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Title: THE EFFECT OF FERTILIZER TREATMENTS ON NUTRIENT UPTAKE, YIELD, AND QUALITY OF WINTER WHEAT ON SELECTED WESTERN OREGON SOILS

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for Thomas L. Jackson

A series of nine experiments designed to evaluate the effects of N, P, and K fertilizers on the production of wheat in western Oregon were seeded in the fall and carried through the 1967 growing season. The experimental sites were selected to represent different soils that are used for production of wheat in western Oregon. The locations also provided a range in yields, nutrient content, test weight and protein content of the three wheat varieties used for the experiments.

The soils of the experimental sites included two of the most productive soils in the Willamette valley, Chehalis and Woodburn series, and the Steiwer and Willakenzie series which represent large areas of hill soils in western Oregon. The other selected sites represented the Aloha, Amity, Laurelwood, Newberg and Wapato

series.

Three wheat varieties, Druchamp, Nugaines and Gaines, were used on the experiments in a completely randomized block design. Treatment combinations of different rates of N, P and K fertilizers were applied on one selected variety of winter wheat at each location. A varietal comparison was included for which an optimum fertilizer treatment was applied to plots of each variety.

In the fall a small amount of N plus the P and K fertilizers were banded with the seed at plating time. A spray application of Karmex (3-3,4 dichlorophenyl 1 methoxy 1 methylurea) was applied immediately following seeding except for the Dromgoold site where Karmex was sprayed prior to planting. On some but not all of the plots a spray application of 2,4 D (2,4 dichlorophenoxyacetic acid) was applied in spring to control broadleaf weeds. The major portion of fertilizer was applied in the spring in a broadcast application.

The N, P, and K contents of plant tissue at two stages of growth and protein content of the grain were determined in the laboratory. Yield of grain and test weight on samples harvested were obtained on each experimental plot. The data were statistically analyzed, treatment means were compared and tested for relevant information.

The application of N increased the yield of grain and the concentration of N, P and K in the plant tissue. The application of N also decreased the test weight of the grain and increased protein content of the grain. The application of K produced no major significant changes in any of the variables studied, but P application produced a significant increase in grain yield at one location and somewhat smaller increases in yield at five other locations. Absence of response to P at some locations and K applications at essentially all locations was probably due to the adequate levels of these nutrients in the soil prior to treatment. The present experiments substantiated the previous caliberations for P and K soil analyses.

Nugaines was the highest yielding variety in a majority of the experiments when compared with either Gaines or Druchamp. Nugaines also had a significantly greater test weight than Gaines and Druchamp.

Druchamp had the highest protein content of the three varieties at all locations where rates of fertilizers were comparable, but the concentration of N in plants of the individual varieties at the jointing stage was lowest for the Druchamp variety at all locations.

The climatic conditions in the valley during the growing season of 1967 were unusually mild during winter and drier and warmer than normal during the summer months. These climatic adversities probably resulted in a below average response to the applied fertilizer. Also competition from grass was above average. Stripe and leaf rusts were serious problems throughout western Oregon. These factors created conditions which undoubtedly reduced yields and responses from fertilizer.

The Effect of Fertilizer Treatments on Nutrient Uptake, Yield, and Quality of Winter Wheat on Selected Western Oregon Soils

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (CONTINUED)

THE EFFECT OF FERTILIZER TREATMENTS ON NUTRIENT UPTAKE, YIELD, AND QUALITY OF WINTER WHEAT ON SELECTED WESTERN OREGON SOILS

INTRODUCTION

A diversity in environment with respect to climatic conditions, soils, and relief makes it possible to produce a wide variety of crops in Oregon. There are more than 25 different commercial crops grown in the area comprising the Willamette valley and among these crops wheat has major economic importance (Cheney et al., 1956). For the state of Oregon as a whole, agriculture and forestry are the major sources of income.

Wheat production in the Pacific Northwest began about 85 years ago. Wheat is uniquely adapted to an environment of winter rainfall and dry summers which are typical of this area, it has emerged as number one cash crop in the economy of the region. Most of the wheat is produced under dryland conditions in either a wheat-fallow sequence or in rotation of annual cropping.

The acreage and production of wheat in the Willamette valley and in the entire state for 1966-67 year and averages for the years 1960-66 are given in Table 1.

Table 1. Wheat acreage and production in the State of Oregon and in the Willamette valley region of the state.[1]

Area	year or yearly average	acre	production (bushel)
State of Oregon	1960-66	798,000	26.2 million
	1966-67	785,000	26.5 million
Willamette Valley	1960-66	95,866	4,182,100
	1966-67	111,450	5,528,000

[1] Acreage and production figures from Oregon State University, Agricultural Extension Service, 1967.

New varieties of wheat have been introduced into this area that appear to be adapted for production under higher levels of fertility than have been used previously. Therefore, it seemed advisable to initiate a series of experiments designated to evaluate the effects of N, P and K fertilizers on these varieties of wheat when grown on different soil series in Western Oregon. Accordingly, the objectives set forth for this study were to evaluate:

1. The influence of N, P and K fertilizers on the yield and the concentration of these nutrients in wheat plants grown on soils with a range of fertility levels.
2. The relationship between chemical composition of plant tissues and the level of P and K found in the soil.
3. The effect of fertilization on the changes in the concentration of N, P and K in the wheat plants.

4. The changes in concentrations of nutrients in the plants at selected stages of growth.

This report summarizes one year's data and therefore does not represent a complete evaluation of the response of these winter wheat varieties to the application of fertilizer in Western Oregon. The 1967 growing season had an unusually mild winter followed by a summer that was warmer and drier than normal. These climatic conditions probably resulted in a below average response to applied fertilizer. Also competition from grasses was above average and stripe and leaf rusts (*P. glumarum* and *P. rubigovera*) were serious problems. Since these factors created conditions which undoubtedly resulted in reduced atypical yield and responses, few conclusions may be reached at this stage of the work.

LITERATURE REVIEW

Williams and Smith (1954) summarized the effects of fertilizer treatments on wheat in Kansas. They concluded that N responses were observed more frequently than responses to either P or K, also responses to P were generally less marked than with N, and were dependent upon the presence of an adequate supply of available N. Responses to K were relatively small and were seldom observed.

Warder, Lahane, Hinman and Staple (1963) reported work which showed the effect of N and P fertilization on the yield and protein content of wheat grain in southeastern Saskatchewan. The use of N and P fertilizer gave consistent yield increases on both loam and clay soils which had less than 25 pounds per acre of sodium bicarbonate extractable P. The most notable effects of fertilizer application were increases in early growth, hastened maturity, increased tillering, and a greater number of mature heads at harvest time. The N and P fertilization had little or no effect on the P content of the grain but did increase the total P uptake by the plants.

Wahhab and Hussain (1957) have also obtained significant responses to N fertilization in experiments conducted in West Pakistan. The application of N at seeding time gave the most marked yield increases on soil which was below average fertility. Olson (1923) discussed the factors affecting the N content of wheat and the changes in the N content that occur during the development of wheat. He observed a decrease in the percentage of N in the kernel as the grain matured and at the same time a movement of N from the leaf to the kernel. Furthermore, he observed that N and P entered the grain simultaneously at the early stage of grain development.

The relationship of N to the composition, growth, and yield of wheat in Washington was discussed by Doneen (1934). He concluded that an abundant supply of available soil N prior to tillering of the plant caused an increase in vegetative growth and usually an increase in grain yield. But soil N made available after the tillering stage increased the percentage of N in the grain without markedly increasing the yield.

