	58.0	57.6	57.2	56.8

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[1] On 18 sites in the high rainfall area rates of nitrogen were 50% greater than indicated.

[2] In comparison with 0 pounds nitrogen per acre, at P = 0.05.

Table 19. Summary of average test weights of wheat as affected by nitrogen fertilizer, data from low and high rainfall areas combined (Continued)

Time of application	Number of sites	Test weight of wheat fertilized with nitrogen at indicated rates of pounds per acre[1]					
		0	20	40	60	80	100
		Pounds per bushel					
(All sites.)							
Fall 1953	48	59.2	59.8	60.1	60.3	60.4	......
Fall 1954	46	58.8	59.3	59.4	59.0	58.8	58.4
Fall 1955	26	58.5	58.6	58.9	58.8	58.5	58.6
Fall 1956	33	58.4	58.6	58.9	58.8	58.8	58.6
Average	153	58.8	59.2	59.4	59.3	59.3	58.5
Spring 1954	49	59.2	60.0	60.4	60.6	60.6	......
Spring 1955	48	58.8	59.1	59.1	59.0	58.7	58.5
Spring 1956	26	58.5	58.6	58.8	58.9	58.8	58.9
Spring 1957	33	58.4	58.5	58.6	58.7	58.7	58.4
Average	156	58.8	59.2	59.4	59.4	59.3	58.6

[1] On 18 sites in the high rainfall area rates of nitrogen were 50% greater than indicated.

Protein content

With the exception of Turkey Red, soft white wheat varieties were grown in these experiments (Table 7). They are used chiefly for making pastry flour. Quality of pastry wheat is impaired when the protein content is higher than about 10%.[4] Pastry-type wheats are not suitable for bread making, even when their protein content is as high as that of good bread wheat. Consequently, it is desirable to regulate nitrogen supply to obtain optimum yields without increasing protein content to undesirably high values. The relationship between yield increases produced by nitrogen fertilizer and protein content of pastry wheats is of considerable practical importance (3).

Table 20 presents the protein content of wheat from 152 sites in the lower rainfall area. Similar data for the higher rainfall area are shown in Table 21. These data are grouped by class of yield response to nitrogen.

Wheats lowest in average protein content were produced on sites on which nitrogen resulted in significant yield increases. Average protein content exceeded 10% only at the higher rates of nitrogen. Average protein content of wheat grown without nitrogen applications on

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[4] Private communication from Dr. Mark A. Barmore, Western Wheat Quality Laboratory, Pullman, Washington.

these sites was only slightly above 7%. Nitrogen applied in the spring resulted in slightly lower protein content than similar rates applied in the fall.

Wheats with the highest protein content were from sites where the addition of nitrogen significantly decreased yields. On check plots where no nitrogen was applied, average protein content was slightly above 9% and each increment of added nitrogen increased the protein content markedly.

Where effects of nitrogen on yields were not significant, effects on protein content were intermediate. Wheat from the plots receiving no nitrogen contained about 10% protein and the first 20-pound increment of nitrogen increased the protein undesirably.

Relationships of protein content to nitrogen in the high rainfall area were essentially similar to those in the area of low rainfall. However, more nitrogen was required in the high rainfall area to give the same level of response.

Distribution of protein content of wheat produced on each site by the rate of nitrogen which resulted in maximum yield for both the high and low rainfall areas is shown in Figure 1. Maximum yield from fall-applied nitrogen resulted in protein content greater than 10% on only 10 of the 124 sites where yield increases occurred. Of the other 114 sites, it required 20, 40, 60, or 80 pounds of nitrogen in addition to that needed for maximum yield to increase protein content of the wheat above 10% for 22, 20, 12, and 4 sites, respectively. At 56 sites the protein content of wheat never increased above 10%. In the case of spring-applied nitrogen the protein content exceeded 10% on 13 of 128 sites. Of the other 115 sites, the protein content of wheat was increased above 10% when 20, 40, 60, or 80 pounds additional nitrogen was added to that required to produce the maximum yield—for 18, 18, 9, and 4 sites, respectively. Protein content never reached 10% for wheat growers on 56 sites. In general, protein content was not increased to objectionably high levels until more nitrogen was applied than was required to produce maximum yield.

Figure 2 summarizes the protein content of wheat produced without added nitrogen fertilizer (check plots) for each of three classes of yield response to nitrogen. On 80% of the sites where significant yield increases were obtained from added nitrogen, wheat grown on check plots contained less than 8% protein. This was true for only 20% of the sites where yield decreases occurred. Of the 23 sites where no significant yield increases or decreases resulted from addition of nitrogen fertilizer, wheat from only 8 sites (35%) contained less than 8% protein.

These data show that when wheat from sites in the Columbia Basin wheat area contained less than 8% protein, odds were fairly

Table 20. Average protein contents of wheat as affected by nitrogen fertilizer, low rainfall area

Time of application	Number of sites	Protein content of wheat fertilized with nitrogen at indicated rates of pounds per acre					
		0	20	40	60	80	100
					Percent		
(Sites on which one or more rates of nitrogen produced significant[1] yield increases.)							
Fall 1953	28	6.7	7.1	7.8	8.9	9.8	......
Fall 1954	22	7.2	7.7	8.9	10.4	11.8	12.8
Fall 1955	36	7.7	8.0	8.4	9.2	10.0	10.5
Fall 1956	23	6.8	7.2	8.0	8.9	9.8	11.0
Average	109	7.2	7.5	8.3	9.3	10.3	11.3
Spring 1954	34	6.9	7.7	8.5	9.2	10.0	......
Spring 1955	25	7.3	7.6	8.5	9.4	10.6	11.8
Spring 1956	31	7.5	7.9	8.0	9.1	9.6	10.2
Spring 1957	22	6.8	7.1	7.6	8.2	8.9	9.7
Average	112	7.2	7.6	8.2	9.0	9.8	10.6
(Sites on which effects of nitrogen on yields were too small to be significant.)							
Fall 1953	8	8.8	9.6	11.4	12.8	13.7	......
Fall 1954	10	8.6	9.9	11.5	12.8	14.2	15.0
Fall 1955	3	10.0	10.2	11.8	11.8	12.2	12.1
Fall 1956	3	8.3	8.8	10.9	11.6	12.5	11.3
Average	24	8.8	9.7	11.4	12.5	13.6	13.8
Spring 1954	6	9.6	11.6	12.4	13.6	14.0	......
Spring 1955	10	8.9	9.5	10.9	11.7	13.2	13.9
Spring 1956	8	9.3	10.2	10.5	11.1	11.4	11.7
Spring 1957	5	8.8	9.7	10.6	11.8	12.9	13.1
Average	29	9.1	10.2	11.1	11.9	12.8	13.0
(Sites on which one or more rates of nitrogen produced significant yield decreases and no significant increases occurred.)							
Fall 1953	4	9.1	10.7	12.7	14.0	14.5	......
Fall 1954	9	8.4	10.4	12.1	13.9	14.9	15.7
Fall 1955	0	......	......	......	......	......	......
Fall 1956	6	9.8	11.6	13.9	14.6	15.5	16.4
Average	19	9.0	10.8	12.8	14.1	15.0	16.0
Spring 1954	0	......	......	......	......	......	......
Spring 1955	6	8.7	10.1	11.5	12.8	14.2	15.0
Spring 1956	0	......	......	......	......	......	......
Spring 1957	5	9.8	12.3	12.7	13.8	14.5	15.3
Average	11	9.2	11.1	12.0	13.3	14.3	15.1

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[1] Compared with 0 pounds nitrogen per acre, at $P = 0.05$.

Table 20. Average protein contents of wheat as affected by nitrogen fertilizer, low rainfall area (Continued)

Time of application	Number of sites	Protein content of wheat fertilized with nitrogen at indicated rates of pounds per acre					
		0	20	40	60	80	100
					Percent		
		(All sites.)					
Fall 1953	40	7.4	7.9	9.0	10.2	11.0	......
Fall 1954	41	7.8	8.9	10.3	11.8	13.1	14.0
Fall 1955	39	7.9	8.2	8.7	9.4	10.2	10.6
Fall 1956	32	7.5	8.1	9.4	10.2	11.2	12.1
Average	152	7.7	8.3	9.4	10.4	11.4	12.4
Spring 1954	40	7.3	8.2	9.1	9.9	10.6	......
Spring 1955	41	7.9	8.5	9.5	10.5	11.8	12.8
Spring 1956	39	7.9	8.4	8.5	9.5	10.0	10.5
Spring 1957	32	7.6	8.3	8.8	9.7	10.4	11.1
Average	152	7.7	8.3	9.0	9.9	10.7	11.5

Table 21. Average protein content of wheat as affected by nitrogen fertilizer, high rainfall area

Time of application	Number of sites	Protein content of wheat fertilized with nitrogen at indicated rates, pounds per acre					
		0	30	60	90	120	150
					Percent		
(Sites on which one or more rates of nitrogen produced significant[1] yield increases.)							
Fall 1953	8	7.1	7.5	8.5	9.5	11.3	......
Fall 1954	3	6.1	6.4	7.4	9.1	10.5	11.1
Fall 1955	3	6.7	6.9	7.0	8.3	8.8	9.8
Fall 1956	2	6.9	7.4	8.2	8.8	9.8	10.6
Average	16	6.8	7.2	8.0	9.1	10.5	10.4
Spring 1954	9	7.1	8.0	8.9	10.1	11.3	
Spring 1955	2	6.1	6.1	7.3	9.0	10.0	10.4
Spring 1956	3	6.7	7.1	7.8	9.4	9.8	10.4
Spring 1957	2	6.9	7.8	8.2	9.1	9.9	10.8
Average	16	6.8	7.6	8.4	9.7	10.7	10.5

[1] Compared with 0 pounds nitrogen per acre, at $P = 0.05$.

