Fertilizer Experiments with Winter Wheat in Western Oregon

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S. Roberts, E. H. Gardner, W. E. Kronstad, N. R. Goetze, I. P. Murarka, and T. L. Jackson

ABSTRACT

In a series of 30 winter wheat fertilizer experiments conducted in the Willamette Valley between 1963 and 1969, optimum rates of nitrogen fertilization varied from 75 to 150 pounds per acre. Fertilization with N, particularly at the higher rates, increased the protein content of the grain. Spring-applied N gave greater yield increases than fall-applied N and, with only one exception, no advantage was gained from applying a portion of the N fertilizer in the fall. Split N applications in the spring gave no advantage over a single spring application of N. Grain yield responses to phosphorus fertilization were obtained at most sites where soil-test levels for P were below 20 ppm. Potassium fertilization increased the yield of grain at one location where the soil-test value for K was 55 ppm. Grain yield response to sulfur fertilization was obtained at only one of the sixteen locations where the effect of S fertilization was measured. Lime applications increased grain yields at two sites located on strongly acid soils.

Three different wheat varieties were included in these experiments. Nugaines outyielded Druchamp on the valley floor soils and Druchamp was superior to Nugaines on the acid hill soils. Yamhill usually outyielded the other two varieties on both hill soil and valley floor soil locations.

INTRODUCTION

Wheat production in Oregon west of the Cascade mountains is concentrated primarily in the Willamette Valley. The climate of this area is suited to winter wheat production, as indicated by the climatological information in Table 1. The rainfall distribution pattern apparently matches the moisture requirements of the wheat plant. The mild winters promote early-season foliar development, which is probably conducive to high yields. Western Oregon soils may be deficient in nitrogen (N), phosphorus (P), potassium (K), and sulfur (S). Consequently, for top wheat yields, usually N and often one or more of the other essential nutrients must be supplied through the use of fertilizer. Soil acidity also may reduce the yield of wheat and other crops. This project was undertaken to establish more clearly the fertilizer and lime requirements for wheat production in western Oregon.

This bulletin presents the data and conclusions from a number of fertilizer experiments with winter wheat which were conducted primarily during the three-year period, 1967-1969. Some data are also included from four preliminary experiments which were conducted in 1963 and 1964. The objectives of the fertilizer experiments with winter wheat were as follows:

1. To obtain information to serve as a basis for improving the fertilizer recommendations for the leading winter wheat varieties in western Oregon.
2. To generate fertilizer response data for use in the calibration of diagnostic soil tests for P and K and in plant tissue tests for N, P, K, and S.
3. To make a preliminary evaluation of the yield response of winter wheat to liming.

Table 1. Climatological data recorded in the Willamette Valley at Salem, Oregon, 1967-1969[1]

	Jan.	Feb.	March	April	May	June	July	Aug.
Temperature (°F)								
Normals	38.3	41.5	45.1	50.5	55.9	60.3	65.5	65.1
Deviation from normal								
1967	+4.4	+1.7	−1.6	−5.1	−0.8	+3.3	+1.7	+5.9
1968	+1.3	+6.2	+2.8	−2.8	−1.3	+0.1	+0.8	−1.0
1969	−5.5	−1.6	+1.0	−2.0	+2.6	+4.8	−1.2	−2.6
Precipitation (inches)								
Normals	7.71	6.17	5.88	3.28	2.78	2.15	0.50	0.72
Deviation from normal								
1967	+2.59	−3.13	−0.28	+0.08	−1.05	−1.09	−0.50	−0.72
1968	−0.74	+1.97	−1.52	−0.93	+1.11	0.00	−0.12	+4.47
1969	1.91	−2.07	−3.05	+0.18	−1.22	+1.49	−0.30	−0.40

[1] From Climatological Data National Summary, Environmental Science Services Administration, U. S. Department of Commerce.

MATERIALS AND METHODS

Over a three-year period, 1967-1969, a series of 26 fertilizer experiments was conducted with winter wheat in nine counties of western Oregon. The results from four similar experiments conducted in 1963 and 1964 are also summarized in this bulletin. The experiments were conducted in commercial wheat fields and the farm cooperators prepared the fields for establishment of the experiments as part of their usual farming operation. Cooperating farmers also handled the application of herbicides for weed control in most instances. Seeding, fertilization, harvesting and, in some cases, weed spraying of the plots was done with special equipment adapted for plot work.

Experimental locations along with other pertinent information for each of the 30 experiments are shown in Table 2. All experimental sites were in the Willamette Valley except those in Douglas County, which were in the Umpqua Valley. The experimental sites were selected to cover a range of different soil series which are most commonly used for wheat production.

Soil samples were collected from each replication or from individual control plots within each replication at each experimental site prior to the application of fertilizer to the plots. In all cases, soil samples were collected from the plow layer; for some of the experiments, the subsoil also was sampled. The soil samples were air dried and passed through a 14-mesh sieve before being analyzed in the OSU Soil Testing Laboratory in accordance with the methods summarized in Table 3. A summary of the soil test results for samples from each of the experimental locations is presented in Tables 4 and 5. For some of the sites, soil tests were run on samples removed using one-foot increments to a depth of 4 feet. The results of these soil tests are recorded in Appendix Table 9.[1]

For all experiments, a randomized block design was used with either three or four replications. There was some variation in plot size, ranging from 10 by 40 feet in 1967 to 5 by 20 feet in 1969. The experimental treat-

[1] The appendix tables are available upon request to the Department of Soil Science, Oregon State University, Corvallis.

Table 2. Site information for the winter wheat fertilizer experiments

Site no.	County	Farm cooperator	Soil series	Previous crop	Variety planted[2]
1	Benton	Allen	Amity	Ryegrass	D
2	Benton	Barclay	Cloquato	Crimson clover	N
3	Benton	Stroda	Bellfountain	Barley	D
4	Benton	Karstens	Willamette	Barley	N
5	Benton	Hyslop I[1]	Woodburn	Fallow	D&G
6	Benton	Hyslop II	Woodburn	....	G&D
7	Clackamas	Coates	Clackamas	Barley	N
8	Clackamas	Eklund	Aloha	Uncropped	N
9	Douglas	Pitchford I	Newberg	....	N
10	Douglas	Pitchford II	Newberg	....	N
11	Douglas	Baimbridge	Hedden	Grass-subclover	D
12	Douglas	Crouch	Non Pareil	Grass-subclover	N
13	Lane	Drew	Chehalis	Barley	N
14	Lane	Drake	Malabon	Fallow	N
15	Linn	Hayes	Amity-Dayton	Oats	D
16	Linn	Lyons	Salkum	....	D&G
17	Marion	Busch	Woodburn	Red clover	N
18	Marion	Bartel	Nekia	Fallow	D
19	Polk	Cadle	Wapato	Barley	N
20	Polk	Stapleton	Steiwer	Barley	D
21	Polk	Muller	Carlton	Barley	N
22	Polk	Day	Willakenzie	Uncropped	D
23	Polk	....	Woodburn	Barley	D&G
24	Washington	Reese	Aloha	Barley	N
25	Washington	Dober	Laurelwood	Barley	D
26	Washington	Berger	Woodburn	Wheat	N
27	Yamhill	Dromgoold I	Willakenzie	Barley	D
28	Yamhill	Dromgoold II	Willakenzie	Wheat	N
29	Yamhill	Hudson	Olympic	Wheat	D
30	Yamhill	Keuhne	Carlton	Barley	N

[1] Indicates name of the farm.
[2] N = Nugaines; D = Druchamp; G = Gaines.

ments consisted of levels of N, P, K, and S applied individually or in various combinations. A lime treatment was included at selected experimental sites.