Boatwright and Haas (1961) reported that N and P fertilizer hastened maturity of wheat plants in North Dakota. The dry matter yield and nutrient uptake by the wheat plants were also increased by fertilization. The concentrations of N and P in the plants were generally highest at an early stage of growth, and the most significant increases in the N and P concentrations in the plants were attributed to the spring applications of fertilizer. There were no significant differences in N and P concentrations in the vegetative parts of the plants at maturity that were attributed to fertilizer treatments. The N and P fertilizer treatments significantly increased the concentration of these nutrients in the grain. Differences in P concentration due to fertilization were very small indicating that P fertilizer had very little effect on P concentration in wheat plants.

Peterson (1952) discussed the effect of N fertilizer on yield and protein content of winter wheat in Utah. In nearly all experiments, N application increased either yield or protein content or both. Russel, Smith and Pittman (1958) have also shown the importance of N in affecting yield and protein content of spring wheat grown on stubble fields in South Alberta.

Seth, Hebert and Middleton (1960) in North Carolina investigated protein synthesis in typical wheat varieties with high protein level as opposed to those with low protein. They found no difference in the total N content of vegetative parts of high and low protein wheat varieties prior to heading, but apparently a greater proportion of the N was translocated to the heads of high protein varieties for incorporation into protein than for the low protein varieties.

In almost all the cases it was pointed out that as the availability of N increases, both the protein content of the grain and the yield of wheat also increase unless other factors are limiting. The amount of N taken up by the wheat plant was influenced by the stage of growth at which N was supplied; plants grew rapidly and there was considerable N uptake within the first month after N application.

(Rankin, 1947).

The influence of weather conditions on yields of wheat in Canada was emphasized by Staple and Lahane (1954). They stated that field crops respond similarly to moisture supply and mean weather conditions, but evapotranspiration has a dominant influence on the yield of individual crops. The components of evapotranspiration, namely seasonal precipitation and the amount of stored moisture available for use, had nearly equal influence on yield. Rannie (1956) studied the effects of fertilizer treatments, soil types and season on the N, P and protein content of wheat. In his experiments in Canada, N fertilization either alone or in combination with P resulted in a consistent decrease in the P content of the grain. In general the effect of either soil type or climate caused greater variations in the percentage of P in the grain than did fertilizer treatment. Ferilization with P increased the P content of the foliage at the early growth stage, but it did not affect the yield.

Viets (1962) reviewed the effect of water on the efficiency of fertilizer usage and concluded that availability of moisture prevents the maximization of yields by application of fertilizer. Lahane and Staple (1962), from experiments in Canada, showed that the distribution of moisture through the growing season was critical for crops grown with a limited supply of moisture. For example a crop subjected to moisture stress at an early stage of growth outyielded the crop subjected to moisture stress late in the season. Significant increases in the yield of grain and decreases in the percentage of protein were obtained by increasing the available soil moisture on a loam soil in a greenhouse experiment by Dubetz (1961). Fernandez and Laird (1959) maintained the available moisture percentage in the soil above 30% for optimum yield of wheat in Mexico.

Eck and Stewart (1959) concluded that soil tests for P alone are of little value in predicting the yield responses to P fertilization under dryland conditions. Consideration of precipitation, soil moisture at planting, temperature during the ripening period and date of seeding together with soil test values improved the estimate of expected response to P. But with all of these variables considered the precision for predicting yield response to P fertilization was low. Bray (1958) in a contrasting report for Illinois stated that variation in soil, season and variety did not change the relative response of wheat to a soluble phosphate. But the difference in distribution pattern between the applied and native sorbed P varied their efficiencies. Power et al. (1961) in Montana reported that yield increases in medium P soils were directly proportional to the amount of moisture at seeding plus the precipitation through the growing season. Supplies of N and available moisture were noted as the principal factors affecting grain protein in wheat by Schlehuber and Tucker (1959).

Grunes (1959) prepared a comprehensive review and discussion on the effect of N fertilization on the uptake of soil and fertilizer P. The placement of N in relation to P and the form of N applied influenced the uptake of P. In most of his studies ammonium N was more efficient than nitrate N for increasing P uptake by plants. It has been pointed out by Rannie and Soper (1958) that ammonium N was more effective than nitrate N in increasing the uptake of P by corn grown in Saskatchewan, but that the reverse was true for plants grown in sand resin in the absence of nitrification. An intimate association of N and P fertilizers was necessary to produce the greatest enhancement in P uptake (Grunes, 1959). Factors such as soil reaction (Yuen and Pollard, 1957), nature of the complementary ion (Lehr and Van Wesemael, 1956), and temperature (Willis, 1957; Doormaar et al., 1960) may also influence the effect of N on P uptake.

Noggle (1966), Dijkshoorn (1958) and Dewit et al. (1963) explained that there is a balance between inorganic cations and the combined total of inorganic plus organic anions in a plant system. If the ionic balance remains more or less constant then it was anticipated that constant charge balance may also exist in the plant. Due to increased anion uptake there is a temporary disruption to the ionic balance and this equilibrium is attained possibly by an increased uptake of K ions. A competition between monovalent and divalent cations also favors the uptake of K over any other cations.

Schufflen (1954) related the uptake of K ions by plant as the result of a reaction between the plant and the soil during the growth period. His ideas can be expressed as

$$K \text{ intake} = f(\text{plant, soil, time})$$

He divides the process of ion absorption into two parts. One part depends on the energy supply of the plant for the accumulation of ions, the other part is connected with the supply of the ions by the soil (or other medium). A mechanism in the root or entire plant functions as a pumping system, the absorbed ions are removed or are rendered inactive by some unknown process. The consequence is a reduction of the electro-chemical potential of the ions in the roots. Naturally this mechanism requires the expenditure of energy with pump function deriving its activities from respiration. All factors governing the respiration also affect the uptake of K, however, the absorption of ions is dependent on the quantity of ions available.

Trop (1962) in a study on mutual interactions in the absorption of NH_4, K and Na in wheat plants found that K absorption is strongly inhibited by NH_4 while conversely K has little, if any, effect on the rate of NH_4 absorption, but the nature of the relation between the K uptake rate and the K concentration is not influenced by NH_4. He has further shown that the absorption rate of the inhibiting ion and not the concentration of the inhibitor in the nutrient solution determines the extent of inhibition.

EXPERIMENTAL MATERIALS AND METHODS

Field Experiments

Experimental Locations and Characterization of Soils

Soil fertility experiments with winter wheat were established in western Oregon at nine different locations as indicated in Table 2. All of the experimental sites were in the Willamette basin except one which was located in the Umpqua river valley of Douglas county. Chemical characterization of the soil at the experimental sites (Table 3) were determined by the routine analytical methods used by the Oregon State University Soil Testing Laboratory. A descriptive resume for these soils provided by the U. S. Department of Agriculture- National Co-operative Survey (1956 through 67) is given in appendix pages 82 through 85.

The Steiwer, Willakenzie and Laurelwood sites were on upland or hill topography. These soils are regarded as being somewhat lower in plant available P, more acid and droughty than the valley soils. For the Steiwer series location used in the experiment, it is noted that the depth to limiting layer with respect to plant rooting was on the order of one to two feet. The Aloha soil series represents an upland terrace position and is moderately fertile soil. The

Table 2. Experimental locations, soil characteristics and geographic situation of the nine experiments.