Table 21. Average protein content of wheat as affected by nitrogen fertilizer, high rainfall area
(Continued)

Time of application	Number of sites	Protein content of wheat fertilized with nitrogen at indicated rates, pounds per acre					
		0	30	60	90	120	150
					Percent		
(Sites on which effects of nitrogen on yields were too small to be significant.)							
Fall 1953	0	......	......	......	......	......	......
Fall 1954	0	......	......	......	......	......	......
Fall 1955	0	......	......	......	......	......	......
Fall 1956	0	......	......	......	......	......	......
Average	0	......	......	......	......	......	......
Spring 1954	0	......	......	......	......	......	......
Spring 1955	2	12.5	13.3	......	15.3	......	17.0
Spring 1956	0	......	......	......	......	......	......
Spring 1957	0	......	......	......	......	......	......
Average	2	12.5	13.3	......	15.3	......	17.0
(Sites on which one or more rates of nitrogen produced significant yield decreases and no significant increases occurred.)							
Fall 1953	0	......	......	......	......	......	......
Fall 1954	5	10.2	12.7	15.9	16.0	16.3	16.7
Fall 1955	0	......	......	......	......	......	......
Fall 1956	0	......	......	......	......	......	......
Average	5	10.2	12.7	15.9	16.0	16.3	16.7
Spring 1954	0	......	......	......	......	......	......
Spring 1955	3	9.1	11.4	......	15.7	......	17.1
Spring 1956	0	......	......	......	......	......	......
Spring 1957	0	......	......	......	......	......	......
Average	3	9.1	11.4	......	15.7	......	17.1
Fall 1953	8	7.1	7.5	8.5	9.5	11.3	......
Fall 1954	6	8.1	9.5	11.7	12.6	13.4	13.9
Fall 1955	3	6.7	6.9	7.0	8.3	8.8	9.8
Fall 1956	2	6.9	7.4	8.2	8.8	9.8	10.6
Average	19	7.3	8.0	9.3	10.2	11.4	12.2
Spring 1954	9	7.1	8.0	8.9	10.1	11.3	......
Spring 1955	7	9.2	10.4	14.6	13.7	19.9[2]	15.1
Spring 1956	3	6.7	7.1	7.8	9.4	9.8	10.4
Spring 1957	2	6.9	7.8	8.2	9.1	9.9	10.8
Average	21	7.7	8.7	8.6	10.6	10.8	13.2

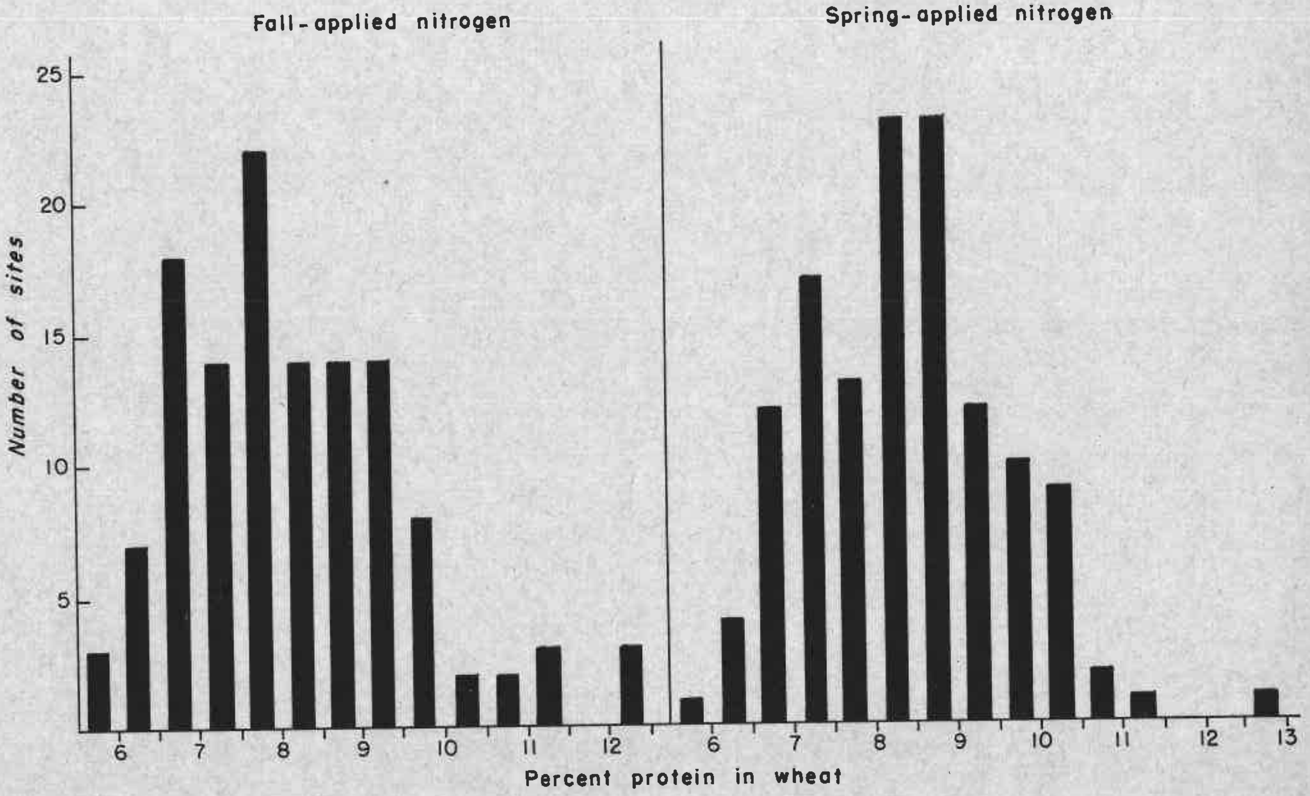

Figure 1. Distribution of protein content of wheat receiving that rate of nitrogen which produced maximum yield at each site where yield increases occurred.

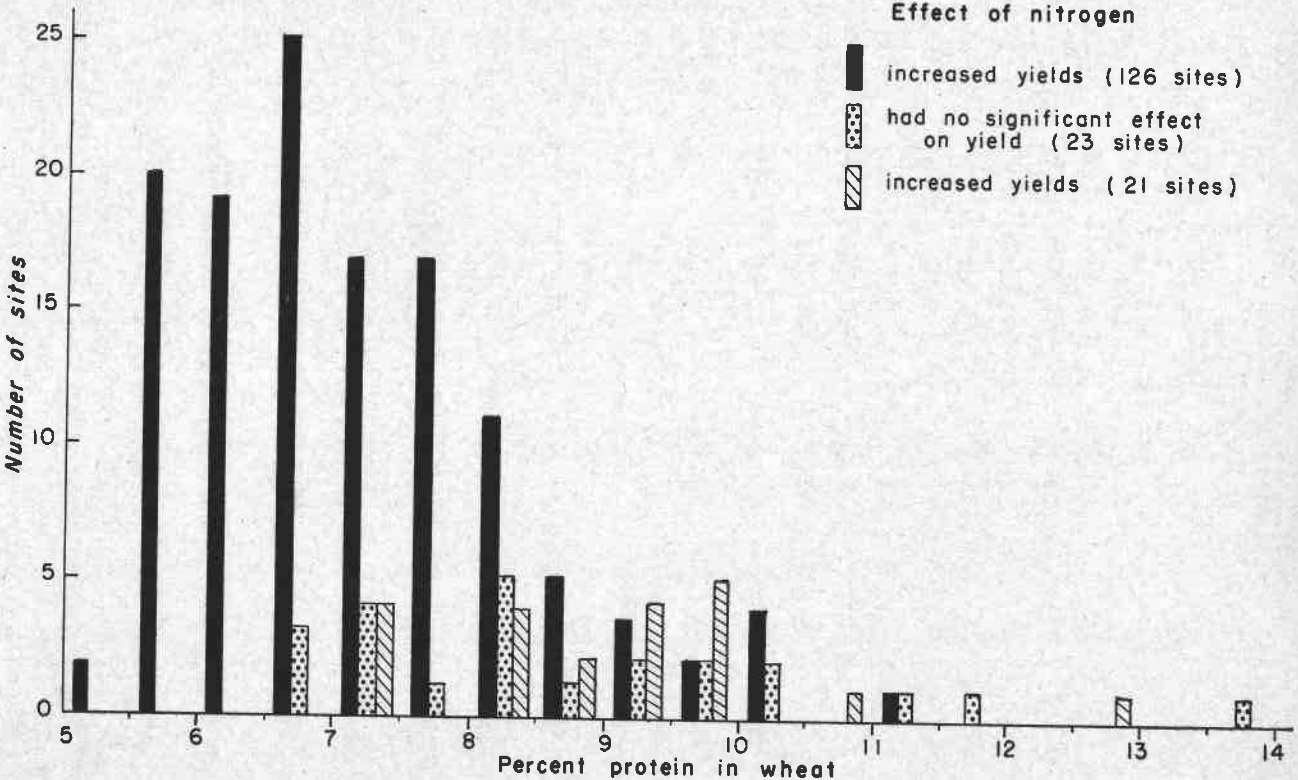

Figure 2. Protein content of wheat from check plots in relation to type of yield response from fall-applied nitrogen.

high that additional nitrogen fertilizer was required to increase the yield. Conversely, it appeared that protein content greater than 9% was indicative of adequate nitrogen supply, relative to other factors limiting yields. The extent of fertilizer usage on a wheat field in the Columbia Basin dryland area may be estimated from the protein content of the wheat, on the basis of present data.

Relationships between yield of wheat (in bushels) and protein (in percent) for 152 sites in the low rainfall area are shown graphically in Figure 3. The mean protein/yield ratio is indicated for each rate of applied nitrogen and for each class of yield response to nitrogen. On all sites where nitrogen significantly increased wheat yields, the ratio remained almost constant, varying slightly between 0.30 and 0.35 over all rates of added nitrogen.

On sites where effects of nitrogen application on yields were not significant, the protein/yield ratio increased slightly from 0.5 with no nitrogen to 0.8 with 100 pounds of added nitrogen. In cases where yields were significantly depressed by increases in fertilizer nitrogen, the protein/yield ratio increased appreciably from 0.45 on the check plot to as high as 1.6 where 100 pounds of nitrogen was added in the fall. From these data it appears that the protein/yield ratio of wheat in this area will be about 0.3 to 0.4 where the addition of nitrogen fertilizer is such as to increase yields significantly.

Determination of residual effects

Table 22 shows average wheat yields for crops harvested in 1956 and 1957 where nitrogen fertilizer was applied two years earlier. Even though visual observations indicated that a residual effect might be expected, only slightly over half the sites harvested gave significant ($P = 0.05$) increases for some increments of nitrogen (4).

Where no residual yield increases were obtained, the overall yield appeared to be much better in 1957 than for the 1955-56 crop, for both fall- and spring-applied nitrogen. On those sites where a residual effect was obtained, yield of check plots was lower for 1956 than for 1957 but increased more rapidly with increments of nitrogen. This may have been a result of much lower rainfall during the 1956-57 crop year.