A chronological record of the field operations involved in conducting the experiments is presented in Table 6. All of the experiments were seeded with a 5-foot drill mounted on a Model G Allis-Chalmers tractor. The drill was equipped with eight sets of double-disc openers to give a spacing of 7 inches between drill rows. Each double-disc opener was supplied with two flexible spouts so that seeding and band placement of fertilizer with the seed were accomplished simultaneously. A seeding rate of 90 pounds per acre was used in all experiments, and the seeds were distributed by a Planet Junior seeding attachment. At planting time, measured amounts of fertilizer were metered into the drill row after being spread manually on an endless belt distribution system which was powered from a traction wheel.

At planting time in 1967 and 1968, the fertilizer material was banded with the seed. In 1969, only P was banded with the seed and the N, K, and S were supplied in a full broadcast application. All spring applications were surface broadcast. The fertilizer materials used in the experiments were

Table 3. Summary of soil test methods

Determination	Reference	Notes on method
Paste pH	Richards (1954)	Aqueous soil paste
Extractable phosphorus		
Dilute acid-fluoride method	Bray and Kurtz (1965)	Results were obtained by method 1a
Sodium bicarbonate method	Olsen and Bray (1965)	Determinations were made using a soil to extractant ratio of 1:10 in addition to the results obtained using the standard ratio of 1:20
Sodium acetate method	Greweling and Peech (1960)	Results were based on a soil to extractant ratio of 1:5
Extractable potassium, calcium, and magnesium	Pratt (1965)	Results were based on a single equilibration extract with neutral 1 N ammonium acetate; soil to extractant ratio was 1:20. Determination of K was by flame emission; Ca and Mg were determined by atomic absorption spectrophotometry
Cation-exchange capacity	Richards (1954)	Results were obtained by first treating the sample with neutral 1 N ammonium acetate and then by washing with ethyl alcohol. The adsorbed ammonium was displaced with HCl distilled from the displacing solution, and determined by titration.

as follows: ammonium sulfate was used to supply N and S in the fall, concentrated superphosphate (52% P_2O_5, equivalent to 22.7% P) and muriate of potash (62% K_2O, equivalent to 50% K) were used to supply P and K. Agricultural gypsum was applied as the source of S when N was excluded from the fertilizer treatment in the fall. Ammonium nitrate was the source of N applied in the spring by broadcasting on the soil surface.

Two herbicides were used for weed control. Diuron [3-(3,4-dichlorophenyl) - 1, 1-dimethylurea] was applied at the rate of 1.6 pounds of active ingredients per acre in the fall. In most cases the diuron was applied immediately following seeding, although in some cases the application was made after emergence. In the spring, at some locations 2,4-D (2-4 dichlorophenoxyacetic acid) was used at the recommended rate to control broadleaf weeds.

In 1963, 1964, and 1967, a self-propelled Massey-Harris combine with a 7-foot header was used to harvest the grain from an area of 7 feet by 33 feet for yield determination. The harvesting operation made it possible to exclude the periphery of the plot area from the yield determination as a means of eliminating any border effect. In 1968, a small International Harvester combine was used to harvest an area 42 inches by 25 feet. Some of the experimental plots in 1968 and all of the plots in 1969 were harvested using a National plot mower to clip an area 35 inches (five drill rows) by 10 feet from each plot. Then the harvested material was bundled and threshed with a "Vogel" thresher.

Table 4. **Results of soil analyses for plow-layer soil samples from experimental sites**

Site no.	Farm cooperator	Soil series	pH[2]	K	Ca	Mg	CEC
				ppm		*meq/100g*	
1	Allen	Amity	5.5	218	9.2	3.0	18
2	Barclay	Cloquato	5.2	265	14.2	5.6	13
3	Stroda	Bellfountain	4.8	187	6.2	1.7	15
4	Karstens	Willamette	5.6	194	6.7	1.5	16
5	Hyslop I[1]	Woodburn	5.5	234	5.9	1.5	18
6	Hyslop II	Woodburn	5.6	180	6.5	1.4	18
7	Coates	Clackamas	5.3	164	6.2	0.9	19
8	Eklund	Aloha	6.3	148	8.0	1.0	14
9	Pitchford I	Newberg	6.0	343	14.5	5.8	25
10	Pitchford II	Newberg	6.3	296	13.9	6.0	22
11	Baimbridge	Heddon	5.2	226	4.6	2.3	20
12	Crouch	Non Pareil	5.6	254	5.5	0.9	21
13	Drew	Chehalis	5.4	359	11.3	5.1	24
14	Drake	Malabon	5.6	608	13.5	5.6	26
15	Hayes	Amity	5.0	101	5.8	1.3	12
16	Lyons	Salkum	5.3	90	5.5	1.2	19
17	Busch	Woodburn	5.6	238	6.0	2.5	14
18	Bartel	Nekia	5.9	55	7.5	0.1	16
19	Cadle	Wapato	5.2	304	21.5	11.9	45
20	Stapleton	Steiwer	5.5	406	15.9	7.2	34
21	Muller	Carlton	5.4	125	9.5	4.6	20
22	Day	Willakenzie	5.1	312	3.5	1.2	11
23	(Not recorded)	Woodburn	5.6	168	9.8	2.8	17
24	Reese	Aloha	5.8	113	7.7	2.4	15
25	Dober	Laurelwood	6.3	277	7.8	1.4	14
26	Berger	Woodburn	5.6	90	7.4	0.9	13
27	Dromgoold I	Steiwer	5.6	300	8.7	3.0	17
28	Dromgoold II	Steiwer	5.3	289	5.1	1.1	14
29	Hudson	Olympic	5.4	133	3.9	0.7	23
30	Kuehne	Carlton	5.7	281	7.4	2.2	17

[1] Indicates name of farm.
[2] See Table 5 for P results.

Grain harvested from each plot was weighed and subsamples were taken from selected sites for the determination of protein content and test weight. The test weight of the grain was determined by the standard method and the grain protein was determined by the method of Udy (1956) by means of the Udy, Model E, Protein Analyzer.[2]

[2] The determination of grain protein was performed under the direction of Charles R. Rohde, Pendleton Experiment Station, and the chemical analysis of plant material was under the direction of D. P. Moore and T. L. Jackson, Department of Soil Science, Oregon State University.

Samples of plant material were collected at three stages of plant growth. From selected locations, plant samples were collected at tillering just prior to the application of N in the spring, at jointing approximately one month after spring fertilization, and at the boot stage. The plant material was oven-dried at 70° C, ground, and analyzed in accordance with the procedures outlined in Table 7.

Statistical analysis of data was performed at the Computer Center of Oregon State University. An analysis of variance was used to evaluate treatment effects. In many cases linear regression analysis was employed to show the relationship between selected variables. The complete sets of data from each experiment are presented in the Appendix tables. To facilitate the discussion, only the results from selected treatments are included in the "Results and Discussion" section of this bulletin.