Soil series (farm)	County	Legal description	Notes on the location
Aloha (Reese)	Washington	NW 1/4 Sec. 7 T2S R2W	1/4 mile east of house on south side of road
Amity (Allen)	Benton	NW 1/4 Sec. 33 T12S R5W	One mile east of the house
Chehalis (Drew)	Lane	NW 1/4 Sec. 23 T16S R5W	West side of the house bordering the yard
Laurelwood (Dober)	Washington	NW 1/4 Sec. 26 T1S R3W	At crossroads west of pumphouse and southeast of the house
Newberg[a] (Pitchford)	Douglas	Not available	South side of the house
Steiwer (Stapleton)	Polk	NE 1/4 Sec. 5 T7S R5W	One mile west of house near crest of hill
Wapato (Cadle)	Polk	SW 1/4 Sec. 25 T7S R5W	1/4 mile east of house on south side of the road
Willakezie (Dromgoold)	Yamhill	SW 1/4 Sec. 33 T2S R4W	East side of road opposite the house
Woodburn (Busch)	Marion	NW 1/4 SW 1/4 Sec. 1 T6S R1W	South of neighboring farmstead

[a]Farm is located in the Umpqua river valley. All other locations are in the Willamette drainage basin.

Table 3. Summary of chemical analyses for soil samples collected from the experimental locations.

Location Soil series (farm)	pH	P (ppm)	K (meq/100 g)	Ca (meq/100 g)	Mg (meq/100 g)	CEC (meq/100 g)	% base saturation
Aloha (Reese)	5.8 ± .07	26 ± 4.6	.29 ± .03	7.7 ± .1	2.4 ± .1	15	68
Amity (Allen)	5.5 ± .12	18 ± 1.0	.56 ± .07	9.2 ± .4	3.0 ± .2	18	72
Chehalis (Drew)	5.4 ± .09	39 ± 7.1	.92 ± .10	11.3 ± .5	5.1 ± .2	24	79
Laurelwood (Dober)	6.3 ± .12	60 ± 4.2	.71 ± .08	7.8 ± .4	1.4 ± .1	14	71
Newberg (Pitchford)	6.0 ± .10	28 ± 4.2	.88 ± .04	14.5 ± .5	5.8 ± .4	25	86
Steiwer (Stapleton)	5.5 ± .11	14 ± 3.6	1.04 ± .11	15.9 ± .9	7.2 ± .6	34	71
Wapato (Cadle)	5.2 ± .14	17 ± 2.3	.78 ± .16	21.5 ± .7	11.9 ± .4	45	76
Willakenzie (Dromgoold)	5.6 ± .07	5 ± 1.3	.77 ± .08	8.7 ± .8	3.0 ± .4	17	72
Woodburn (Busch)	5.6 ± .12	29 ± 5.8	.61 ± .15	6.0 ± .5	2.5 ± .1	14	71

The values reported in the table are the mean plus minus one standard deviation.

remaining five selections (Amity, Chehalis, Newberg, Wapato and Woodburn) are situated on the valley floor topography which forms the most productive soils of the group. These soils have formed on a thick layer of alluvial parent material. They are well drained and with the exception of N, P, K and S are adequately supplied with the essential plant nutrients.

Experimental Design and Treatments

A randomized block design with three replications of the treatments, was used for all of the field experiments; individual plots were 10 ft × 40 ft. The treatments consisted of rates of N, P and K applied individually or in various combinations as shown in Appendix tables 1 through 9. There were 36 treatments in all, but only selected treatments were used at each location. The Druchamp variety of winter wheat was used as the indicator crop on the Willakenzie and Steiwer soils and Nugaines was used in the experiments at the seven other locations to evaluate the various fertility treatments. Each experiment also had three treatments to provide a comparison of Druchamp, Nugaines and Gaines varieties at a single optimum level of fertility with respect to N, P and K.

Druchamp is a soft white winter wheat developed in France and introduced into western Oregon by the Burlingham Meeker Seed Company, Amity, Oregon in 1949. Druchamp originated from a cross of "Vilmorin 27" and "Fleche d' Or."

The Gaines variety was developed from a cross between Brevor and Norin 10 wheat at Pullman, Washington in 1949. Norin is a semidwarf wheat introduced from Japan about 1946. Brevor is a wheat variety developed from the plant breeding program in eastern Washington. Nugaines variety is a sister selection of Gaines and was also developed recently at Pullman, Washington.

Field Plot Technique

A chronological record of most of the field operations involved in conducting the field experiments is presented in Table 4. The experiments were established in areas of fields used for commercial wheat production and in most instances the farm operators prepared the plot areas for seeding. A drill five feet wide mounted on a model G, Allis Chalmers tractor was used to seed the plots by making two passes to cover the plot width of ten feet. The drill was equipped with eight double disk openers to give a spacing of seven inches between drill rows. Each double disk opener was supplied with two flexible spouts so that seeding and band placement of fertilizer with the seed were accomplished simultaneously. Seed was distributed at the rate of 90 pounds per acre by a Planet Junior seeding attachment. Measured amounts of fertilizer were metered into the band after being spread manually on an endless belt distribution system powered

Table 4. Chronological record of field operations.

Soil series (farm)	Seeding	Nitrogen fertilization	Plant sampling at Jointing stage	boot stage	Harvesting
Aloha (Reese)	11-3-66	3-4-67	4-21-67	6-2-67	8-2-67
Amity (Allen)	10-16-66	3-7-67	4-25-67	a	7-27-67
Chehalis (Drew)	10-18-66	3-10-67	4-25-67	5-30-67	7-27-67
Laurelwood (Dober)	11-3-66	3-4-67	4-21-67	5-26-67	8-2-67
Newberg (Pitchford)	11-1-66	3-2-67	4-26-67	a	8-3-67
Steiwer (Stapleton)	10-25-66	3-10-67	4-21-67	5-27-67	7-28-67
Wapato (Cadle)	11-4-66	3-1-67	4-21-67	6-2-67	7-28-67
Willakenzie (Dromgoold)	10-17-66	3-6-67	4-25-67	6-2-67	7-31-67
Woodburn (Busch)	11-2-66	3-6-67	4-21-67	a	8-1-67

a = not sampled.

from the tractor wheel.

The fertilizer which was banded at the time of seeding included 20 pounds of N and 23 pounds of S per acre as ammonium sulfate plus the sources of P and K. Concentrated superphosphate (52% P_2O_5 -22. 7% P) and muriate of potash (60% K_2O - 50% K) were used to supply P and K. Gypsum was broadcast by hand in the fall after seeding to balance the S treatments on the plots that did not receive the fall application of N. Ammonium nitrate was applied in the spring as a broadcast application by hand to complete the N treatments. Rates of application are expressed as pounds of N-P-K per acre. (Appendix Tables 1 through 9).

All the plots received Karmex (3, 3-4 dichlorophenyl 1 methoxy 1 methylurea) application at 1. 6 pounds active ingredient per acre immediately following seeding, except for the Dromgoold site where Karmex was sprayed just prior to planting. In the spring, 2-4 D (2-4 dichlorophenoxyacetic acid) was used to control broadleaf weeds.

A self propelled Massey-Harris combine with a header seven feet wide was used to harvest an area of 7 ft × 33 ft for yield determination from the center of each experimental plot. At the time of harvesting a border three and a half feet wide at both ends of each plot was clipped and discarded to eliminate any border effect between plots. The grain harvested from each plot was weighed at the site. Subsamples of grain were taken for protein and test weight determinations. Yields were calculated and reported in pounds per acre.