Multiple regression equasions

Multiple regression equations were calculated to determine whether or not any relationships existed among the following measured variables and yield responses from nitrogen nitrate, ammonium, and nitrifiable nitrogen, measured in fall and spring for various soil depths; available soil moisture at spring and fall soil sampling; and rainfall occurring between spring soil sampling and harvest. All data

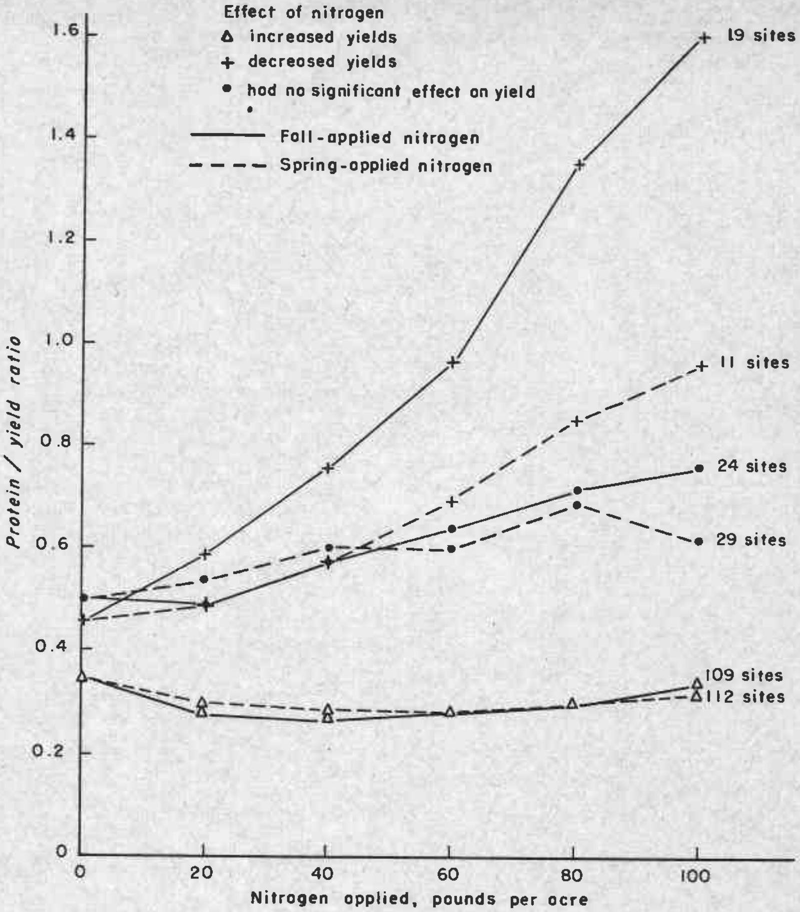

Figure 3. Effect of nitrogen fertilizer on the protein/yield ratio of wheat in the low rainfall area.

were entered for each experiment on IBM punch cards and subjected to machine analyses.

Regression equations were also calculated to relate the yield, Y, from any rate of nitrogen applied in the fall to certain other variables. This was also done for spring-applied nitrogen. These regression coefficients indicated only that there was great variability in yield from

Table 22. Average yields of wheat from sites where nitrogen was applied to the preceding crop 2 years earlier, and residual effects were observed visually in 1956 and 1957

Rate of nitrogen applied	Sites where residual effect was not significant[1]		Sites where residual effect was significant	
	1956	1957	1956	1957
Pounds per acre	*Bushels per acre*			
	Nitrogen applied in fall, 1953 or 1954			
0	24.8 (4)[2]	29.8 (5)	25.8 (6)	28.0 (5)
20	24.6	20.0	34.9	27.7
40	24.0	29.8	40.6	28.8
60	21.5	30.7	42.9	32.1
80	20.0	29.6	44.0	33.5
100	......	30.0	......	35.4
	Nitrogen applied in spring, 1954 or 1955			
0	23.8 (3)	29.8 (5)	26.1 (7)	28.0 (5)
20	28.0	30.0	31.9	29.9
40	24.4	30.3	34.0	30.0
60	24.1	31.1	36.5	31.2
80	24.4	30.6	38.0	34.3
100	......	30.2	......	34.7

[1] Significant at the 5% level.
[2] Numbers in parentheses are number of sites included each year.

year to year in response to particular variants. Only in certain years did individual variants have significant effects.

None of the multiple regression equations indicated relationships consistent enough to permit evaluation of fertilizer needs of the wheat crop on any Columbia Basin wheat farm. These regressions employed data from all sites for all the indicated variables—regardless of location, soil type, soil depth, or type of response to nitrogen fertilizer.

Simple regression equations for soils

To further determine whether or not individual variants had any effect on maximum yield, simple regressions of the type $Y = a + bx$ were calculated for all soils included in the study where nitrogen increased yields. These results are given in Table 23.

Out of the first 13 comparisons, 9 appeared to be highly significant. Not one of the comparisons considered individually would be adequate to predict amount of nitrogen nor moisture required to obtain maximum yield. Considering all soils, spring-sampled nitrogen

Table 23. Values of a, b, and r from the simple regression equation of the type $Y = a + bx$ for several variables for all of the soils for all years

Y	X	d.f.	a	b	r
Maximum yield (F)[1]	Spring soil moisture + spring rainfall[2]	97	18.41	2.045	0.435**
Maximum yield (F)	Spring soil moisture	107	25.19	1.732	0.434**
Maximum yield (F)	$NO_3^- + NH_4^+$ + applied nitrogen (F)	108	24.76	0.102	0.341**
Maximum yield (F)	Fall soil moisture	93	32.79	1.188	0.277**
Maximum yield (F)	NO_3^- + applied nitrogen (F)	108	27.35	0.095	0.268**
Maximum yield (F)	NO_3^- — nitrogen (F)	108	30.49	0.118	0.210*
Maximum yield (F)	Fall soil moisture + spring rainfall	84	31.71	0.835	0.208
Maximum yield (Sp)[3]	$NO_3^- + NH_4^+$ + applied nitrogen (Sp)	110	13.16	0.562	0.562**
Maximum yield (Sp)	NO_3^- + applied nitrogen (Sp)	110	17.36	0.215	0.510**
Maximum yield (Sp)	Spring moisture	110	26.96	1.330	0.325**
Maximum yield (Sp)	Spring soil moisture + spring rainfall	102	23.85	1.285	0.272**
Maximum yield (Sp)	NO_3^- — nitrogen (Sp)	110	30.97	0.120	0.171
Maximum yield (Sp)	Spring rainfall	102	33.25	0.662	0.115

[1] (F) indicates nitrogen from fall-sampled soil, fall-applied nitrogen, or yield from fall-applied nitrogen.

[2] Between dates of spring soil sampling and harvest.

[3] (Sp) indicates nitrogen from spring-sampled soil, spring-applied nitrogen, or yield from spring-applied nitrogen.

plus spring-applied nitrogen gave the best correlations. Use of spring soil moisture or spring soil moisture plus spring rainfall showed the best relationship with maximum yield from fall-applied nitrogen.

Results of some simple regression analyses for four soil series are given in Table 24. None of the variables measured proved to be of any value in predicting maximum yield for the Walla Walla soils when all four years were considered. Although not given in the table, the correlation coefficient, r, for fall nitrate plus fall-applied nitrogen vs. maximum yield from fall-applied nitrogen was 0.730** for 1953-

54 and 1954-55 only and 0.631** for the three years 1953-54, 1954-55, and 1956-57. Something unaccountable occurred in 1956 to reduce yield.

Table 24. Values of a, b, and r from the simple regression equation of the type $Y = a + bx$ for several variables for four soil series for all years

Y	X	d.f.	a	b	r
	Walla Walla				
Check yield (F)[1]	NO_3^- — nitrogen (Sp)[2]	41	19.23	0.184	0.396*
Check yield (F)	NO_3^- — nitrogen (F)	41	25.59	0.040	0.102
Maximum yield (F)	NO_3^- — nitrogen (Sp)	33	17.70	0.580	0.418*
Maximum yield (Sp)	NO_3^- — nitrogen + applied nitrogen (Sp)	34	16.70	0.139	0.386*
Maximum yield (F)	Spring soil moisture + spring rainfall[3]	40	18.24	2.297	0.386*
Maximum yield (F)	NO_3^- + applied nitrogen (F)	41	30.76	0.107	0.311*
Maximum yield (F)	$NO_3^- + NH_4^+$ + applied nitrogen (F)	41	32.99	0.037	0.279
Maximum yield (F)	NO_3^- + nitrifiable + nitrogen (F)	41	31.69	0.071	0.250
	Ritzville				
Check yield (F)	NO_3^- — nitrogen (Sp)	35	16.25	0.098	0.259
Check yield (F)	NO_3^- — nitrogen (F)	35	15.62	0.091	0.253
Maximum yield (F)	NO_3^- + applied nitrogen (F)	34	15.49	0.150	0.516**
Maximum yield (F)	Spring soil moisture + spring rainfall	34	10.44	2.359	0.426**
Maximum yield (F)	NO_3^- — nitrogen (Sp)	26	27.02	0.077	0.118
	Walla Walla plus Ritzville				
Maximum yield (F)	Spring soil moisture + spring rainfall	75	5.53	3.364	0.607**
Maximum yield (F)	NO_3^- + applied nitrogen (F)	76	19.90	0.170	0.518**
Maximum yield (F)	NO_3^- — nitrogen (Sp)	60	27.87	0.237	0.282

[1] Nitrogen from fall-sampled soil, fall-applied nitrogen, or yield from fall-applied nitrogen.

[2] Nitrogen from spring-sampled soil, spring-applied nitrogen, or yield from spring-applied nitrogen.

[3] Between dates of spring soil sampling and harvest.

Table 24. Values of a, b, and r from the simple regression equation of the type $Y = a + bx$ for several variables for four soil series for all years (Continued)

Y	X	d.f.	a	b	r
	Condon				
Spring soil moisture	Soil depth	35	–2.580	2.443	0.857**
Maximum yield (F)	Soil depth	36	9.08	7.458	0.641**
Fall soil moisture	Soil depth	34	0.075	0.999	0.591**
Check yield (F)	Soil depth	36	16.36	3.190	0.404*
Maximum yield (F)	Spring soil moisture	35	9.17	7.433	0.638**
Maximum yield (F)	NO_3^- + nitrifiable + applied nitrogen (F)	36	20.99	0.120	0.489**
Maximum yield (F)	NO_3^- + NH_4^+ + applied nitrogen (F)	36	20.33	0.096	0.450**
Maximum yield (F)	Fall soil moisture	34	–1.846	1.523	0.216
Maximum yield (F)	NO_3^- + applied nitrogen (F)	36	10.80	0.312	0.174
	Morrow				
Check yield (F)	NO_3^- — nitrogen (Sp)	10	19.78	0.114	0.274
Check yield (F)	NO_3^- — nitrogen (F)	10	22.10	0.021	0.062
Maximum yield (F)	NO_3^- + applied nitrogen (F)	11	12.30	0.194	0.632**
Maximum yield (F)	Spring soil moisture + spring rainfall	11	12.86	2.011	0.315
Maximum yield (F)	Spring soil moisture	11	20.00	2.309	0.246

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[1] Nitrogen from fall-sampled soil, fall-applied nitrogen, or yield from fall-applied nitrogen.