Table 5. Results of soil analyses for phosphorus for plow-layer soil samples from experimental sites

Site no.	Extractable P by the method indicated			
	Acid-fluoride	$NaHCO_3$ (1:10)	$NaHCO_3$ (1:20)	$NaC_2H_3O_2$
	ppm	*ppm*	*ppm*	*ppm*
1	54	18	28	2.4
2	14	16	23	2.1
3	8	6	9	0.7
4	53	21	27	1.7
5	40	31	....	....
6	49	38	....	....
7	5	3	5	0.2
8	92	60	65	4.4
9	35	28	39	3.3
10	15	16	24	3.1
11	2	1	2	0.1
12	8	5	7	0.9
13	59	39	58	4.6
14	42	26	31	5.6
15	29	13	22	1.9
16	8	6	....	....
17	46	29	39	3.1
18	4	4	6	0.2
19	21	17	33	2.3
20	36	14	27	1.9
21	5	3	5	0.9
22	11	6	9	0.4
23	44	27	35	3.6
24	45	26	39	2.6
25	107	57	69	4.8
26	31	14	20	2.5
27	13	5	8	0.5
28	21	7	14	0.9
29	3	3	4	0.3
30	28	14	19	2.0

Table 6. Summary of time schedule for field operations

Field operation	Time interval
Seeding and fall fertilization	Oct. 15-Nov. 15
Spraying with diuron	Oct. 15-Dec. 1
Plant sampling at tillering prior to spring fertilization	March 1-15
Spring fertilization with N[1]	March 1-15
Plant sampling at jointing	April 15-30
Plant sampling at boot stage	June 25-July 10
Grain harvest	July 27-Sept. 10

[1] Alternate dates for the split application of N for the experiments conducted in 1963 and 1964 were February 25 and March 25.

Table 7. **Summary of methods used for chemical analysis of leaf tissue and grain of wheat**

Test or determination	Reference	Notes on the method
Calcium, magnesium, iron, manganese, and zinc	Gieseking and others (1935)	The Perkin Elmer, Model 303, atomic absorption spectrometer was used to determine these elements in the nitric-perchloric acid digest
Grain protein	Udy (1956)	Determined with Udy Model E Protein Analyzer
Nitrogen	Johnson and Ulrich (1959)	Micro Kjeldahl procedure to include nitrate-N was used to determine total N in the plant tissue
Phosphorus	Jackson (1958)	Molybdate-vanadate colorimetric method was used to determine P in nitric-perchloric acid digest; color intensity was measured on a Bausch and Lomb spectronic 20 spectrophotometer
Potassium	Brown and others (1948)	Beckman Model DU spectrophotometer with flame emission attachment was used to determine K in nitric-perchloric acid digest
Sulfur	Chesnin and Yien (1950)	Turbidimetric determination of sulfate in nitric-perchloric acid digest

EXPERIMENTAL RESULTS AND DISCUSSION

Response to Nitrogen

Yield

The average yield data for the N rate studies with winter wheat are summarized in Table 8 (also Appendix Tables 1 to 8). In this table, only the rates of spring-applied N are indicated, but in all treatments except the zero-N control treatment an additional 20 to 25 pounds of N per acre was also applied in the fall at seeding time. In all cases a sufficiency of other nutrients, including P, K, and S, was insured either by fertilizer application or on the basis of a high soil-test value.

Fertilization with N produced a marked increase in grain yield at all locations excepting sites 18 and 25 (Table 8), and one or more of the specified rates of N resulted in a yield of grain exceeding 6,000 pounds per acre in seven of the experiments. A grain yield in the range of 5,000 to 6,000 pounds per acre was recorded for three experiments, and for eight additional experiments the top grain yields were in the range of 4,000 to 5,000 pounds per acre.

The yield data for the experiments at sites 18 and 25 indicated no significant response to N fertilization. The negligible response to N at these two sites is most likely attributable to previous cropping and management. For example, the field at Site 18 was in fallow at the time the experiment was seeded, and red clover was grown on the field for two years preceding the experimental wheat crop. The two previous crops at Site 25 were red clover and spring barley. It was assumed that growth of the leguminous crop in the rotation enhanced the supply of N for subsequent crops.

The optimum yield of grain was obtained in nearly all experiments when N was applied at rates which ranged from 75 to 150 pounds of N per acre. On Site 15 on the Hayes farm (Table 8) 200 pounds of N per acre consistently produced a greater

Table 8. Wheat yields and protein levels for different rates of nitrogen application

Site	Nitrogen fertilizer rate[1] 0	1	2	3	0	1	2	3
	Average yield (lbs./A)				Average percent protein			
				Nugaines				
1	3,460	5,360	5,410	3,650	7.4	7.5	9.8	13.2
2	3,100	5,640	5,530	5,400				
4	3,490	6,200	6,220	5,540	7.1	7.5	9.3	11.4
5[2]	....	6,610	6,350	5,170		8.6	8.9	10.7
6[2]	....	4,560	3,960	2,640		7.5	9.2	10.4
7	570	2,420	2,720	2,810	8.6	8.9	11.0	11.4
8	2,460	4,470	3,960	2,920	9.2	8.9	10.3	12.9
9	1,950	4,360	....	3,680	8.3	9.5		11.9
10	1,210	3,880	....	3,440	7.0	8.1		11.2
11	920	2,950	2,680	2,930				
12	2,530	4,110	4,290	3,930				
13	3,770	6,040	5,340	4,730	7.9	9.5	10.8	13.0
14	3,890	5,560	6,190	5,570	7.2	7.2	8.8	10.0
17	4,200	5,610	4,960	3,990	7.9	9.2	9.9	12.6
19	2,430	3,890	4,620	4,480	9.0	9.0	9.6	11.3
21	2,260	3,650	3,320	2,630				
23[2]	....	5,960	6,050	5,350		7.2	7.5	10.0
24	2,270	4,460	5,000	3,840	9.1	9.3	11.0	12.7
25	3,490	3,790	3,780	2,900	9.1	11.2	13.4	14.6
26	2,790	5,040	5,340	5,900	7.6	7.5	8.2	9.9
28	1,590	4,510	4,950	4,670	7.4	8.5	9.7	10.3
30	1,950	2,740	3,350	3,230				
AVERAGE	2,543	4,628	4,700	4,063	8.1	8.6	9.8	11.6
				Druchamp				
1	....	4,730	4,140	2,500		10.2	12.1	14.5
2	....	4,590	5,200	5,220				
3	3,470	4,350	3,890	3,650	9.8	10.5	12.0	12.6
5	3,810	5,010	5,140	4,680	8.8	11.3	11.8	13.9
6	3,600	5,760	6,120	5,940	9.6	10.1	11.7	12.8
11	....	3,690	4,210	3,170				
15	1,410	1,510	2,260	2,980	10.8	10.5	11.3	13.2
16	3,360	5,220	5,880	6,240	7.2	9.1	10.8	13.0
18	3,560	3,790	3,750	2,790				
20	2,040	3,550	3,200	3,260	8.6	12.3	13.9	15.7
22	1,610	3,020	3,630	3,390	8.6	10.0	12.5	13.1
23	3,460	5,950	6,830	6,950	7.8	8.8	9.6	11.6
27	1,890	3,820	4,250	3,640	8.8	9.6	11.7	14.1
29	490	1,650	1,820	2,840				
30	....	2,760	2,750	3,310				
AVERAGE	2,609	3,960	4,205	4,037	8.9	10.2	11.7	13.4

[1] Nitrogen fertilizer rates 0, 1, 2, 3 equal 0, 75 to 100, 125 to 150, and 200 to 250 pounds nitrogen per acre respectively.

[2] These yields are for Gaines wheat.

yield than the moderate rate of N used in this experiment (125 pounds per acre). At the time of spring fertilization, Site 15 was extremely wet, indicating imperfect drainage, and considerable N may have been lost by denitrification.