Soil and Plant Sampling

Soil samples were collected from plow layer (0 to 8 inches) at each experimental site before seeding and fertilization. Four to five plots in each of the three replications were sampled systematically by compositing 8 to 10 cores of soil obtained from each plot with a probe type sampler. The soil samples were brought to the laboratory, air dried for about 48 hours, and ground to pass through a 14 mesh screen to prepare them for analysis. Chemical analyses were then carred out on the samples. The average analytical value and the indicated standard deviation for the 12 to 15 samples from a given location were reported to characterize the fertility status at each location (Table 3).

Samples of wheat plant tissues were collected at two stages of growth. Plots of all experimental sites were sampled at the 4 to 5 leaf stage (jointing) and plots at all but Allen, Pitchford and Busch sites were sampled at the boot stage. At the jointing stage of growth the entire tops of 30 to 40 plants which were mostly leaf material, were clipped about two inches above the soil surface. At the boot stage of growth the top two leaves of the plants were collected. Approximately 20 spots in a plot were picked at random for obtaining leaf samples. The samples were then dried in a forced draft oven at 70 °C for three to four days and then finely ground in the dry state by means of an osterizer blender to prepare them for analyses.

Laboratory Methods

Soil Chemical Analysis

Soil chemical analysis was conducted by the Oregon State University Soil Testing Laboratory. The methods used for the analyses are listed in Table 5. Soil reaction was reported in pH units, "available phosphorus (P) in parts per million and calcium (Ca), magnesium (Mg), potassium (K) and cation exchange capacity (CEC) in milliequivalents per 100 grams of soil (Table 3).

Plant and Grain Analyses

The finely ground plant tissue was prepared for chemical analysis by wet ashing with perchloric acid (Jackson, 1958). The procedures used for determining the concentration of nutrients in the plant tissues and the concentration of protein in the grain are given in Table 6.

Table 5. A summary of the methods used for the soil chemical analysis.

Test or determination	Reference	Notes on the method
Available P	Olson et al., 1954 (modified method)	On 1:10 soil to extract ratio using 0.5 N sodium-bicarbonate, adjusted to pH 8.5, extractable P was determined by the molybdenum blue colorimetric procedure using the Bausch and Lomb Spectronic 20 spectrophotometer.
Cation Exchange Capacity	Schollenberger & Simon 1945	CEC was determined with 1 N ammonium acetate buffered at pH 7.0.
Exchangeable bases (Ca, Mg, K.)	Schollenberger & Simon 1945	On a single extraction (1:10 soil to extractant ratio) using 1 N ammonium acetate, adjusted to pH 7.0; the exchangeable bases were determined by means of a flame emission spectrophotometer.
pH	Jackson, 1958	1:2 soil water suspension method was used to determine the pH of the soil samples.

Table 6. A summary of the methods used for the chemical analysis of leaf tissue and grain of wheat.

Test or determination	Reference	Notes on the method
Ca, Mg, Fe, Zn, and Mn		The Perkin Elmer, Model 303, atomic absorption spectrometer was used to determine these elements in the perchloric acid digest.
Grain protein	Udy - 1956	Determined with Udy Model E Protein Analyzer.
N	Johnson & Ulrich 1959.	Micro Kejhdahl procedure to include nitrate-N was used to determine total N in the plant tissue.
P	Jackson, 1958.	Molybdate-Vanadate colorimetric method was used to determine P in perchloric acid digest. The color intensity was measured on a Bausch and Lomb spectronic 20 spectrophotometer.
K	Brown et al., 1948.	Beckman Model D.U. spectrophotometer with flame emission attachment was used to determine K in perchloric acid digest.

Statistical Analysis

Statistical analysis of data was obtained on the 3300 digital computer at the Computer Center of Oregon State University with some additional calculations on a desk calculator. An analysis of variance was obtained for each set of data from individual experimental sites and linear regressions were used to show the relationship between selected variables.

RESULTS AND DISCUSSION

In Western Oregon wheat is grown on soils that represent many different soil series and consequently these soils also differ widely in their productivity. One factor which adversely affects the productivity of some soils in this area is the low inherent fertility with respect to the supply of available P. Typically the residual soils on the upland areas fall in this category and crops on these soils respond markedly to P fertilization. Most non-leguminous crops respond to N fertilization regardless of the soil series and responses to K fertilization may be obtained occasionally.

Proper fertilization largely overcomes the fertility differences among soils but a second factor related to the production of non-irrigated crops on these soils is their moisture holding capacity. During the winter rainy season the entire rooting zone of these soils becomes moistened by water infiltration and thus it is apparent that the texture, structure, and thickness of the soil cover have a dominant influence on the amount of stored moisture that will be available for a non-irrigated crop such as wheat. The quantity of available moisture in the rooting zone at the close of the rainy season is of utmost importance during the growing season with little or no precipitation.

Since soils in western Oregon differ in morphology, moisture holding capacity and available nutrient content, soil series designations, soil depths and soil test results were used as criteria for selecting experimental sites for these fertilizer trials on winter wheat. An attempt was made to obtain experimental sites which provided a sampling of a range of soil series which were representative of soil used for a cereal production in the region and which also ranged from high to low with respect to plant available P and K content.

Vegetative Growth and Weed Competition

The plantings at the nine experimental sites produced acceptable stands of wheat and there appeared to be marked differences among the three varieties with respect to germination. However, some vegetative growth differences were observed at the different sites.

There was considerable competition from wild oats and ryegrass at most of the sites although the intensity varied to a great extent from one location to another. It appeared that Druchamp may have competed more favorably with the weedy grasses than did the semidwarf varieties of Nugaines and Gaines. At least grass was not as evident on the plots seeded with Druchamp wheat. This was attributed to the greater height of Druchamp during the winter and also through the growing season. In addition to competition from weeds, several plots at both Reese and Drew sites had some irregularities in stand. Rodent damage appeared to have produced some small barren spots in the plots at the Reese site. A carryover from spot treatments with herbicide applied the previous year prevented the establishment of stands in small sections of plots at the Drew site.

Stripe and Leaf Rusts

Predominantly stripe rust (*P. glumarum*) and some leaf rust (*P. rubigovera*) were serious problems during the 1967 growing season throughout western Oregon. Gaines variety was the most susceptible to the rust while Nugaines and Druchamp were comparatively rust resistant. Apparently the Gaines wheat suffered more rust damage than the other two varieties and undoubtedly the yield was decreased because of this. In the case of the Nugaines and Druchamp varieties one would anticipate less yield depression because of stripe rust.

Rust fungi on wheat plants use the water and nutrient materials needed for developing the wheat kernels. As a result the kernels can be considerably shriveled. Yields then are smaller and wheat is of inferior quality (U.S. Department of Agriculture, 1953).

Climatic Conditions

Climatic conditions were unusual for the growing season. Table 7 compares the normal with 1967 temperatures and precipitation (U.S. Weather Bureau, 1967). From the climatological data it is clear that the three months preceding wheat harvest were drier and warmer than normal. The records showed 1.73 and 1.06 inches of precipitation for May and June with only trace in July. The normal precipitation is 2.78, 2.15, and 0.5 inches respectively for this period. The mean monthly temperatures were 55.1, 63.6, and 67.2°F for May, June and July compared to the normals of 55.9, 60.3, and 65.5°F respectively.

As the experiments were non-irrigated the high temperatures and low precipitation undoubtedly had a depressing effect on grain yield. On the Hill site at Stapleton's the supply of moisture limited the yield as moisture stress was evident at the time of heading. This was true for most of the other sites with varying degree of intensity. The moisture stress and high temperatures may have also caused drying of the plants before complete filling of the grain.

Grain Yield Response to N Fertilization

The response in yield attributed to N fertilization varied considerably from one location to another (Table 8), but the average

Table 7. Normals and recorded climatological data for the Willamette valley for 1967.