[2] Nitrogen from spring-sampled soil, spring-applied nitrogen, or yield from spring-applied nitrogen.

[3] Between dates of spring soil sampling and harvest.

On the Ritzville soil, both fall soil nitrate plus fall-applied nitrogen and spring moisture plus spring rainfall gave significant correlations with maximum yield for all 4 years. However, they were still not completely satisfactory.

When the Walla Walla and Ritzville soils were analyzed together, the correlations obtained were better than for either soil individually. Fall soil nitrate plus fall-applied nitrogen and spring moisture plus spring rainfall gave significant correlations with yields. This indicates that these two soils, both of which are fairly deep, should be treated together as far as predictions for maximum yield based on nitrogen and moisture are concerned (6,7).

Condon soils present an entirely different situation. Here depth of soil is important. Condon soils range in depth from 2 to 5½ feet; the majority are 2½ to 3½ feet deep. Maximum yield from fall-applied nitrogen, fall soil nitrate plus fall-applied nitrogen, and fall and spring soil moisture all showed a significant correlation with soil depth. The highest correlation was with spring soil moisture. It was shown that spring soil moisture also gave the highest correlation with maximum yield. On Condon soils a knowledge of soil depth and amount of soil moisture available in the spring should aid in predicting the amount of nitrogen needed to produce maximum yield.

The Morrow soil series represents the very shallow sites. Soils of the 12 sites ranged in depth from 2 to 2½ feet. Maximum yield is closely correlated with fall nitrate and the amount of nitrogen added (Table 24). About half of these soils did not respond to any application of nitrogen while the rest responded to amounts up to 60 pounds per acre.

Summary and Conclusions

During the 4-year period 1953-57 fertilizer experiments were completed on 173 dryland wheat farms in Umatilla, Morrow, Gilliam, Sherman, and Wasco counties in north central Oregon. Of 173 experimental sites, 152 were in areas of low rainfall, 21 in areas of higher rainfall.

In these experiments major emphasis was placed on effects of nitrogen fertilizer with lesser emphasis on sulfur, phosphorus, and certain micro nutrients. In low rainfall areas, nitrogen was surface-applied as ammonium nitrate in increments of 20 pounds over a range from 0 to 80 or 0 to 100 pounds per acre. Rates in the higher rainfall areas were 50% greater. At each site fall and spring applications of nitrogen were compared. Fertilizers other than nitrogen were applied in the fall.

At application, in fall and spring, soil samples were taken by 1-foot depth increments to 6 feet or to bedrock or other restricting layer. These were analyzed for available moisture and for nitrate, ammonium, and nitrifiable nitrogen. Records of rainfall between spring soil sampling and harvest were obtained from rain gauges. All soils were identified as to type.

Significant yield increases were produced by one or more rates of fall- and spring-applied nitrogen, respectively, on 109 and 112 of 152 sites in the low rainfall area. For 109 sites, average yield increases from 20, 40, 60, 80, and 100 pounds of nitrogen per acre were, respectively, 6.4, 10.2, 12.2, 12.2, and 12.2 bushels per acre. Average yield increases from spring-applied nitrogen at rates of 20, 40, 60, 80, and 100 pounds, respectively, were 4.9, 8.8, 11.2, 11.9, and 12.8 bushels per acre. Effects of fall- and spring-applied nitrogen fertilizer were too small to be significant on 15.8 and 19.1%, respectively, of the sites in low rainfall areas. Significant yield decreases were produced by one or more rates of fall-applied nitrogen on 12.5% and by spring-applied nitrogen on 7.2% of low rainfall area sites. Considering all sites in the low rainfall area, average yield increases from 20, 40, and 60 pounds of fall-applied nitrogen were 4.8, 7.3, and 8.3 bushels per acre, respectively; higher rates produced lower average yields. For 20, 40, 60, 80, and 100 pounds of spring-applied nitrogen average yield increases were, respectively, 3.9, 6.5, 8.3, 8.5, and 8.7 bushels per acre.

During the 4-year period for all sites fall-applied nitrogen was superior to spring-applied nitrogen on 38, inferior on 42, and not significantly different on 91 sites. Fall-applied nitrogen resulted in larger average yield increases and also a greater number of yield depressions than spring-applied nitrogen. Yield depressions from fall-applied nitrogen were usually associated with soil depths of less than 4 feet.

The amount of nitrogen required to increase wheat yield by 1 bushel per acre varied with year, experimental site, and soil type. It ranged, over the 4 years, from 2.8 to 6.3 for fall-applied and 3.2 to 6.0 pounds for spring-applied nitrogen. For 109 sites an average of 3.7 pounds of fall-applied nitrogen was required to increase wheat yields by 1 bushel per acre. Spring-applied nitrogen was less efficient in increasing yields, requiring an average of 4.3 pounds of nitrogen per bushel increase.

Residual effects of spring-applied were greater than those of fall-applied nitrogen. Substantial residual effects of both fall- and spring-applied nitrogen were measured on 10 sites following a year of fallow.

Protein contents of wheat in this area may be a useful index to the adequacy of fertilizer nitrogen usage on an individual field. In these experiments, protein contents were not, in general, increased to objectionably high levels except by rates of nitrogen greater than the rate required to produce maximum yield. Substantial yield increases were usually obtained from added nitrogen on fields where the grain from the no-nitrogen plots contained less than 8% protein. Protein contents of 9% or more indicated adequate supplies of nitrogen relative to other factors limiting yields.

Amount of available moisture and of nitrate, ammonium, and nitrifiable nitrogen in the soil varied between sites, years, and soil types. Multiple regression equations relating yield responses to available soil moisture (fall and spring), rainfall between time of spring fertilization application and harvest, amounts of nitrogen fertilizer applied, and amounts of nitrate, ammonium, and nitrifiable nitrogen were not useful in explaining observed variations in yields.

Simple regression analyses, relating maximum yields on all sites to single variables such as available moisture and various forms of soil nitrogen, did not provide an adequate basis for estimating fertilizer needs of wheat crops under the specific conditions of this experiment. When consideration is limited to sites on which nitrogen applications resulted in yield increases, simple regression analyses indicate statistically significant or highly significant relationships between certain pairs of variables. However, the magnitude of the correlation coefficients is such as to indicate that only small portions of the observed variations in yield may be explained by the variations measured in available soil moisture, rainfall, and amounts of nitrogen. Simple regression analyses calculated for individual soil types resulted in higher degrees of correlation between maximum yields and soil variables.

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Appendix Table 1. Summary of data on soil types, yield of check and maximum yield plots, rates of *fall-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture, and rainfall between date of spring application of fertilizer and harvest, for all sites in *low rainfall area,* 1954-57

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Fall NO_3^- — nitrogen[3]	Fall NH_4^+ — nitrogen[4]	Available soil moisture		Spring rainfall[5]
											Fall	Spring	
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	*%*	*%*	*Lbs./A.*	*Lbs./A.*		*Inches*	
(Sites on which one or more rates of fall-applied nitrogen produced significant yield increases.)													
4U2	Wl	6.0	40	36.4	50.7	14.3	39.3	8.2	52	30	4.4	7.2	2.6
4U5	Rs	6.0	40	23.6	40.2	19.4	82.2	7.4	45	57	3.2	7.6	2.0
4U6	Wl	5.0	40	29.8	26.1	26.3	88.3	7.5	55	53	4.5	8.4	3.3
4U7	Mc	4.0	20	28.1	33.0	4.9	17.4	7.8	35	61	9.2	4.7	5.8
4U9	Pi	4.0	20	22.4	30.5	8.1	36.6	8.0	42	46	5.2	5.5	3.1
4U10	Wh	3.5	40	24.7	32.3	7.6	30.8	8.2	71	43	......	......	4.3
4U13	RS	6.0	60	8.3	19.1	10.8	130.1	9.8	25	20	2.6	5.2	2.0
4U14	Wm	6.0	40	37.4	45.1	7.7	20.6	8.6	65	39	4.3	9.5	3.5
4U15	Ri	5.0	40	8.4	16.1	7.7	91.7	8.5	55	32	2.9	6.0	1.9
4M3	Rs	4.0	20	14.3	20.6	6.5	45.5	7.2	37	11	......	3.5	2.0
4M5	Rs	5.0	20	28.5	31.9	3.4	11.9	9.3	48	13	1.0	4.7	3.3
4M6	Rs	3.8	20	29.1	33.8	4.7	13.7	8.3	42	15	1.1	3.7	3.3
4G1	Ri	4.0	40	32.1	38.6	6.5	20.2	7.8	34	28	3.2	5.5	1.3
4G2	Ri	5.0	40	24.1	30.0	5.9	24.5	9.2	57	15	2.5	5.2	1.5
4G6	Wd	3.8	60	28.5	37.5	9.0	31.6	8.5	75	20	2.2	4.7	1.5
4G7	Co	2.5	80	17.6	25.7	8.1	46.0	7.2	14	23	1.5	2.1	2.9
4S1	Wl	6.0	60	30.2	49.5	19.3	63.9	6.8	27	28	6.4	10.2	2.0
4S2	Wc	6.0	60	21.3	45.4	24.1	113.1	7.6	46	21	4.5	10.2	2.1
4S3	Wd	4.0	80	24.7	43.2	18.5	74.9	8.6	56	23	3.8	7.9	2.1

[1] First number—year, second letter—county (see table 12), last number—cooperator (references 1 and 2).
[2] See Table 3.
[3] Nitrate-nitrogen for complete profile depth.
[4] Ammonium-nitrogen for first foot.
[5] Rainfall from time of spring soil sampling until harvest.