In the series of experiments there was a wide range in the optimum yields of wheat. There appeared to be less efficient utilization of N fertilizer at the sites which produced less than 4,000 pounds of wheat per acre (Table 8 and Appendix Tables 7 and 8) than at the sites where production was above this level. From 75 to 150 pounds of N per acre were required to obtain the peak yield in most cases, even on the low-yielding sites. Until some precise technique is developed for predicting the nitrogen-supplying power of the soil, further refinement in N fertilizer recommendations for wheat will be difficult.

The supply of available moisture was most likely a dominant factor in regulating the yield of wheat at some of the sites. Fernandez and Laird (1959) concluded that the yield of wheat was depressed in central Mexico when the available soil moisture percentage dropped below 30. Lathane and Stapel (1959) showed that the yield of wheat was greatly dependent upon the moisture supply during the filling stage of growth for the wheat plant. The moisture stress for wheat grown on shallow soil in the Willamette Valley is probably frequently severe during the filling stage. A study by Rossner (1968) in the Willamette Valley indicated that irrigation was not beneficial for increasing the yield of winter wheat on the deep, well-drained valley soil.

A complete evaluation of the supply of soil moisture was not included as part of this study. In 1968, at Site 14 the soil moisture was determined periodically through the growing season to a depth of 4 feet in the Malabon soil. On July 5, during the critical stage for filling of kernels, the moisture in the surface 0 to 24 inches of soil profile ranged from 6 to 14 percent. In plots which received 125 to 200 pounds of spring-applied N per acre, an average of 18 percent moisture was measured at a depth of 4 feet. These soil moisture values indicate a very low level of available soil moisture to at least a depth of 4 feet. The normal precipitation for July in the central Willamette Valley is only 0.5 inches (Table 1). The July rainfall in 1968 was below normal. It is apparent that the moisture reserve in the soil is an important factor in supplying the moisture needs of the wheat crop during July.

Many of the experimental sites included in this study most likely exhibited a much lower capacity for storage of moisture in the soil profile than the sites where Rossner (1968) conducted his study, or at Site 14 where soil moisture was measured. Note particularly sites 7 and 12 (Table 8) which had limiting layers of rock fragments at varying depths less than 4 feet. Perhaps the effective rooting depth was less than 4 feet at various other sites. The end result would be a severe moisture stress for the wheat crop just prior to maturity, a time when grain yield could be adversely affected.

Test weight

The effect of different rates of N on test weight is presented for selected experiments in Appendix Tables 1 through 8. In most instances rates of N up to the level of fertilization required for optimum yield had little effect on the test weight. With the exception of a few cases, moderate rates of N (150 pounds per acre or lower) produced grain with test weights approximating 60 pounds per bushel. Optimum N fertilization resulted in test weights which were both higher and lower than the test weight values recorded by the zero-N treatment. The most noticeable trend in the relationship between test weight and rate of N fertilization was the sharp reduction in test weight resulting from applications of 250 pounds or more of N per acre in the 1967 experiments.

In some of the experiments, N fertilization was increased by a sizable increment without a corresponding increase in grain yield. Under these conditions the test weight was depressed sharply below 60 pounds per bushel.

Grain protein

The effect of different rates of N on grain protein is presented for selected experiments in Table 8. With the exception of a few cases, moderate rates of N (150 pounds per acre or lower) produced grain with less than 12 percent protein. Hunter and others (1961) indicated that ordinarily the protein level of soft white wheat suitable for milling into pastry flour should not exceed 10 percent.

Added increments of fertilizer N in most cases produced increases in grain protein, although the initial small increments of applied N which resulted in marked yield increases caused a slight depression in the percentage of grain protein. A similar relationship between N rate and grain protein was noted by Koehler (1961), who regarded the negative correlation between N rate and protein percentage as an indication of a dilution effect. In some of the experiments, N fertilization was increased by a sizable increment without a corresponding increase in grain yield. Under these conditions the percentage of protein in the grain greatly exceeded the desired range of 10 to 12 percent. Hunter and others (1958) and Fernandez and Laird (1959) reported similar observations; consequently, the practice of overfertilization with N is discouraged because this results in undesirable protein levels of soft wheat.

Variety comparisons

The fertilizer experiments also were designed to compare the performance of different varieties of wheat at varying levels of N (Table 8 and Appendix Tables 1 through 8). Earlier observations on the different wheat varieties for western Oregon have shown that (1) the variety Druchamp was superior on both acidic "hill soils" and poorly drained bottom land, and (2) the semi-dwarf varieties Gaines and Nugaines were superior for wheat production on the permeable, well-drained "valley soils." Kerridge and Kronstad (1968) reported that Druchamp wheat had a relatively high tolerance to soluble aluminum in the nutrient culture. The level of soluble aluminum in soils frequently is directly related to the degree of soil acidity.

The data from these experiments largely corroborate the conclusions drawn from previous observations. At 8 of 13 experimental sites Nugaines produced higher grain yields than Druchamp (Table 9). At eight additional sites, a three-way comparison was made by growing the varieties Yamhill, Druchamp, and Nugaines. The highest yielding varieties were Yamhill at five sites, Nugaines at two sites, and Druchamp at one site.

The superior yielding capacity of Nugaines over Druchamp on the highly productive sites is indicated in Table 9 for sites 13 and 14. Both of these sites are representative of deep, well-drained soil in the Willamette Valley floor. Yields of Druchamp and Nugaines varieties are comparable for Site 26 (Table 9). This site is representative of a large area of imperfectly drained lowland soil, where a considerable depth of rooting occurs after cessation of winter precipitation. Although it was possible to make yield comparisons at only a single rate (125 pounds of N per acre), Yamhill substantially outyielded Druchamp and Nugaines at Site 26.

The data for Site 3 (Table 9) provide an excellent example of the yielding superiority of the Druchamp and Yamhill varieties over Nugaines on an acidic "hill soil." In other experiments a distinct varietal response pattern was less clear, and more research will be needed to clarify the wheat variety x fertility x soil interaction. The results of this study indicate that previously outlined recommendations relevant to the use of Druchamp and Nugaines on different soil types have a degree of validity. These limited data indicate that Yamhill is probably adapted to a wider range of soil conditions than the other two varieties and that it may be suitable for production on

Table 9. Average yields of wheat varieties at the different experimental sites

Variety	Wheat yield (pounds per acre)												
	Site												
	1	2	3	5	6	7	9	11	12	13	14	15	16
Nugaines	5,410	5,530	2,880	....	....	2,720	4,360	2,680	4,290	5,340	6,190	1,860	....
Druchamp	4,140	5,200	3,890	5,140	6,120	2,850	2,710	4,210	3,090	4,270	4,360	2,260	5,880
Gaines	4,170	....	....	6,350	3,960	....	2,840	....	....	4,070	....	....	4,320
Yamhill	....	6,000	4,440	....	....	....	....	3,570	3,980	....	5,330	....	....
	17	18	19	20	21	23	24	25	26	27	29	30	
Nugaines	4,960	2,930	4,620	3,150	3,320	....	5,000	3,780	5,340	4,660	2,640	3,350	
Druchamp	4,410	3,750	4,780	3,200	3,520	6,830	3,950	2,690	5,530	4,250	1,820	2,750	
Gaines	4,340	....	3,020	2,810	....	6,050	3,390	3,790	....	4,060	....	....	
Yamhill	....	....	....	....	4,680	....	....	....	7,090	....	....	4,240	

most of the soil types in western Oregon. One subtle characteristic of the Yamhill variety relates to the efficiency of N utilization. The Yamhill variety produced top grain yields when fertilized with N at the same rate which was considered optimum for the other varieties. For a maximum yield of Yamhill, higher rates of N may be required.