		January	February	March	April	May	June	July	August
Temperature (°F)	Normals	38.3	41.5	45.1	50.5	55.9	60.3	65.5	65.1
	1967	42.7	43.2	43.5	45.4	55.1	63.6	67.2	71.0
	Deviation	+4.4	+1.7	-1.6	-5.1	-0.8	+3.3	+1.7	+5.9
Precipitation (inches)	Normals	7.71	6.17	5.88	3.28	2.78	2.15	0.50	0.72
	1967	10.30	3.04	5.60	3.36	1.73	1.06	Trace	Trace
	Deviation	+2.59	-3.13	-0.28	+0.08	-1.05	-1.09	-0.50	-0.72

Table 8. The effect of N application on grain yield at the nine experimental locations.

Location Soil series (farm)	Variety	Grain yield (pounds per acre) on rates of N application (pounds per acre) 0	100	150	250	400
Aloha (Reese)	Nugaines	2270	4460	3930	3840	3830
Amity (Allen)	Nugaines	2380	5360	5540	3650	2530
	Druchamp	a	4730	4130	2500	2070
Chehalis[1] (Drew)	Nugaines	4140	6040	5630	4730	4130
Laurelwood (Dober)	Nugaines	3490	3790	3780	2900	2570
Newberg[1] (Pitchford)	Nugaines	1950	4360	a	a	2630
Steiwer (Stapleton)	Druchamp	2040	3550	3200	3260	a
Wapato (Cadle)	Nugaines	2430	3860	4360	4180	4510
Willakenzie (Dromgoold)	Druchamp	1880	3820	4090	3640	a
Woodburn (Busch)	Nugaines	4200	5610	5070	3990	3420

a = not determined.

[1]The yield was reduced an additional 740 lbs/A by increasing the N rate to 550 at the Drew farm; yield was reduced by 800 lbs/A by increasing the N rate from 100 to 200 at the Pitchford farm.

response curve in Figure 1 is typical of the relationship between increasing rate of applied N and grain yield for the nine locations. In all instances the yield of grain reached a peak value at 100 to 150 pounds of N per acre and then decreased markedly with each additional increment of N. The experimental results for individual N rates and location are presented in Table 8 and appendix tables 1 through 9. The mean values reported in Table 8 are averages for several treatments with the indicated rate of applied N irrespective of whether applications of P and K were included in the treatments. There was one exception to this generalization. At the Stapleton site the yields obtained for plots receiving the respective N treatments but without added P were excluded from the average. This was done in view of the fact that P fertilization significantly increased yield on this site.

The application of 100 pounds of N per acre at the Drew location produced a yield of 6040 pounds per acre which was the highest yield for any treatment at any location (Table 8). The yield increased from 4140 pounds of grain per acre on the unfertilized plots to 6040 pounds of wheat per acre on the plots treated with 100 pounds of N per acre. Yield increase attributed to this treatment at the other sites ranged from 300 pounds per acre at the Dober site to a high of 2980 pounds of wheat per acre at the Allen site (Table 9). At all the sites when N was applied at the rate of 100 pounds per acre, the

Figure 1. Average yield response to N application for the nine experimental locations.

Table 9. A summary of optinum N rates, yield increases from N, and optimum yields for the nine experimental locations.

Location Soil series (farm)	Variety	N rates (lbs. /A)	Yield increase (lbs. /A)	Optimum yield (lbs. /A)
Aloha (Reese)	Nugaines	100	2200	4460
Amity (Allen)	Nugaines	100	2980	5360
Chehalis (Drew)	Nugaines	100	2260	6040
Laurelwood (Dober)	Nugaines	100	300	3790
Newberg (Pitchford)	Nugaines	100	2420	4360
Steiwer (Stapleton)	Druchamp	100	1510	3550
Wapato (Cadle)	Druchamp	150	2190	4460
Willakenzie (Dromgoold)	Nugaines	150	2380	4660
Woodburn (Busch)	Nugaines	100	1410	5610

recorded yields exceeded those observed for plots which were unfertilized. These yield increases were statistically significant (0.01 level) at all but the Dober site. The analysis of variance for each experiment is summarized in appendix tables 10 through 18.

The individual response patterns for the nine experiments indicated that increasing the rate of applied N from 100 pounds to 150 pounds per acre caused some slight increase in yield at some locations but depressed yields at other sites (Table 8). With but one exception for the nine experiments, the yield obtained with 150 pounds of N per acre was not significantly different (0.05 level) than yields obtained with 100 pounds of N per acre. A significant decrease in yield was obtained at the Drew site when the N rate was increased from 100 to 150 pounds per acre. But for the Dromgoold, Cadle, and Allen sites the yields from plots which received 150 pounds of N per acre were slightly greater than those from plots receiving 100 pounds of N per acre (Table 8).

Applications of N ranging from 200 to 550 pounds of N per acre produced numerically lower yields than 100 pounds of N at all the locations. These decreases in yield were significant at the 0.05 level at the Dober, Allen, Pitchford and Busch sites. There was a slight increase in yield from the rates greater than 100 pounds of N per acre at the Cadle site, while the other remaining sites showed numerically lower yields for all rates above 100 pounds of N, but none of these were statistically significant.

A soil test for N is not used as a basis for recommending nitrogenous fertilizers for field crops. Rates of N ranging from 30 to 150 pounds of N per acre are recommended for high yielding winter wheat varieties grown on non-irrigated fields in the Willamette valley (Fertilizer recommendation sheet 9, Oregon State University Agricultural Extension Service). Higher applications are suggested where wheat is grown under irrigation and when wheat follows other cereal or grass seed crops. Less N fertilizer is required when a crop of wheat follows a legume in the rotation or when there is a substantial amount of residual N fertilizer from the previous crop. For the high yielding varieties approximately 5 pounds of added N is required for each additional hundred weight of grain. The data from the experiments appear to support the current N recommendation for the winter wheat in the Willamette valley (Fertilizer Recommendation sheet 9, Oregon State University Agricultural Extension Service).

A reference to the cropping and fertilization history (Table 10) explains a few of the points about the diverse nature of the response to N fertilization in this series of experiments. In the cases where the yield on the unfertilized plot is low, invariably the previous crop was a grass or field crop such as barley or oats. These crops are known to deplete the supply of available N. For example, at these

Table 10. Summary of the cropping and fertilization history for past two years on the experimental locations.

Location Soil series (farm)	Year	Crop produced	Fertilizer used (lbs. /A of)	Yield (lbs. /A)
Aloha	1965	Red clover		6500
Reese	1966	Red clover		6000
	1966	Spring Barley	500 10-10-10	4000
Aloha	1965	Rye grass	350 20- 0- 0	1400
(Allen)	1966	Rye grass	350 20- 0- 0 (Spring)	
			125 16-20- 0 (Fall)	1200
Chehalis	1965	Orchard grass	500 21- 0- 0	550
(Drew)	1966	Orchard grass	550 21- 0- 0	700
	1966	Spring Barley	500 10-10-10	4000
Laurelwood	1965	Clover seed	100 10-20-20	100
(Dober)	1966	Clover hay		5000
	1966	Clover seed		100
	1966	Spring Barley	500 10-10-10	4000
Steiwer	1965	Oats		1000
(Stapleton)	1965	Barley		2000
	1966	Hairy Vetch		400
	1966	Spring Barley	500 10-10-10	4000
Wapato	1965	Redmont Wheat	50 32 sol	4250
(Cadle)	1966	Hairy Vetch		1000
	1966	Spring Barley	500 10-10-10	4000
Willakenzie	1965	Spring Oats	80 46- 0- 0	1500
(Dromgoold)			100 16-20- 0	
	1966	Spring Oats	100 16-20- 0	3000
			240 46- 0- 0	
	1966	Spring Barley	500 10-10-10	4000

sites the response to applied N greatly exceeded the yield responses at the Reese and Dober sites where the previous crop in the rotation was clover. The Dromgoold, Cadle, Allen, Drew, and Stapleton sites had low levels of residual N and consequently these were the sites where the greatest N responses were obtained. Although the current recommendation for N fertilization appears to cover the appropriate range, more refinement is needed in adjusting for previous cropping and fertilization history.