Appendix Table 1. Summary of data on soil types, yield of check and maximum yield plots, rates of *fall-applied* nitrogen for maximum yield, protein content of wheat frommaximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture, and rainfall between date of spring application of fertilizer and harvest, for all sites in *low rainfall area,* 1954-57 (Continued)

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Fall NO_3^- — nitrogen[3]	Fall NH_4^+ — nitrogen[4]	Available soil moisture		Spring rainfall[5]
											Fall	Spring	
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	*%*	*%*	*Lbs./A.*	*Lbs./A.*		*Inches*	
(Sites on which one or more rates of fall-applied nitrogen produced significant yield increases.)													
4S6	Wl	6.0	40	35.0	50.2	15.2	43.4	6.3	41	25	5.6	9.6	2.1
4S7	Co	3.5	40	31.6	45.5	13.9	44.0	7.6	13	19	2.6	5.8	2.2
4S8	Wl	6.0	40	41.0	51.2	10.2	24.9	7.5	70	25	4.6	9.4	2.1
4S9	Wl	4.5	40	27.1	38.1	11.0	40.6	6.6	50	27	5.6	9.9	2.0
4S10	Wd	6.0	80	34.6	62.1	27.5	79.5	7.6	33	27	2.7	8.1	2.1
4W1	Tu	2.5	40	22.5	30.1	7.6	33.8	9.1	40	31	1.4	2.8	3.3
4W3	Tu	2.0	20	9.7	18.2	8.5	87.6	9.5	25	30	......	2.3	3.3
4W5	Wl	6.0	60	22.9	43.9	21.0	91.7	6.1	31	22	4.8	10.7	2.3
4W6	Co	3.5	20	21.8	27.7	5.9	27.1	5.9	62	24	3.5	6.6	2.3
5U1	Mc	3.0	20	32.1	38.1	6.0	18.7	8.7	15	33	3.6	4.4	5.7
5U3	Wm	6.0	40	24.6	37.1	12.5	50.8	8.0	27	23	4.3	6.2	4.3
5U7	Wl	6.0	40	12.2	30.4	18.2	149.2	7.8	22	24	2.4	5.2	3.4
5U9	Mc	1.5	40	17.0	35.1	18.1	106.5	7.0	30	26	2.4	3.2	5.6
5U10	Ri	6.0	80	14.0	28.3	14.3	102.1	12.3	30	26	3.4	5.3	3.1
5U11	Pi	2.0	40	15.8	25.9	10.1	63.9	9.4	34	17	1.5	1.6	4.6
5U12	Rs	5.0	40	14.1	24.8	10.8	76.6	10.0	23	20	4.4	5.3	2.6
5U14	Ri	4.8	20	12.3	16.1	3.8	30.9	11.0	28	9	2.5	3.4	2.4
5U17	Ri	6.0	60	22.1	37.1	15.0	67.9	10.5	50	22	3.1	4.4	3.7
5M1	Ri	4.3	20	15.0	19.9	4.9	32.7	9.4	17	17	......	2.3	1.9
5M2	Ri	6.0	40	9.6	20.6	11.0	114.6	9.8	17	20	......	3.3	2.1
5M5	Co	2.8	20	16.9	21.6	4.7	27.8	8.5	17	26	......	2.3	3.1
5M7	Mo	2.3	20	24.4	27.8	3.4	13.9	10.2	36	38	2.6	3.3	......
5G2	Wd	4.3	80	23.1	37.8	14.7	63.6	9.7	24	20	3.5	4.6	1.8
5G5	Co	3.5	20	28.0	34.8	6.8	24.3	8.6	59	23	5.4	5.7	3.5

5G6........	Co	3.0	40	18.0	26.2	8.2	45.6	9.3	38	19	1.8	2.8	2.7
5G7........	Co	4.0	20	31.4	40.8	9.4	29.9	7.0	37	27	3.9	5.2	1.9
5S1........	Wl	6.0	60	29.7	54.1	24.4	82.2	7.3	26	21	4.8	6.2	3.0
5S4........	Wl	6.0	60	26.8	47.3	20.5	76.5	7.6	42	17	4.3	5.9	2.8
5S7........	Wd	6 0	40	30.9	41.3	10.4	33.7	7.0	25	26	4.8	6.1	2.5
5W2........	NB	5.8	60	19.7	45.4	25.7	130.5	6.9	34	19	......	6.9	3.1
5W7........	Wc	6.0	40	28.5	38.5	10.0	35.1	6.7	37	17	1.6	5.3	2.3
6U2........	Mo	2.0	20	24.1	28.1	5.1	21.2	8.6	59	31	0.3	2.6	4.0
6U5........	Mo	2.0	60	19.5	30.6	11.1	56.9	9.9	64	40	0.4	2.5	4.0
6U6........	Wm	6.0	80	23.7	55.0	21.3	89.9	7.9	80	59	2.4	6.8	3.2
6U7........	Ri	6.0	40	28.0	43.4	15.4	55.0	6.5	78	62	1.1	6.5	1.8
6U8........	Rs	5.0	40	22.3	35.9	13.6	61.0	8.6	67	41	1.1	5.7	1.7
6U9........	Mc	2.5	60	13.4	27.6	14.2	106.0	8.1	55	74	2.0	3.8	5.3
6U10......	Wl	6.0	40	29.9	45.8	15.9	53.2	8.4	61	56	2.4	7.1	3.6
6U12......	Wl	6.0	60	25.4	33.5	8.1	31.9	9.3	92	54	2.2	8.3	2.8
6M1........	Rs	3.5	40	17.1	20.8	3.4	19.9	11.1	57	27	......	5.3	1.1
6M2........	Co	3.0	60	29.4	57.5	28.1	95.6	6.8	49	30	1.1	4.2	3.7
6M5........	Ri	6.0	40	19.3	27.9	8.6	44.6	9.6	72	26	0.3	7.2	2.2
6M3........	Co	2.5	20	24.6	30.9	6.3	25.6	9.0	56	40	1.3	3.9	3.2
6M4........	Rs	3.5	100	16.2	39.1	22.9	141.4	9.3	51	30	1.7	7.0	2.2
6G1........	Mo	2.3	80	18.2	41.0	22.8	125.3	8.6	35	20	1.3	4.8	2.8
6G2........	Mo	2.3	40	19.8	29.7	9.9	50.0	6.7	27	28	4.0	5.0	4.3
6G4........	Ri	3.5	40	17.4	25.4	8.0	46.0	9.2	45	13	1.6	6.2	2.1
6G5........	Ri	5.3	40	18.3	32.2	13.9	76.0	8.6	50	12	2.3	8.5	1.3
6G6........	Ri	6.0	40	9.0	14.2	5.2	44.1	12.3	86	7	......	9.1	2.3
6S1........	Wd	6.0	20	20.7	25.2	4.5	21.7	7.7	55	15	3.4	5.8	2.3
6S3........	Wd	6 0	40	18.6	25.3	6.7	36.0	11.4	48	25	......	7.7	2.5
6S4........	Wl	6.0	80	15.3	42.8	27.5	179.7	9.6	70	20	5.5	8.6	3.1
6S5........	Wd	5.3	40	23.9	37.8	13.9	58.2	8.5	36	16	......	7.5	3.4
6S6........	Co	3.5	40	27.1	34.4	7.3	26.9	8.4	43	11	......	4.6	3.5
6S7........	Co	4.5	80	33.0	60.4	27.4	83.0	7.2	41	20	3.2	7.2	3.3
6S8........	Co	3.5	40	17.8	29.3	11.5	64.6	7.7	31	20	1.3	4.2	3.8
6S9........	Wc	6.0	100	13.7	24.5	10.8	78.8	12.3	53	24	4.8	7.6	2.0

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[1] First number—year, second letter—county (see Table 12), last number—cooperator (references 1 and 2).

[2] See Table 3.

[3] Nitrate-nitrogen for complete profile depth.

[4] Ammonium-nitrogen for first foot.

[5] Rainfall from time of spring soil sampling until harvest.

Appendix Table 1. Summary of data on soil types, yield of check and maximum yield plots, rates of *fall-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture, and rainfall between date of spring application of fertilizer and harvest, for all sites in *low rainfall area*, 1954-57 (Continued)

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Fall NO_3^- — nitrogen[4]	Fall NH_4^+ — nitrogen[4]	Available soil moisture		Spring rainfall[5]
											Fall	Spring	
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	%	%	*Lbs./A.*	*Lbs./A.*		*Inches*	
(Sites on which one or more rates of fall-applied nitrogen produced significant yield increases.)													
6S10......	Sh	2.5	40	22.8	30.6	7.8	34.2	8.4	20	13	......	4.8	3.6
6W1......	Co	5.5	100	21.6	42.7	21.1	97.7	7.6	41	27	4.8	13.1	2.6
6W2......	Tu	1.8	60	12.9	31.0	18.1	140.3	7.9	8	17	......	1.5	2.7
6W3......	Wc	6.0	60	15.7	29.6	13.9	88.5	10.8	65	34	1.0	8.5	......
6W4......	Wm	5.3	40	22.1	33.9	11.8	53.4	5.8	63	39	7.0	12.9	......
6W5......	NA	4.0	80	9.7	28.9	19.2	197.9	9.0	34	18	5.8	7.5	......
6W6......	Co	2.0	40	17.1	24.4	7.3	42.7	7.6	10	13	......	2.4	2.8
6W7......	NE	4.5	80	21.2	32.8	11.6	54.7	6.8	39	22	3.1	12.0	3.0
6W8......	NA	4.8	80	10.7	18.8	8.1	75.7	7.4	68	28	5.3	10.4	2.4
6W9......	Du	3.8	60	18.1	31.4	12.7	70.2	7.9	44	19	2.2	7.4	1.6
7U1........	Wm	6.0	20	43.9	49.8	5.9	13.4	7.2	71	52	5.7	8.5	1.5
7U6........	Rs	6.0	60	23.3	40.4	17.1	73.4	9.5	42	61	4.5	7.9	1.1
7U8........	Rs	6.0	40	27.0	37.5	10.5	38.9	7.5	44	41	5.4	7.8	1.1
7U9........	Wl	6.0	60	28.4	53.0	24.6	86.6	8.4	44	61	5.5	8.0	1.3
7M2........	Co	4.0	20	28.7	34.8	6.1	21.3	7.0	57	49	5.7	9.6	1.4
7M5........	Rs	6.0	20	30.2	34.6	4.4	14.6	9.1	52	32	3.5	5.9	0.6
7G1........	Ri	6.0	40	25.8	34.1	8.3	32.2	9.0	56	27	6.2	6.5	0.7
7G4........	Wd	3.8	40	30.2	41.0	10.8	35.8	9.4	88	18	4.0	6.2	1.1
7S1........	Ri	4.5	20	36.8	42.0	5.2	14.1	8.0	58	36	4.8	8.0	1.0
7S3........	Co	3.5	20	31.3	34.0	2.7	8.6	7.9	34	40	4.5	5.0	1.1
7S4........	Co	4.0	20	35.2	41.9	6.7	19.0	6.8	33	45	5.0	7.6	0.9
7S5........	Wl	6.0	20	37.2	47.9	10.7	28.8	6.6	36	60	9.5	8.4	1.0
7S6........	Co	4.0	20	36.6	37.6	1.0	2.7	7.3	26	29	3.6	6.8	0.9
7S8........	Wl	6.0	40	35.9	48.0	12.1	33.7	6.6	38	33	11.0	8.0	1.0