Spring and fall application

Plant chemical analyses, yield determinations, and related data were used to evaluate the treatment effects of the time of N application on the response to N. Treatments from several different experiments were designed to evaluate these effects (Table 10). Both grain yield and total N in the plants at tillering prior to spring fertilization with N were used as a basis for determining the effectiveness of fall-applied N.

All plants which were sampled and analyzed at the tillering stage contained more than 4 percent total N. At Site 4 (Table 10) the plants which were fall-fertilized with 100 pounds of N per acre contained a significantly higher concentration of N at tillering than the unfertilized plants. But in all cases 75 pounds of N per acre applied in the spring produced a higher yield than 100 pounds of fall-applied N.

The yield response data (Table 10) indicate that, with the exception of Site 19, N applied in the spring was utilized much more efficiently than fall-applied N. At Site 19, which proved to be an exceptional experiment, the banding of 20 pounds of N per acre with the seed at seeding time increased the grain yield by 1,400 pounds per acre (Table 10). This large yield increase likely resulted from improved seedling vigor and stand survival over the winter as a result of fall-applied N. Other than this isolated case, there was no advantage in applying N to wheat in the fall. Apparently much of the fall-applied N was removed from the rooting zone by leaching or by denitrification during the winter and was not available to the plants during the growing season.

A split application in which part of the N was applied in February and the remainder in March was no more effective than a single application in March. (The complete details of these comparisons appear in Appendix Tables 18, 19, 29, and 36.)

The N fertilization rate studies produced a wide range of values for both grain yield and total N in the wheat plants. Data from five different experiments which had grain yields approaching 6,000 pounds per acre (Figure 1) show the relationship between total N in the plants at jointing and grain yield at harvest. Additional data showing the N in wheat plants are reported in Appendix Tables 10, 11, and 12. In all cases the plant nutrients other than N were believed in optimum supply. Unlike the very narrow range of values for N at tillering, there were marked differences in N at jointing which were closely associated with N application. Figure 1 indicates that for optimum grain yield, a minimum of 2.6 percent N was required in the plant tops at the jointing stage of growth. On the other hand, if plant N exceeded 3.5 percent at jointing, there was a general trend toward depression in grain yield.

From the standpoint of a useful diagnostic test for evaluating the N status of the wheat plant, the Kjeldahl N determination at the jointing stage is probably better than tests taken at any other time. In the present series of experiments, sampling at the jointing stage was done about one month after spring fertilization with N, and the amount of N in the plants was influenced extensively by the N treatments. Most likely a low-N crop would benefit from a supplemental application of N any time during or before the early jointing stage if followed by a significant rainfall.

In 1967, samples of the upper leaves were collected at selected experimental sites when the plants reached the boot stage (Appendix Table 10). There was

Table 10. Effect of fall versus spring applications of nitrogen on the yield response of winter wheat

Experimental site[1]	N applied in (fall and spring)	Grain Yield	Grain Test wt.	Grain Protein	Plant N at tillering
	lbs./A	*lbs./A*	*lbs./bu.*	*%*	*%*
Site 4	(0 + 0)	3,490	60.0	7.1	4.50
Karstens Farm	(25 + 50)	5,720	59.2	7.3	......
1969	(0 + 75)	6,560	59.6	7.5	......
	(25 + 75)	6,200	59.0	7.5	......
	(100 + 0)	4,810	59.6	6.6	4.89
	(25 + 125)	6,220	59.1	9.3	4.48
LSD .05		840	......	0.85	0.21
Site 8	(0 + 0)	2,460	58.4	9.2	4.17
Eklund Farm	(25 + 50)	4,110	54.9	8.3	......
1969	(0 + 75)	4,730	56.6	8.7	......
	(25 + 75)	4,470	48.3	8.9	......
	(25 + 125)	3,960	48.1	10.3	4.07
LSD .05		511	......	0.83	N.S.
Site 19	(0 + 150)	3,210	61.0	......	......
Cadle Farm	(20 + 150)	4,620	61.6	......	......
1967					
LSD .05		971	......	......	......
Site 22	(0 + 0)	1,610	58.1	8.6	4.73
Day Farm	(25 + 50)	2,090	58.1	8.7	......
1969	(0 + 75)	3,110	58.5	9.5	......
	(25 + 75)	3,020	58.1	10.0	......
	(100 + 0)	2,540	58.4	9.1	4.93
	(25 + 125)	3,630	58.1	12.5	4.77
LSD .05		519	......	0.73	N.S.
Site 26	(0 + 75)	4,650	61.6	......	......
Berger Farm	(20 + 75)	4,690	61.1	......	......
1968	(0 + 125)	6,020	61.5	......	......
	(20 + 125)	5,340	61.5	8.2	......
LSD .05		500	N.S.	......	......
Site 28	(0 + 0)	1,590	62.1	7.4	4.51
Dromgoold Farm	(25 + 50)	3,840	62.0	7.6	......
1969	(0 + 75)	3,970	61.9	7.9	......
	(100 + 0)	2,690	62.6	7.8	4.55
	(25 + 75)	4,510	61.9	8.5	......
	(25 + 125)	4,950	62.3	9.7	4.47
LSD .05		548		0.66	N.S.

[1] The variety for all sites except 22 was Nugaines. The variety for Site 22 was Druchamp.

no apparent advantage in sampling at the boot stage of growth rather than at jointing, particularly for diagnosing the N status of the wheat plant. Most values for N were lower at the boot stage than at the jointing stage, but the highest values were consistently found in plant samples collected at tillering stage.

Response to Phosphorus

One objective of the study was to obtain fertilizer response data for winter wheat which would provide the basis for soil-test calibration. Yield responses to P fertilizer were measured in approximately one-third of the experiments. The experimental sites rep-

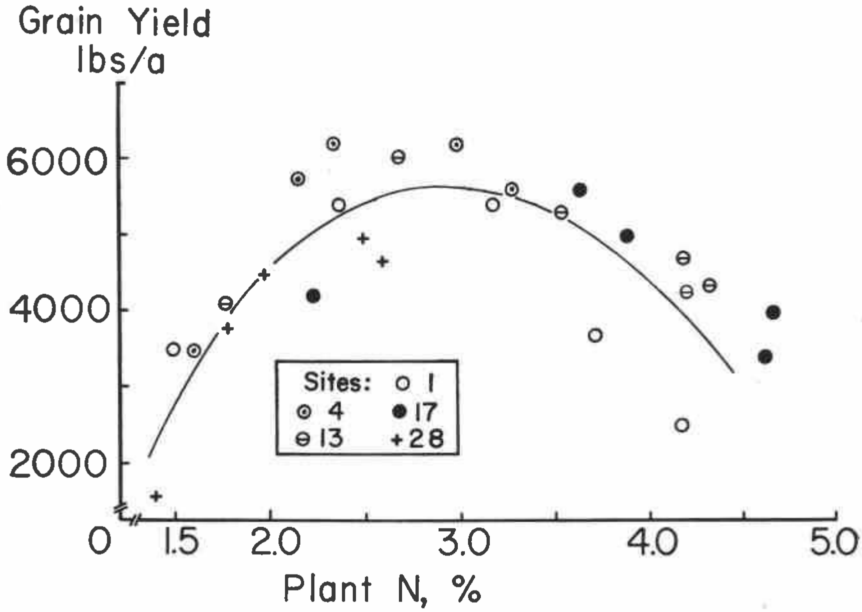

Figure 1. Relationship between total nitrogen in Nugaines wheat plants at jointing and yield of grain for the nitrogen-rate studies at five experimental sites.

resented many different soil series, and values for the standard dilute acid-fluoride test ranged from 3 to 107 parts per million (ppm) phosphorus (Table 5).