The depression in yields on dryland crops which results from the application of excessive amounts of N is a common occurrence and this effect was evident in these experiments. A reasonable explanation for yield depression is that a proportionately large amount of available moisture is used for vegetative growth under the high N regime and this reduces the supply of water available to the plants when the heads are filling. The abundant supply of N also stimulates the growth of various grasses in the wheat plots which competes with the grain for the limited supply of moisture. This competition probably resulted in reduced grain yields.

Wheat Varieties and Yields

The recent release of the variety Nugaines which has straw strength superior to that of Druchamp and greater resistance to stripe rust than Gaines, made it mandatory to evaluate more fully its perfromance in western Oregon. Gaines and Nugaines wheats are the first of the semidwarf wheat varieties released for commercial production in the Pacific Northwest.

Previous work has shown that in many cases the yields of the Druchamp variety frequently exceeded the yield of the semidwarf variety Gaines. If Nugaines (sister variety of Gaines) proves to be adapted to the environmental conditions in western Oregon, there is no doubt that it can tolerate the conditions of high fertility and abundant moisture supply under which Druchamp is subject to lodging. But the Druchamp variety which has a winter growth habit competes well with winter annual weeds and is also outstanding in its resistance to stripe rust.

A limited comparison of Nugaines, Druchamp and Gaines varieties at a single fertility level was made in the series of experiments. For the variety trial, N was applied at the rate of 200 pounds per acre at the Pitchford site and 150 pounds at all the other sites. An optimum level of fertility with respect to P and K was obtained by applying either 18 or 36 pounds of P per acre and either zero or 25 pounds of K per acre depending upon the adequacy of these nutrients in the soil as reflected by the soil analyses.

The results for yield obtained on the three wheat varieties are presented in Table 11 together with the statistical comparisons using least significant difference (LSD) values. A comparison of the

Table 11. Yield comparisons on the varieties for the nine experimental locations.

Location Soil series (farm)	Nugaines (lbs. /A)	Druchamp (lbs. /A)	Gaines (lbs. /A)
Aloha (Reese)	4100	3945	3390
Amity (Allen)	5400B	4140A	4170A
Chehalis (Drew)	5340b	4270a	4070a
Laurelwood (Dober)	3620B	2690A	3790B
Newberg (Pitchford)	3680B	2710A	2840A
Steiwer (Stapleton)	3150	3490b	2810a
Wapato (Cadle)	4620B	4780B	3020A
Willakenzie (Dromgoold)	4650	4250	4060
Woodburn (Busch)	4960b	4410a	4340a

B is significantly higher than A at 0.01 significance level.
b is significantly higher than a at 0.05 significance level.
All tests of significance are within a site.

numerical yield values revealed that Nugaines was the highest yielding variety at seven of the nine sites and four of the seven sites were on the valley floor soils. At the remaining two sites (one hill soil and one valley soil) Druchamp produced the highest yield. By statistical analysis it was found that the yields of Nugaines at the Drew, Allen, Pitchford, Busch, and Dober sites were significantly greater than Druchamp at 0.01 level of significance. These were all valley floor sites with the exception of the Dober's which was a hill site. There were no significant yield differences between Nugaines and Druchamp at the Dromgoold and Stapleton sites (both on hill soils) nor at the valley and terrace soils at the Cadle and the Reese sites respectively. Gaines wheat was not the highest yielding variety at any of the sites and in fact yielded significantly less than Nugaines at the Drew, Cadle, Allen, Pitchford and Busch sites. Nugaines was beyond doubt the most consistent high yielding variety under the conditions of comparisons.

Some of the varietal comparisons were made at other than optimum levels of fertility with respect to N. That is, in some cases, the yield at 150 or 200 pounds of N per acre which were used for the variety comparisons, was significantly less than the yield obtained for the treatment consisting of 100 pounds of N per acre. At two of the five sites enumerated previously where Nugaines yielded significantly more than Druchamp, we observed that the yield of the indicator variety was decreased significantly as the rate of N increased from 100 to 150 or from 100 to 200 pounds of N per acre. It is possible that in some cases the yield differential between Druchamp and Nugaines may result from the more adverse effect of the high N fertilizer on the yield of Druchamp than on Nugaines.

The comparatively lower yields recorded by the Gaines variety as compared to the Nugaines variety were related to the lower rust resistance and comparatively poorer adaptation to the environment by the Gaines variety.

A summary of observations and previous findings in Oregon Agricultural Progress (1956) recommends the use of Druchamp for hill soils. It is anticipated that with adequate moisture and with N rates above 150 pounds per acre Druchamp may lodge. Lodging usually causes a marked reduction in yield if it occurs before maturity. On the contrary, lodging is much less of a problem with Nugaines due to superior straw strength and adaptability to high N fertility. Some observations on the susceptibility to lodging were made at the Allen and the Stapleton sites. For example, at the Allen site 50 to 100% lodging was observed on Druchamp wheat which received N applications ranging from 250 to 400 pounds per acre, but Nugaines with comparable rates of N showed no lodging. Druchamp showed no indication of lodging even when 250 pounds of N per acre was applied at the Stapleton site, but perhaps the severe moisture stress which was apparent at the boot stage of growth tended to limit the utilization of N. It appears that when the supply of moisture is limiting, lodging may not occur even with high rates of N.

Effect of P Fertilization on Yield

Several research workers in other areas have concluded that soil tests for P alone are of little value in predicting yield responses from P fertilization under dryland conditions. Attempts to improve the precision of predicting response through the use of soil test values by taking other factors into consideration still gave a low degree of precision for predicting yield responses to P fertilization (Eck and Stewart, 1959; Power et al., 1961; and Bray, 1958). Precipitation, soil moisture at planting time, temperature during the ripening period and date of seeding were considered together with the soil analyses values for P but these considerations only improved the precision of the prediction to a small degree (Eck and Stewart, 1959). The fertilization of field crops with P generally produces less marked effects than N fertilization, but significant increases in yield have been obtained in some cases. The greatest responses to P are noted when P is applied in combination with N (Williams and Smith, 1954).

In Oregon the P recommendation for winter wheat is based on the sodium bicarbonate soil analyses. The Fertilizer

Recommendation Sheet 9 which summarizes previous information on fertilization of winter wheat in the Willamette valley, recommends application of P fertilizers on soils with analyses values lower than 20 ppm of P. It is further recommended that the best results from P fertilization would be obtained if the P fertilizer is banded with the seed. There are a number of research reports on the placement of P fertilizer for many different crops. All of the results of the field experiments in western Oregon favor the use of the band placement method for P application.

Active programs in plant breeding and in weed control have made it possible to release improved wheat varieties and to refine the techniques for checking weed growth. These two factors have tended to increase wheat yields considerably. It was desired to obtain information from these field trials pertaining to the plant nutrients needed to produce the higher yields of wheat now obtainable and to evaluate the existing relationships between soil test and fertilizer recommendations.