7S9........	Wc	6.0	20	36.2	40.8	4.6	12.7	6.9	39	30	5.8	8.2	0.9
7S10......	Wd	6.0	20	33.5	39.8	6.3	18.8	6.4	37	38	9.6	8.5	0.9
7S11......	Wc	4.8	60	20.7	33.9	13.2	63.8	7.2	43	46	11.3	11.5	0.8
7W1......	Co	3.5	40	31.2	44.0	12.8	41.0	7.4	41	48	3.6	5.4	......
7W3......	Du	5.0	60	29.5	51.8	22.3	75.6	6.8	62	48	7.2	12.3	......
7W4......	Wl	6.0	60	30.1	51.2	21.1	70.1	7.4	66	31	5.6	9.3	......
7W5......	Tu	1.5	20	28.4	31.0	2.6	9.2	8.7	34	57	0.7	2.7	......
7W7......	Wc	5.5	20	33.2	41.1	7.9	23.8	5.8	84	91	5.7	7.3	......
7W8......	Wc	6.0	20	18.5	26.2	7.7	41.6	7.4	26	44	5.1	6.7	......
		(Sites on which effects of fall-applied nitrogen on yields were too small to be significant.[6])											
4U8........	Pi	2.0		10.2				11.6	90	19	1.4	2.6	2.7
4M1.......	Co	2.3		29.3				8.1	44	36	2.3	3.3	4.7
4M2........	Mo	1.8		30.4				7.4	44	26	1.3	2.2	4.7
4M8........	Rs	4.5		24.7				8.4	61	15	1.5	3.3	3.3
4M9........	Mo	2.5		27.9				8.2	58	25	2.1	3.1	4.7
4G3........	Mo	2.5		33.4				12.0	74	29	1.9	2.2	2.9
4S4........	Co	5.0		42.1				7.4	55	24	4.6	7.3	2.2
4S5........	Co	2.5		25.9				7.3	45	30	2.5	4.7	2.3
5U2........	Wv	5.0		9.0				8.4	28	27	......	0.8	......
5U4........	Mo	2.0		12.4				9.2	27	14	0.7	2.0	5.6
5U16......	Wv	6.0		27.9				7.6	52	23	2.9	4.1	7.8
5M3........	Rs	3.0		14.4				6.8	24	23	2.1	2.6	5.4
5M4........	Ri	4.8		16.2				8.0	49	13	1.1	1.0	4.5
5G3........	Rs	6.0		19.3				8.5	32	14	2.8	4.0	6.3
5G4........	Mo	2.0		21.7				9.6	44	22	0.9	1.4	6.4
5S3........	Co	3.3		29.7				7.1	49	28	5.0	5.2	8.4
5W1......	Tu	2.0		16.4				13.9	34	31	0.4	1.6	4.8
5W4......	Co	3.3		21.7				6.7	29	21	4.4	5.0	......
6G3........	Co	3.0		27.1				10.4	55	10	0.9	4.6	3.4
6G7........	Rs	2.5		17.2				9.3	32	10	......	5.4	2.3
6S2........	Wd	6.0		24.3				10.2	104	12	2.6	7.6	2.0

[1] First number—year, second letter—county (see table 12), last number—cooperator (references 1 and 2).
[2] See Table 3.
[3] Nitrate-nitrogen for complete profile depth.
[4] Ammonium-nitrogen for first foot.
[5] Rainfall from time of spring soil sampling until harvest.
[6] Protein content of wheat from check plots.

Appendix Table 1. Summary of data on soil types, yield of check and maximum yield plots, rates of *fall-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture, and rainfall between date of spring application of fertilizer and harvest, for all sites in *low rainfall area,* 1954-57 (Continued)

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Fall NO$_3^-$ — nitrogen[3]	Fall NH$_4^+$ — nitrogen[4]	Available soil moisture		Spring rainfall[5]
											Fall	Spring	
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	*%*	*%*	*Lbs./A.*	*Lbs./A.*	*Inches*		
7U5	Pi	3.0		29.1				6.7	43	74	4.4	6.5	1.3
7M1	Ri	3.5		20.9				9.9	64	54	3.1	6.7	1.0
7W6	Wa	4.0		38.8				......	59	36	8.4	8.8	......
(Sites on which one or more rates of fall-applied nitrogen produced significant yield decreases.[6])													
(Sites on which effects of fall-applied nitrogen on yields were too small to be significant.[6])													
4U11	Mo	2.0		13.8				11.0	78	30	......	2.6	3.1
4M4	Mo	2.0		22.6				9.3	67	42	2.3	4.2	4.7
4M7	Co	2.8		28.3				7.1	43	24	1.3	3.5	3.3
4G4	Co	2.7		31.3				9.1	104	36	3.2	3.9	2.9
5M6	Ri	4.5		11.5				......	39	21	0.6	1.7	4.9
5G1	UN	3.3		22.5				......	45	14	4.2	4.3	......
5S2	Wd	3.0		19.8				9.8	34	23	4.0	5.3	7.5
5S5	Wl	6.0		35.3				9.6	70	21	5.4	5.0	7.8
5S6	Wc	6.0		33.4				7.2	40	16	4.4	6.7	8.9
5S8	Co	2.8		21.6				8.5	44	15	3.9	3.7	6.0
5S9	Ri	4.0		26.5				7.2	45	21	3.6	4.0	5.7
5S10	Sh	2.3		21.2				8.4	50	24	3.3	3.1	5.8
5W3	NC	2.0		12.4				8.4	16	22	1.8	2.4	......
7M3	Co	3.0		30.5				9.6	101	49	1.8	4.4	0.9
7M6	Wd	5.5		30.8				9.1	50	50	3.6	7.6	1.1
7G2	Co	2.5		40.2				7.1	45	33	4.7	5.8	1.2
7G3	Co	2.3		24.6				12.8	110	33	3.1	4.7	0.8
7S2	Ri	3.3		22.4				10.6	97	58	6.0	9.1	0.6
7S7	Co	2.0		14.4				9.7	34	33	1.6	3.5	0.9

Appendix Table 2. Summary of data on soil types, yield of check and maximum yield plots, rates of *spring-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture and rainfall between date of spring application of fertilizer and harvest, for all sites in *low-rainfall area,* 1954-57

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Spring NO_3^- — nitrogen[3]	Spring NH_4^+ — nitrogen[4]	Spring soil moisture	Spring rainfall[5]
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	*%*	*%*	*Lbs./A.*	*Lbs./A.*	*Inches*	
(Sites on which one or more rates of spring-applied nitrogen produced significant yield increases.)												
4U2	Wl	6.0	80	36.4	53.2	16.8	46.2	9.6	66	34	7.2	2.6
4U5	Rs	6.0	60	23.6	34.3	13.6	57.6	8.3	39	19	7.6	2.0
4U6	Wl	5.0	60	29.8	46.4	16.6	55.7	8.3	40	50	8.4	3.3
4U7	Mc	4.0	40	28.1	38.5	10.4	37.0	8.6	71	44	4.7	5.8
4U9	Pi	4.0	60	22.4	38.8	16.4	73.2	8.8	24	47	5.5	3.1
4U10	Wh	3.5	60	24.7	41.9	17.2	69.6	8.9	......	......	......	4.3
4U13	Rs	6.0	40	8.3	11.9	3.6	43.4	9.4	29	20	5.2	2.0
4U14	Wm	6.0	40	37.4	41.9	4.5	12.0	8.1	90	37	9.5	3.5
4U15	Ri	5.0	20	8.4	11.7	3.3	39.3	8.1	36	21	6.0	1.9
4M2	Mo	1.8	60	30.4	35.6	5.2	17.1	10.3	21	33	2.2	4.7
4M3	Rs	4.0	60	14.3	22.8	8.5	59.4	10.9	11	17	3.5	2.0
4M5	Rs	5.0	40	28.5	30.8	2.3	8.1	10.4	54	17	4.7	3.3
4M6	Rs	3.8	20	29.1	33.4	4.3	14.8	8.4	41	16	3.7	3.3
4M8	Rs	4.5	20	24.7	26.9	2.2	8.9	10.5	35	24	3.3	3.3
4M9	Mo	2.5	20	27.9	35.1	7.2	25.8	8.8	24	46	3.1	4.7
4G1	Ri	4.0	20	32.1	36.6	4.5	14.0	7.9	46	28	5.5	1.3
4G2	Ri	5.0	40	24.1	30.8	6.7	27.8	10.3	59	22	5.2	1.5
4G4	Co	2.8	20	31.3	34.0	2.7	8.6	9.1	18	47	3.9	2.9
4G6	Wd	3.8	60	28.5	40.2	11.7	41.0	8.7	21	24	4.7	1.5

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[1] First number—year, middle letter—county (see table 12), last number—cooperator (references 1 and 2).

[2] See Table 3.

[3] Nitrate-nitrogen for complete profile depth.

[4] Ammonium-nitrogen for first foot.

[5] Rainfall from time of spring soil sampling until harvest.

[6] Protein content of wheat from check plots.