The dilute acid-fluoride method was regarded as a standard basis for comparing three other testing methods. The other testing methods for P included 0.5M sodium bicarbonate ($NaHCO_3$) with either a 1 to 10 or a 1 to 20 ratio of soil sample to extractant and 0.7M sodium acetate ($NaC_2H_3O_2$) with a 1 to 5 ratio. The significant correlation between selected pairs of soil tests for P are illustrated in Appendix Figures 1, 2, and 3.

The dilute acid-fluoride extractable P was more closely correlated with the $NaHCO_3$-extractable P obtained with either a 1:10 ($r = 0.94$) or 1:20 ($r = 0.94$) soil to solution ratio than with $NaC_2H_3O_2$-extractable P. For 95 entries, the mean values for soil-test P for the four methods (ranked in decreasing order) were: dilute-acid fluoride $>$ $NaHCO_3$ (1:20) $>$ $NaHCO_3$ (1:10) $>$ $NaC_2H_3O_2$. The values for $NaC_2H_3O_2$-extractable P were approximately 10 percent of the values obtained by the other methods, and the correlation coefficient relating $NaC_2H_3O_2$-extractable P and dilute acid-fluoride extractable P was 0.83.

These results are in agreement with a two-part study on phosphorus availability by Alban and others (1964) and Jackson and others (1964). Alban's study showed the same quantitative relationship among the extractable P values obtained with the different methods of analysis, with one notable exception. The values for $NaC_2H_3O_2$-extractable P obtained by Alban were much higher than any of the values obtained in this study. Jackson concluded that the dilute acid-fluoride and the $NaHCO_3$ extractants were comparable for predicting the soil P status. The degree of correlation illustrated for the comparisons of these extracting systems certainly supports the earlier conclusions.

For soil-test calibration a graphical approach was used to relate the yield response of wheat to the values for extractable soil P. Figures 2 and 3 show the relative yield response to P fertilization at each site versus the extractable P obtained by four methods. The yield index (relative yield response to P) was calculated from the yield ratio of the unfertilized control to the fertilized plot times 100. Individual points in the figures were keyed to the original site numbers in Table 4 and the curves were fitted by inspection.

The graphs show a sharp increase in yield index with each increment of increase in soil-test P in the low range for each of the testing methods. Once a soil-test level of 21 ppm P was attained with the dilute acid-fluoride method, for example, the yield index approached 90 or more and any additional response to P fertilization was

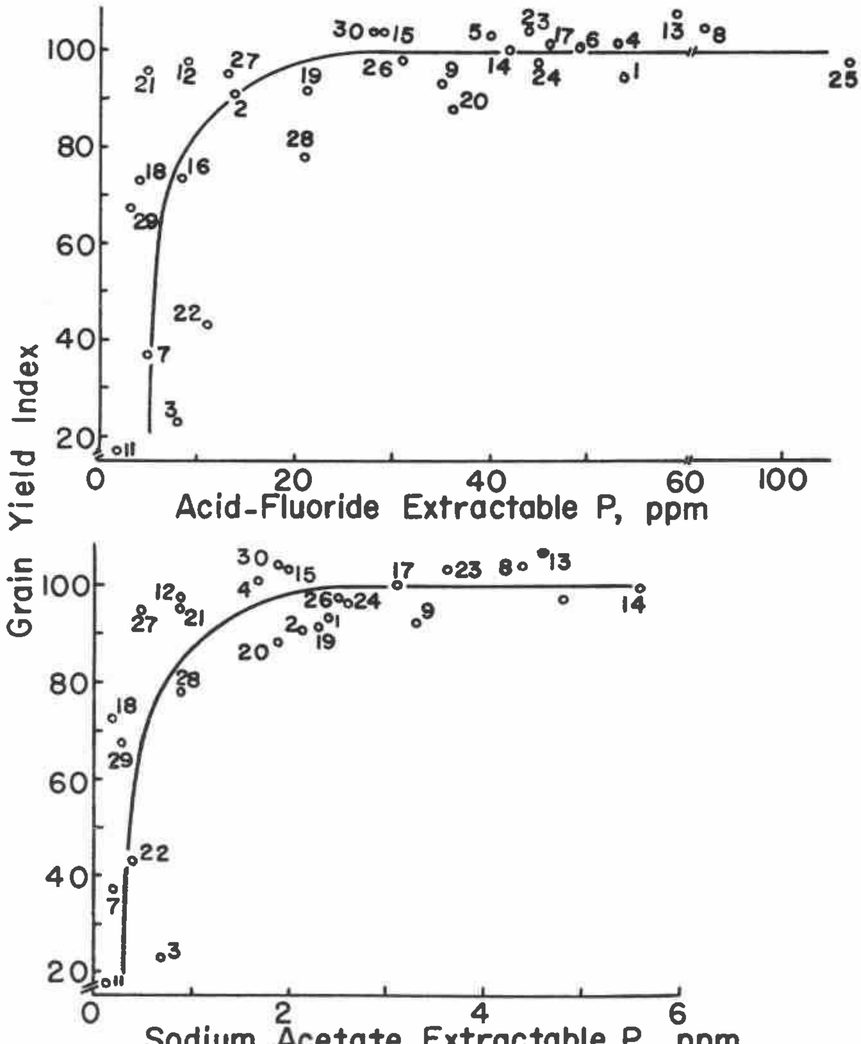

Figure 2. Soil-test calibration of the dilute acid-fluoride extractable phosphorus and sodium acetate extractable phosphorus, using winter wheat as the indicator crop.