The data which were recorded for the specific treatments used to evaluate the response to P fertilization are presented in Table 12. The response is related to the soil tests for P in Figure 2. A significant (0.05 level) P response from P application was obtained at the Stapleton site. At the other eight sites the response from P application was not significant at the 0.05 level, but there were increases

Table 12. The effect of P and K fertilization on yield of grain on the nine experimental locations.

Location Soil series (farm)	P soil test (ppm)	P application rates (lbs./A)	Yield from P rates (lbs./A)	K soil test (meq/100 g)	K application rates (lbs./A)	Yield from K rates (lbs./ A)
Aloha	26	0	3820	0.29	0	3830
(Reese)		18	4040		50	4030
Amity	18	0	5330	0.56	0	5340
(Allen)		18	5250		25	5250
Chehalis	39	0	5780	0.92	0	4290
(Drew)		18	5340		25	3760
Laurelwood	60	0	3540	0.71	0	3440
(Dober)		18	3650		25	3750
Newberg	28	0	3470	0.88	0	3580
(Pitchford)		18	3650		25	3540
Steiwer	14	0	2980	1.04	0	3110
(Stapleton)		36	3420		25	3285
Wapato	17	0	4230	0.78	0	4320
(Cadle)		18	4500		25	4400
Willakenzie	5	0	3970	0.77	0	4070
(Dromgoold)		36	4210		25	4120
Woodburn	29	0	5120	0.61	0	5100
(Busch)		18	5010		25	5030

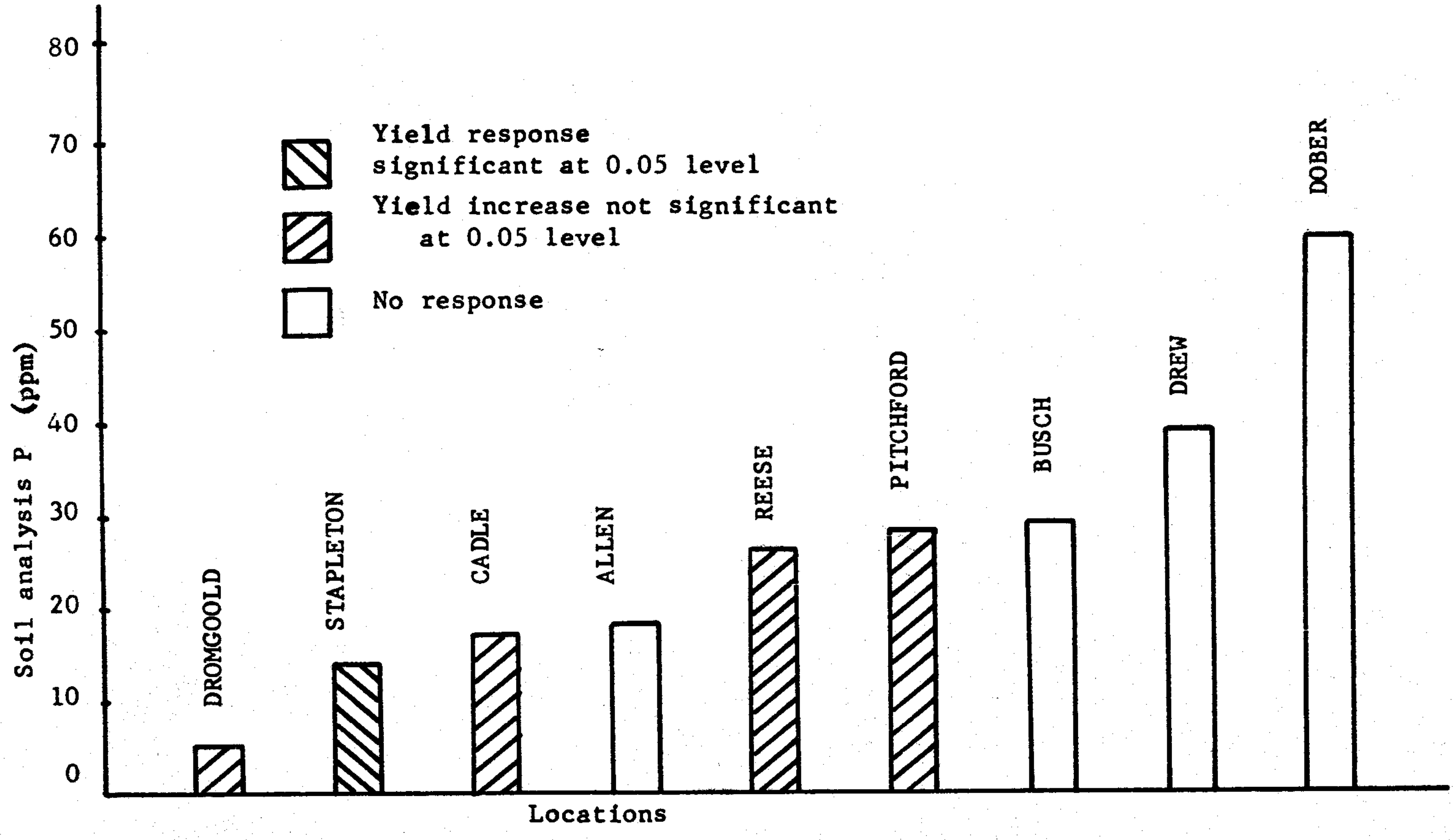

Figure 2. Relationship between soil test values for P and yield response to P fertilization for the nine experimental locations.

in yields due to P fertilization at the Dromgoold, Reese, Cadle, Pitchford and Dober sites which may have indicated a slight response to P fertilization (Table 12 and Figure 2). The slight decreases observed due to P application at the Allen, Drew and Busch sites were not significant.

The absence of response from P fertilization on some sites was apparently due to the relatively high soil analyses values (Figure 2). The unusual climatic conditions (previously discussed) also limited the yields obtained. While the number of sites with response to P application was limited, these data do indicate that soils with test values above 20 ppm of available P per acre with sodium-bicarbonate extract have an adequate supply of P for the production of winter wheat in Western Oregon.

It should be pointed out that at some of the sites the P response was evaluated at a level of N that was somewhat greater than that needed for optimum yield. As alluded to previously in the discussion of variety comparisons, the possibility of having interaction of N rate with the main treatment effect of interest cannot be completely ignored. At the Pitchford and Drew locations, the N rates used for P response comparisons significantly decreased yields compared to the optimum yielding application of 100 pounds of N per acre. This may have also depressed the P response on these sites. But at these specific sites the level of soil P was well above the critical value and therefore no response was anticipated. This work indicates that more experimental investigation is needed in fields with intermediate levels of soil P under conditions where other factors are not limiting the response to P. It should be possible to evaluate more precisely the critical soil test values for P.

Effect of K Fertilization on Yield

A crop of winter wheat utilizes a considerable quantity of K and responses to K fertilization are common on low testing soils. But previous observations in the Willamette valley have predicted that a K response should be anticipated only when soil analyses values are less than 0.25 meq/100 g of soil; Fertilizer Recommendation Sheet 9 is based on these observations. According to the recommendations K should be banded near the seed at planting time as was done in these experiments, particularly when P is also applied. Broadcast applications may be worked into the soil prior to seeding. These series of experiments were conducted to evaluate the reliability of the fertilizer recommendations presently used.