Appendix Table 2. Summary of data on soil types, yield of check and maximum yield plots, rates of *spring-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture and rainfall between date of spring application of fertilizer and harvest, for all sites in *low-rainfall area,* 1954-57 (Continued)

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Spring NO_3^- — nitrogen[3]	Spring NH_4^+ — nitrogen[4]	Spring soil moisture	Spring rainfall[5]
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	*%*	*%*	*Lbs./A.*	*Lbs./A.*	*Inches*	
(Sites on which one or more rates of spring-applied nitrogen produced significant yield increases.)												
4G7	Co	2.5	60	12.6	28.9	16.3	129.4	9.0	9	42	2.1	2.9
4S1	Wl	6.0	40	30.2	40.9	10.7	35.4	6.9	45	29	10.2	2.0
4S2	Wc	6.0	40	21.3	25.1	3.8	17.8	6.7	39	21	10.2	2.1
4S3	Wd	4.0	60	24.7	33.0	8.3	33.6	7.7	35	20	7.9	2.1
4S4	Co	5.0	20	42.1	48.2	6.1	14.5	8.7	69	39	7.3	2.2
4S5	Co	2.5	20	25.9	30.3	4.9	18.9	8.3	31	15	4.7	2.3
4S6	Wl	6.0	40	35.0	42.4	7.4	21.1	6.9	51	32	9.6	2.1
4S7	Co	3.5	60	31.6	42.3	10.7	33.9	8.4	31	36	5.8	2.2
4S8	Wl	6.0	60	41.0	46.5	5.5	13.4	7.3	54	17	9.4	2.1
4S9	Wl	4.5	40	27.1	37.3	10.2	37.6	6.3	38	9	9.9	2.0
4S10	Wd	6.0	60	34.6	42.0	7.4	21.4	8.0	46	19	8.1	2.1
4W1	Tu	2.5	40	22.5	27.7	5.2	23.1	9.8	28	20	2.8	3.3
4W3	Tu	2.0	20	9.7	16.0	6.3	64.9	9.6	19	29	2.3	3.3
4W5	Wl	6.0	80	22.9	37.9	15.0	65.5	7.1	17	16	10.7	2.3
4W6	Co	3.5	40	21.8	30.8	9.0	41.3	8.1	18	24	6.6	2.3
5U1	Mc	3.0	20	32.1	39.7	7.6	23.7	8.4	46	65	4.4	5.7
5U3	Wm	6.0	40	24.6	38.2	13.6	55.3	7.4	46	24	6.2	4.3
5U4	Mo	2.0	20	12.4	26.4	14.0	112.9	9.3	27	34	2.0	3.6
5U7	Wl	6.0	100	12.2	33.6	21.4	175.4	9.6	22	28	5.2	3.4
5U9	Mc	1.5	40	17.0	33.4	16.4	96.5	7.0	12	36	3.2	5.6
5U10	Ri	6.0	60	14.0	23.8	9.8	70.0	10.3	38	9	5.3	3.1
5U11	Pi	2.0	40	15.8	24.9	9.1	57.6	9.4	11	40	1.6	4.6
5U12	Rs	5.0	40	14.1	24.1	10.1	71.6	9.4	21	21	5.3	2.6
5U14	Ri	4.8	20	12.3	14.2	1.9	15.4	12.7	40	11	3.4	2.4

5U16	Wv	6.0	20	27.9	28.5	0.6	2.2	8.8	46	17	4.1	3.7
5U17	Ri	6.0	60	22.1	34.9	12.8	57.9	8.9	31	18	4.4	3.7
5M1	Ri	4.3	20	15.0	18.5	3.5	23.3	8.6	18	16	2.3	1.9
5M2	Ri	6.0	40	9.6	21.1	11.5	119.8	9.8	17	18	3.3	2.1
5M3	Rs	3.0	40	14.4	20.0	5.6	38.9	8.3	28	21	2.3	3.1
5M5	Co	3.0	60	16.9	22.9	6.0	35.6	7.8	15	24	4.6	1.8
5G2	Wd	4.3	60	23.1	33.4	10.3	44.6	8.3	43	15	4.0	2.3
5G3	Rs	6.0	40	19.3	22.3	3.0	15.5	10.2	37	23	5.7	3.5
5G5	Co	3.5	20	28.0	36.2	8.2	29.3	8.2	33	23	2.8	2.7
5G6	Co	3.0	40	18.0	27.4	9.4	52.2	9.0	39	24	5.2	1.9
5G7	Co	4.0	40	31.4	40.7	9.3	29.6	7.4	37	24	6.2	3.0
5S1	Wl	6.0	80	29.7	53.0	23.3	78.4	6.8	37	27	5.9	2.8
5S4	Wl	6.0	80	26.8	48.5	21.7	81.0	7.3	52	24	6.1	2.5
5S7	Wd	6.0	60	30.9	42.0	11.1	35.9	7.5	8	74	6.9	3.1
5W2	NB	5.8	80	19.7	51.3	31.6	160.4	7.0	25	15	5.3	2.3
5W7	Wc	6.0	60	28.5	40.7	12.2	42.8	6.9	28	26	2.3	3.1
6U2	Mo	2.0	20	24.1	28.9	4.8	19.9	8.4	23	57	2.6	4.0
6U6	Wm	6.0	80	23.7	52.7	29.0	122.4	8.4	34	43	3.5	3.2
6U7	Ri	6.0	40	28.0	39.9	11.9	42.5	7.5	22	30	6.5	1.8
6U8	Rs	5.0	60	22.3	30.6	8.3	37.2	9.1	36	30	5.7	1.7
6U9	Mc	2.5	60	13.4	30.8	17.4	129.8	8.9	22	46	3.8	5.3
6U10	Wl	6.0	60	29.9	44.1	14.2	47.5	9.0	47	48	7.1	3.6
6M1	Rs	3.5	20	17.1	19.8	2.4	14.0	10.7	37	46	5.3	1.1
6M2	Co	3.0	100	29.4	66.8	37.4	127.2	9.2	10	87	4.2	3.7
6M3	Ri	6.0	20	19.3	25.1	5.8	30.0	9.7	52	45	7.2	2.2
6M4	Co	2.5	20	24.6	30.2	5.6	22.8	9.4	43	61	3.9	3.2
6M5	Rs	3.5	60	16.2	29.2	13.0	50.2	9.0	33	34	7.0	2.2
6G1	Mo	2.3	60	18.2	43.3	15.1	83.0	7.9	14	38	4.8	2.8
6G2	Mo	2.3	40	19.8	37.9	18.1	91.4	7.3	22	39	5.0	4.3
6G4	Ri	3.5	40	17.4	21.2	4.8	27.6	9.2	35	26	6.2	2.1
6G5	Ri	5.3	100	18.3	31.1	12.8	69.9	8.4	37	21	8.5	1.3
6G6	Ri	6.0	40	9.0	11.7	2.7	22.9	10.4	46	16	9.1	2.3

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[1] First number—year, middle letter—county (see Table 12), last number—cooperator (references 1 and 2).

[2] See Table 3.

[3] Nitrate-nitrogen for complete profile depth.

[4] Ammonium-nitrogen for first foot.

[5] Rainfall from time of spring soil sampling until harvest.

Appendix Table 2. Summary of data on soil types, yield of check and maximum yield plots, rates of *spring-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture and rainfall between date of spring application of fertilizer and harvest, for all sites in *low-rainfall area,* 1954-57 (Continued)

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Spring NO_3^- — nitrogen[3]	Spring NH_4^+ — nitrogen[4]	Spring soil moisture	Spring rainfall[5]
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	*%*	*%*	*Lbs./A.*	*Lbs./A.*	*Inches*	
(Sites on which one or more rates of spring-applied nitrogen produced significant yield increases.)												
6S1	Wd	6.0	40	20.7	23.9	3.2	15.4	8.9	35	21	5.8	1.6
6S4	Wl	6.0	80	15.3	35.8	20.5	134.0	8.2	46	50	8.6	3.1
6S5	Wd	5.3	60	23.9	37.1	13.2	55.2	9.1	40	56	7.5	3.4
6S6	Co	3.5	40	27.1	34.2	7.1	26.2	8.7	27	26	4.6	3.5
6S7	Co	4.5	100	33.0	60.2	27.2	82.4	9.0	39	38	7.2	3.3
6S8	Co	3.5	60	17.8	28.6	10.8	60.7	9.8	33	46	4.2	3.8
6S10	Sh	2.5	40	22.8	33.1	10.3	45.2	8.0	21	37	4.8	3.6
6W1	Co	5.5	100	21.6	49.1	27.5	127.3	8.4	22	51	13.1	2.6
6W2	Tu	1.8	40	12.9	25.5	12.6	97.7	8.2	8	49	1.5	2.7
6W3	Wc	6.0	100	15.7	27.0	11.3	72.0	10.5	55	47	8.5	......
6W4	Wm	5.3	60	22.1	40.4	18.3	82.8	6.8	30	124	12.9	......
6W5	NA	4.0	40	9.7	24.9	15.2	156.7	6.9	21	58	7.5	......
6W7	NE	4.5	80	21.2	39.0	17.8	84.0	8.4	24	41	12.0	3.0
6W8	NA	4.8	80	10.7	29.6	18.9	176.6	8.5	41	17	10.4	2.4
6W9	Du	3.8	40	18.1	21.8	3.7	20.4	8.2	41	69	7.4	1.6
7U1	Wm	6.0	40	43.9	50.0	6.1	13.9	8.6	47	43	8.5	1.5
7U5	Pi	3.0	40	29.1	39.6	10.5	36.1	7.1	8	42	6.5	1.3
7U6	Rs	6.0	60	23.3	36.5	13.2	56.6	9.5	37	45	7.9	1.1
7U8	Rs	6.0	40	27.0	36.0	9.0	33.3	8.2	18	18	7.8	1.1
7U9	Wl	6.0	80	28.4	47.7	19.3	67.9	9.0	46	35	8.0	1.3
7M2	Co	4.0	20	28.7	31.2	2.5	8.7	9.8	51	51	9.6	1.4
7M5	Rs	6.0	20	30.2	35.4	5.2	17.2	8.9	64	56	5.9	0.6
7G1	Ri	6.0	40	25.8	32.5	16.7	64.7	8.6	44	16	6.5	0.7
7G4	Wd	3.8	60	30.2	43.1	12.9	42.7	9.7	40	21	6.2	1.1