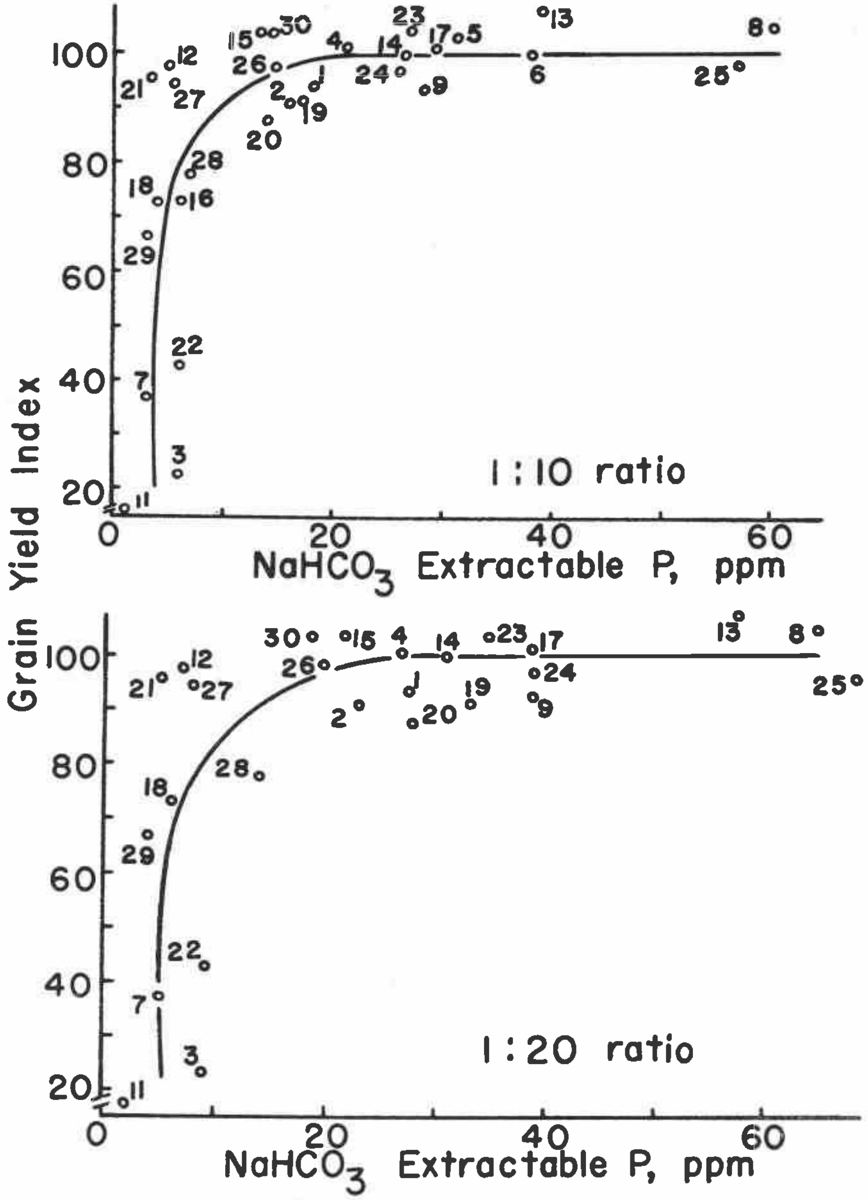

Figure 3. Soil-test calibration of the sodium bicarbonate (1:10) and sodium bicarbonate (1:20) extractable phosphorus.

small. Site 20, with a yield index of 88 and 36 ppm acid-fluoride P, deviated slightly from the response pattern. The calibration of the dilute acid-fluoride test for P indicated that for practical purposes there was a very low probability of obtaining a response to P when the soil-test value exceeded a tentative critical level of 20 ppm P. By contrast, when the soil test was 5 ppm or less there was a high probability of obtaining a response to P fertilization, and some of the yield responses obtained were of considerable magnitude. Similar reasoning may apply equally well to the graphs for the other testing methods. The critical levels indicated by the graphs are approximately 2 ppm P for soil sample extraction with sodium acetate (Figure 2) and just under 20 ppm P for extraction with $NaHCO_3$ (Figure 3).

There were several sites at which only a small P response was obtained. The only explanation for lack of response at these sites appeared to be that some factor other than P availability was limiting yield. In 1968 and 1969, the relationship between P in the plow layer and in the subsoil was evaluated at the experimental sites. Without exception, the acid-fluoride extractable P was lower in the subsoil than in the plow layer (Appendix Table 9). Consequently, there was no basis for concluding that high subsoil P accounted for lack of P response on any of the low-level sites or that extremely low subsoil P provided an explanation for a site being more responsive to P fertilization than was predicted by soil-test P in the plow layer.

Samples of wheat plants from selected experiments were analyzed for P. These results are presented in Figure 4 and in Appendix Tables 10, 11, and 12. The tillering stage of growth was without question the most appropriate time for evaluating the effect of P application on the P status of the wheat plant. Fertilization with

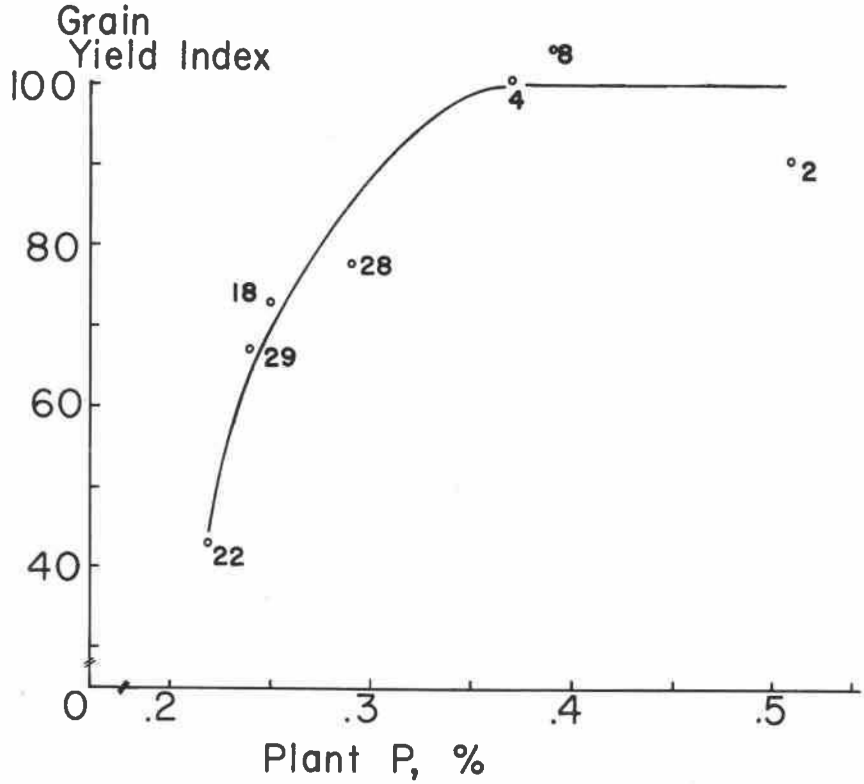

Figure 4. A diagram of plant phosphorus concentration at tillering for plants unfertilized with phosphorus versus the grain yield index (ratio of yield with and without phosphorus fertilization x 100).

P produced a marked increase in the concentration of P in the plants, particularly at the sites responsive to P.

The data plotted in Figure 4 indicates that a critical level for P occurred in the range of 0.30 to 0.37 percent plant P. Increases in grain yield were obtained at all experimental sites where plants not fertilized with P had less than 0.37 percent P. Even at the nonresponsive sites, plant P at tillering was increased to some extent by the application of P fertilizer. Plant analysis at the tillering stage indicated that the wheat plants were utilizing the P fertilizer which was banded with the seed at seeding time.

Selected data for plant P at other stages of growth (Appendix Tables 10, 11, and 12) illustrate two noteworthy trends. Plant P at the jointing stage generally increased with N fertilization and generally decreased with advancing maturity of the plants. When the wheat plants reached the jointing stage, there was little remaining evidence of the effect of P fertilization on plant P.

The data clearly indicate that the time of sampling was a critical factor in evaluating P treatment effects on wheat. A delay in sampling beyond the tillering stage not only minimized the P treatment effect on plant P, but also accentuated the effect of other factors, such as N fertility level, on the uptake of P.

Response to Potassium

Potassium fertilization resulted in a grain yield response at Site 18 (Appendix Table 11) where the soil-test value for K was 55 ppm. All other locations had a soil-test value for K of 90 ppm or greater. The current critical soil-test level for winter wheat below which a K yield response is anticipated in western Oregon is 100 ppm.