7S1	Ri	4.5	20	36.8	43.9	7.1	19.3	7.2	57	27	8.0	1.0
7S4	Co	4.0	20	35.2	42.3	7.1	20.2	7.7	42	31	7.6	0.9
7S5	Wl	6.0	60	37.2	52.6	15.4	41.4	6.9	43	33	8.4	1.0
7S6	Co	4.0	20	36.6	40.5	3.9	10.6	7.1	61	38	6.8	0.9
7S8	Wl	6.0	40	35.9	48.8	12.9	35.9	6.1	41	30	8.0	1.0
7S9	Wc	6.0	40	36.2	43.2	7.0	19.3	7.4	50	24	8.2	0.9
7S10	Wd	6.0	40	33.5	43.0	9.5	28.3	7.6	52	26	8.5	0.9
7S11	Wc	4.8	60	20.7	35.1	14.4	69.6	6.7	25	24	11.5	0.8
7W1	Co	3.5	40	31.2	45.3	14.1	45.2	7.1	29	21	6.6	......
7W3	Du	5.0	80	29.5	56.2	28.7	97.3	7.5	28	44	12.3	......
7W4	Wl	6.0	80	30.1	52.8	22.7	75.4	7.6	43	23	9.3	......
7W5	Tu	1.5	20	28.4	29.4	1.0	3.5	8.7	39	42	2.7	0.7
7W7	Wc	5.5	20	33.2	37.6	4.4	13.2	6.4	27	28	7.3	......
7W8	Wc	6.0	20	18.5	28.2	9.7	52.4	7.0	42	24	6.7	......
(Sites on which effects of spring-applied nitrogen on yields were too small to be significant.[6])												
4U8	Pi	2.0		10.2				11.6	90	19	2.6	2.7
4U11	Mo	2.0		13.8				11.0	78	30	2.6	3.1
4M1	Co	2.2		29.3				8.1	44	36	3.3	4.7
4M4	Mo	2.0		22.6				9.3	67	42	4.2	4.7
4M7	Co	2.8		28.3				7.1	43	24	3.5	3.3
4G3	Mo	2.5		33.4				12.0	74	29	2.2	2.9
5U2	Wv	5.0		9.0				8.4	42	21	0.8	......
5M4	Ri	4.8		16.2				8.0	1	12	1.0	4.5
5M7	Mo	2.3		24.4				8.7	34	55	3.3	......
5G1	UN	3.3		22.5				10.6	88	21	4.3	......
5G4	Mo	2.0		21.7				9.6	44	16	1.4	6.4
5S3	Co	3.3		29.7				7.1	57	26	5.2	8.4
5S6	Wc	6.0		33.4				7.2	75	34	6.7	8.9
5S8	Co	2.8		21.6				8.5	38	21	3.7	6.0
5W1	Tu	2.0		16.4				13.9	62	48	1.6	4.8
5W4	Co	3.3		21.7				6.7	72	30	5.0	......

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[1] First number—year, middle letter—county (see Table 12), last number—cooperator (references 1 and 2).

[2] See Table 3.

[3] Nitrate-nitrogen for complete profile depth.

[4] Ammonium-nitrogen for first foot.

[5] Rainfall from time of spring soil sampling until harvest.

[6] Protein content of wheat from check plots.

Appendix Table 2. Summary of data on soil types, yield of check and maximum yield plots, rates of *spring-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture and rainfall between date of spring application of fertilizer and harvest, for all sites in *low-rainfall area,* 1954-57 (Continued)

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Spring NO_3^- — nitrogen[3]	Spring NH_4^+ — nitrogen[4]	Spring soil moisture	Spring rainfall[5]
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	*%*	*%*	*Lbs./A.*	*Lbs./A.*	*Inches*	
(Sites on which one or more rates of fall-applied nitrogen on yields were too small to be significant.[6])												
6U5	Mo	2.0		19.5				7.7	34	82	2.5	4.0
6U12	Wl	6.0		25.4				8.1	64	51	8.3	2.8
6G3	Co	3.0		27.1				10.4	49	24	4.6	3.4
6G7	Rs	2.5		17.2				9.3	23	17	5.4	2.3
6S2	Wd	6.0		24.3				10.2	59	31	7.6	2.0
6S3	Wd	6.0		18.6				10.2	42	47	7.7	2.5
6S9	Wc	6.0		13.7				10.5	47	65	7.6	2.0
6W6	Co	2.0		17.1				7.9	9	49	2.4	2.8
7M1	Ri	3.5		20.9				9.9	64	40	6.7	1.0
7S3	Co	3.5		31.3				7.3	39	33	5.0	1.1
7S7	Co	2.0		14.4				9.7	36	23	3.5	0.9
7W6	Wa	4.0		38.8				......	58	38	8.8	......
(Sites on which one or more rates of spring-applied nitrogen produced significant yield decreases.[6])												
5M6	Ri	4.5		11.5				......	45	21	2.0	4.9
5S2	Wd	3.0		19.8				9.8	42	35	5.3	7.5
5S5	Wl	6.0		35.3				9.6	101	26	5.0	7.8
5S9	Ri	4.0		26.5				7.2	36	23	4.0	5.7
5S10	Sh	2.3		21.2				8.4	33	26	3.1	5.8
5W3	NC	2.0		12.4				8.4	50	20	2.4	......
7M3	Co	3.0		30.5				9.6	62	42	4.4	0.9
7M6	Wd	5.5		30.8				9.1	75	38	7.6	1.1
7G2	Co	2.5		40.2				7.1	45	15	5.8	1.2
7G3	Co	2.3		24.6				12.8	104	21	4.7	0.8
7S2	Ri	3.3		22.4				10.6	98	27	9.1	0.6

Appendix Table 3. Summary of data on soil types, yields of check and maximum yield plots, rates of *fall-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture, and rainfall between date of spring application of fertilizer and harvest, for all sites in *high rainfall area*, 1954-57.

Site[1]	Soil type[2]	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Fall NO_3^- — nitrogen[3]	Fall NH_4^+ — nitrogen[4]	Available soil moisture		Spring rainfall[5]
											Fall	Spring	
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	%	%	*Lbs./A.*	*Lbs./A.*		*Inches*	
		(Sites on which one or more rates of fall-applied nitrogen produced significant yield increases.[6])											
4U1	At	6.0	30	17.2	23.2	6.0	34.9	8.7	39	62	....	5.5	3.8
4U3	At	6.0	30	30.9	46.5	15.6	50.5	7.9	28	57	....	7.1	....
4U12	Wm	6.0	30	21.8	33.7	11.9	54.6	8.9	48	59	....	5.5	3.8
4U16	At	5.0	60	25.1	52.7	27.6	110.0	9.2	16	52	1.3	6.7	4.7
4G5	Mo	3.0	30	37.1	44.1	7.0	18.9	11.1	80	44	3.9	4.8	....
4W2	NS	4.0	60	39.6	42.7	3.1	7.8	7.8	70	44	6.4	13.6	3.5
4W4	Du	6.0	60	28.7	52.3	23.6	82.2	8.0	57	36	5.8	10.7	2.3
4W7	NS	6.0	90	29.4	47.0	17.6	59.9	6.3	62	48	9.3	11.4	2.5
5W5	NA	2.8	30	30.8	43.1	12.3	39.9	6.2	37	29	4.3	6.9	4.2
5W6	Du	3.5	30	23.1	34.7	11.6	50.2	6.5	30	24	4.0	5.4	2.9
6U1	At	6.0	30	48.0	56.9	8.9	18.5	6.7	89	60	....	9.5	5.4
6U3	Wh	3.0	90	22.8	54.0	31.2	136.8	7.8	65	63	32.0	43.4	5.5
6U11	Wm	6.0	60	23.5	43.6	20.1	85.5	6.7	51	50	2.4	10.8	3.5
7U3	At	6.0	90	57.8	78.6	20.8	36.0	8.2	49	57	3.6	10.6	1.5
7U7	Wm	6.0	30	37.6	43.0	5.4	14.4	7.8	55	75	....	6.9	....

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[1] First number—year, second letter—county (see Table 12), last number—cooperator (references 1 and 2).
[2] See Table 3.
[3] Nitrate-nitrogen for complete profile depth.
[4] Ammonium-nitrogen for first foot.
[5] Rainfall from time of spring soil sampling until harvest.
[6] Protein content of wheat from check plots.

Appendix Table 4. Summary of data on soil types, yield of check and maximum yield plots, rates of *spring-applied* nitrogen for maximum yield, protein content of wheat from maximum yield plots, nitrate and ammonium nitrogen in soil, available soil moisture, and rainfall between date of spring application of fertilizer and harvest, for all sites in *high rainfall area*, 1954-57.

Site[1]	Soil type	Soil depth	Nitrogen rate for maximum yield	Check yield	Maximum yield	Yield increase		Protein content	Spring NO_3^- nitrogen[3]	Spring NH_4^+ nitrogen[4]	Spring soil moisture	Spring rainfall[5]
		Feet	*Lbs./A.*	*Bu./A.*	*Bu./A.*	*Bu./A.*	*%*	*%*	*Lbs./A.*	*Lbs./A.*	*Inches*	
(Sites on which one or more rates of spring-applied nitrogen produced significant yield increases.)												
4U1	At	6.0	30	17.2	24.7	7.5	43.6	9.0	56	47	5.5	3.8
4U3	At	6.0	60	30.9	50.2	19.3	62.5	10.0	51	27	7.1	......
4U4	At	5.0	90	......	31.8	......	......	11.2	24	83	5.6	3.8
4U12	Wm	6.0	30	21.8	33.3	11.5	52.8	9.1	53	52	5.5	3.8
4U16	At	5.0	90	25.1	50.0	24.9	99.2	10.4	35	30	6.7	4.7
4G5	Mo	3.0	60	37.1	50.6	13.5	36.4	9.6	26	50	4.8	2.0
4W2	NS	4.0	60	39.6	45.2	5.6	14.1	8.6	40	32	13.6	3.5
4W4	Du	6.0	90	28.7	49.1	20.4	71.1	7.6	30	41	10.7	2.3
4W7	NS	6.0	60	29.4	49.4	20.0	68.0	7.5	36	51	11.4	2.5
5W5	NA	2.7	30	30.8	40.6	9.8	31.8	6.0	31	24	6.9	4.2
5W6	Du	3.5	30	23.1	33.1	10.0	43.3	6.1	68	16	5.4	2.9
6U1	At	6.0	30	48.0	58.0	10.0	20.8	7.4	32	53	9.5	53.9
6U3	Wh	3.0	60	22.8	47.9	25.1	110.1	7.8	17	8	43.4	55.3
6U11	Wm	6.0	90	23.5	54.6	31.1	132.3	8.4	23	57	10.8	34.8
7U3	At	6.0	60	57.8	74.9	17.1	29.6	7.5	75	73	10.6	......
7U7	Wm	6.0	30	37.6	43.5	5.9	15.7	7.8	81	56	6.9	......

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[1] First number—year, second letter—county (see Table 12), last number—cooperator (references 1 and 2).

[2] See Table 3.

[3] Nitrate-nitrogen for complete profile depth.

[4] Ammonium-nitrogen for first foot.

[5] Rainfall from time of spring soil sampling until harvest.