The yield response to K at Site 18 (Appendix Table 11) was accompanied by an increase in plant K from 1.4 percent to 2.5 percent at the jointing stage of growth. The value of 1.4 percent K obtained in the plant top at jointing was probably considerably below the critical level for this stage of growth in view of the severity of the K deficiency. At the tillering growth stage the concentrations of K in the plants were 2.05 percent and 2.83 percent for non-K and K-fertilized treatments respectively (Appendix Table 31).

In addition to the low soil test for K in the plow layer at Site 18, the subsoil was also extremely low in extractable K. Data for Site 18 (Appendix Table 9) indicate that all subsoil samples, which ranged in depth from 1 to 4 feet, contained only 15.6 ppm of K. These values were much lower than for any of the other subsoil samples which were analyzed.

In the absence of K fertilizer at Site 15 (Appendix Table 11, Treatment 4), where soil-test K was 101 ppm, the plant concentration was 1.53 percent K at jointing, approaching the level for the K-deficient plants at Site 18. The application of 50 pounds of K per acre increased the level of plant K to 1.93 percent (Treatment 2). At Site 2, where soil-test K was 265 ppm, plant K concentrations for the non-K and K-fertilized treatments were 3.48 percent and 3.53 percent respectively. These plant K concentrations are well above the critical value.

The concentration of K in the wheat plants at the boot stage of growth was 1.75 percent in the treatment without K fertilizer at Site 24, where the soil-test value for K was 113 ppm (Appendix Table 10). The soil-test value for K at Site 27 was 300 ppm and the K concentration in the plants was 2.7 percent for the fertilizer treatment which did not include K. Melsted and others (1969) reported a critical level of 1.80 percent K for the wheat plant, a value which was based on the total plant top at the boot stage of growth. The results reported in this study agree reasonably well with the values referred to in the literature, although the data presented here were based on the two uppermost leaves at the boot stage rather than on the total plant top specified by Melsted.

The application of K at Site 29 (Appendix Table 11) appeared to depress grain yield (Treatment 2 versus 4). The yield depression was probably caused by banding fertilizer with the seed at seeding time under fairly low soil moisture conditions. For the series of experiments in 1968, all fertilizers except the spring-applied N were banded in the drill row along with the seed. In any case, these data for Site 29 were interpreted as an indication that the method of fertilizer application was unsuitable for the rate of application used in the experiment.

Two trends were evident in the analytical data for K. The concentration of plant K increased with N fertilization (Appendix Tables 10, 11, and 12) but decreased with time as the plants grew toward maturity. Although the critical level for plant K probably decreased with time, there appeared to be a complete lack of specificity in the time for detecting K deficiency by plant analysis.

Evidence from this study indicates that the soil-testing approach was reliable for evaluating the status of the soil with respect to P and K fertility. It appears that 100 ppm is a suitable critical value for soil-test K. Plant analysis was also a definite asset as an alternate approach for diagnosing P and K deficiency or for monitoring the uptake of P and K from fertilizers.

Response to Lime

Liming expressly for wheat production is infrequent, but lime is often applied prior to seeding a legume or possibly some other crop in the rotation. Response of wheat to lime is considered possible on soil with a reaction below pH 5.5.

A lime treatment was included in the experiments at Site 3 in 1968 and at Sites 8 and 22 in 1969, and selected results are presented in Appendix Table 12. The soil samples from Sites 3, 8, and 22 indicate pH values of 4.8, 6.0, and 5.2, respectively, and values for extractable cations are presented in Appendix Table 9. Druchamp wheat responded to lime at Sites 3 and 22, but the lime application had a tendency to depress the yield of Nugaines wheat at Site 8, where the pH was 6.0 prior to liming (Appendix Table 12). The yield of grain obtained for the liming treatment at Site 3 was 5,080 pounds per acre compared to 3,890 pounds per acre in the absence of lime application. Lime application significantly increased the concentration of phosphorus and calcium in the plants sampled at jointing for the lime-responsive Site 22, but had no effect on the nutrient composition of plants at the nonresponsive Site 8 (Appendix Table 12). Although lime increased the concentration of both P and Ca in the wheat plant, a limiting supply of P rather than Ca was regarded as one of the key factors in the lime response by wheat.

Many of the values reported in Appendix Tables 11 and 12 for calcium and magnesium (Mg) in the wheat plants at jointing were much lower than the critical levels reported by Melsted and others (1969). Melsted's critical levels were 0.25 percent Ca and 0.15 percent Mg at the boot stage of growth. The discrepancy in values for Ca and Mg was probably attributable to the growth stage at sampling time, in that the levels would normally be higher at the boot stage than at jointing.

The data on Ca and Mg in Appendix Table 13 show a trend toward a greater concentration of Ca and Mg in the upper leaves at the boot stage than was recorded for the total plant at the jointing stage. Half of the Ca values and all of the Mg values were above Melsted's critical levels for the boot stage of growth.

The values shown for manganese (Mn) and zinc (Zn) in Appendix Table 13 were also equal to or greater than the critical levels indicated by Melsted. The values for iron were included for reference, but there was no basis for their evaluation.

Response to Sulfur

The possibility for yield response of winter wheat to sulfur (S) is recognized in extensive areas of western Oregon. In the series of experiments all treatments included S other than the zero-S treatments used to measure S response. A suitable soil test to predict S fertilizer requirement for western Oregon soils has not been found, and soil-test values for S were not included in this research.

A treatment variable to evaluate the response to S fertilization was incorporated in 12 experiments in 1968 and in four experiments in 1969. There was no attempt to assess the S status of the soil, but the grain yield was determined in all cases and the concentration of S in the plants was determined in some cases. Selected experimental results are reported (Table 11) to illustrate the effects of the S treatments. The light green color of the plant, a symptom indicative of S deficiency, was apparent only on wheat plants at Site 11, and the results (Table 11) indicate a yield response to S which was significant at the 0.05 level of probability. For all remaining experiments S fertilization failed to significantly increase yields. The relatively low number of sites showing a response to S was anticipated, since S fertilizer is used extensively in western Oregon.

The N:S ratio technique suggested by Dijkshoorn and others (1960) and further evaluated by Stewart and Whitfield (1965) and Roberts and Koehler (1965) was used to determine the S status of the wheat plants. The N:S ratios in Table 11 were calculated from results of experiments conducted at Sites 11 and 18 in 1968. Dijkshoorn and others regarded values of 17 or greater for N:S ratio as indicative of S deficiency. The N:S ratios in Table 11 indicate that Site 11 was S deficient, but that Site 18 probably was not. In the work reported by Roberts and Koehler (1965) there was no increase in grain yield when the N:S ratio was 25 or less, but S application greatly increased S uptake by the wheat plants. Their data showed that when the N:S ratio dropped to 13, which is comparable to the values for Site 18 (Table 11), higher rates of S produced little increase in S uptake and no increase in yield.

Table 11. Effect of sulfur application on grain yield and plant sulfur at jointing in wheat plants, 1968

Treatment N (fall + spring) + P + K + S	Grain yield	Sulfur	N:S ratio
lbs./A	*lbs./A*	%	
Site 11, Baimbridge Farm (Nugaines)			
(0+0)+26+50+23	920	0.15	9
(20+125)+26+50+23	2,680	0.14	17
(20+125)+26+50+0	940	0.12	27
Site 18, Bartel Farm (Druchamp)			
(0+0)+26+50+23	3,560	0.19	14
(20+125)+26+50+23	3,750	0.26	13
(20+125)+26+50+0	3,040	0.27	13
LSD .05	705		

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