The soil analyses values (Table 3) on the experimental sites were above the level of 0.25 meq/100g. of soil. These values would then indicate an adequate level of K for winter wheat. Accordingly, no significant response to K fertilization was obtained in these experiments although a slight increase in yield was noted at the

Dromgoold, Reese, Cadle, Stapleton and Dober sites. On the other hand, a slight decrease was obtained at the remaining sites of Drew, Allen, Pitchford and Busch (Table 12). These slight increases and decreases were attributed to experimental error. Some additional experimentation is needed on soils with K analyses values near the critical level to provide a better basis for predicting yield response to K fertilization.

Effect of Fertilization on Test Weight and Protein Content of Grain

The quality of wheat is usually judged by its suitability for a particular use. The wheat is used for human food and is milled either to flour or to granular products. Differences in the quality of the by-products used for animal feed are usually considered to be relatively unimportant in evaluating wheat quality. One of the most widely used and simplest criteria of wheat quality is the weight of wheat per unit volume and is important in all wheat grading systems. In the U.S. and Canada this is expressed in terms of pounds per bushel, and in most countries using the metric system, in terms of kilograms per hectoliter.

The term "test weight" is the grading designation used in the official grain standards established by the Grain Division of the U. S. Department of Agriculture. It represents the weight of the volume of grain required to fill a Winchester bushel of 2150.42

cubic inches capacity. Its importance lies primarily in the fact that it is an index of the yield of flour that can be obtained. Because there is a close relation between higher test weight and increased flour yield, this determination is one of the most important and widely used measure for quality in wheat.

Another test of quality is the protein content of wheat grain. Cereal chemists have long recognized that the proteins of wheat flour govern to a large extent the plastic and elastic properties of bread doughs and some types of batters. Flours for purposes of yeast leavened bread generally require 11 to 12% protein content; whereas, flours for other purposes generally are made from wheats of lower protein content. In effect, the protein content is important for its relationship to gluten in the grain.

In the present series of experiments both test weight and protein content of the grain were determined. The relationship between the amount of N applied and the protein content of wheat grain is presented in Figure 3 and Table 13. The figure and the table show that at all locations, increasing the rate of N fertilization resulted in a consistent trend toward an increase in the protein content of the grain. At a given location the zero N treatment produces grain with the lowest level of protein; whereas, the plots treated with 400 pounds of N per acre consistently produced grain with the highest level of protein.

The concentration of protein in the grain from plots fertilized

Table 13. The effect of N application on the protein content of grain on the nine experimental locations.

Location soil series (farm)	Variety	Protein concentration (%) in grain on N rates (pounds per acre) 0	100	150	250	400
Aloha (Reese)	Nugaines	9.1	9.3	11.0	12.7	12.6
Amity (Allen)	Nugaines	7.4	7.5	9.8	13.2	14.1
	Druchamp	a	10.2	12.1	14.5	15.4
Chehalis (Drew)	Nugaines	7.9	9.5	10.8	13.0	14.2
Laurelwood (Dober)	Nugaines	9.1	11.2	13.4	14.6	15.8
Newberg[1] (Pitchford)	Nugaines	8.3	9.5	a	a	14.1
Steiwer (Stapleton)	Druchamp	8.6	12.3	13.9	15.7	a
Wapato (Cadle)	Nugaines	9.0	9.0	9.6	11.3	11.6
Willakenzie (Dromgoold)	Druchamp	8.8	9.6	11.7	14.1	a
Woodburn (Busch)	Nugaines	7.9	9.2	10.0	12.6	13.1

a = not determined.

1 = The protein was increased by 2.4% by increasing the N rate from 100 to 200 at the Pitchford location.

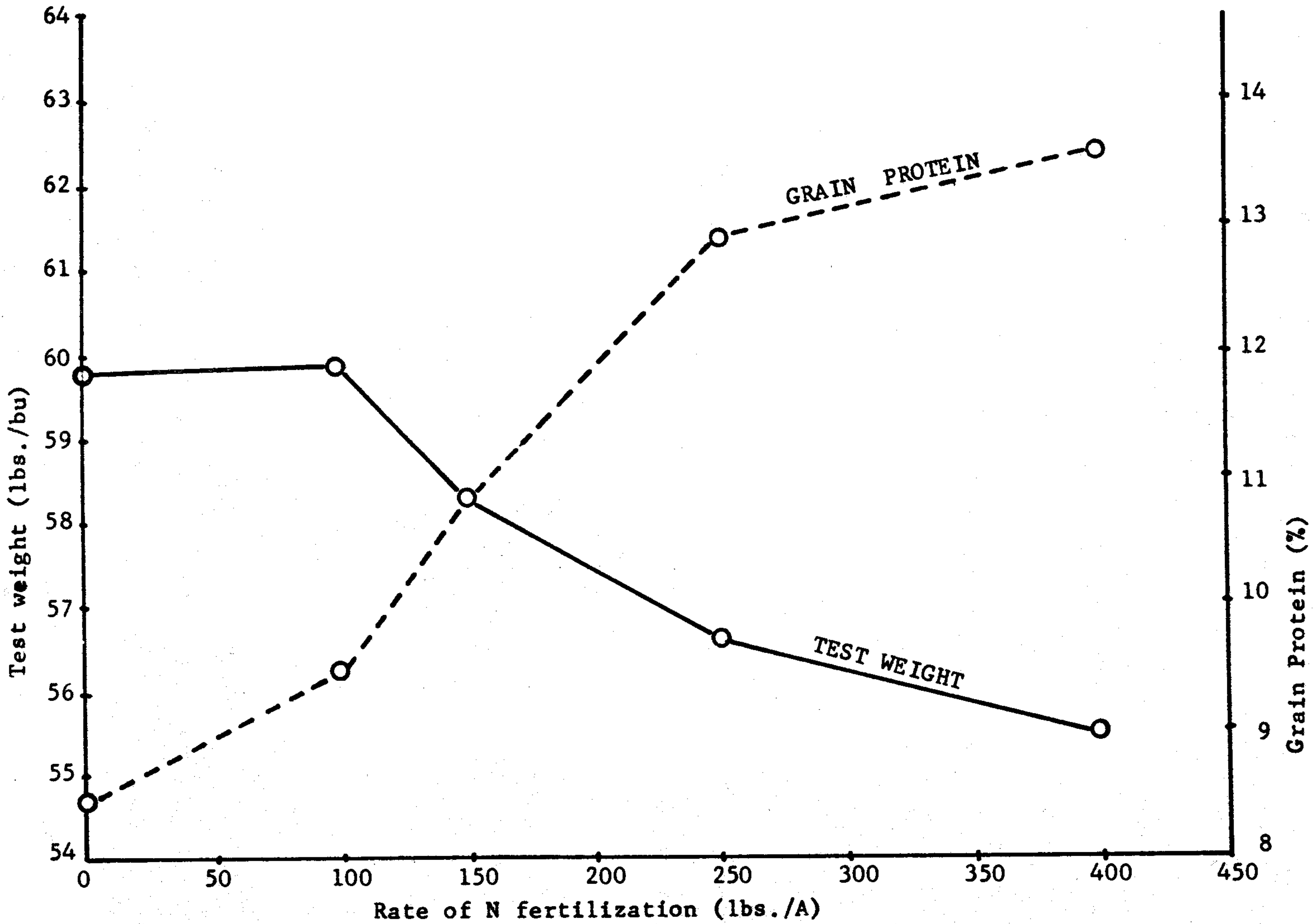

Figure 3. Relationship between N application, average test weight, and average grain protein for the nine experimental locations.

with 150 pounds or more of N per acre was significantly greater (0.05 level) in all the cases than the corresponding values for the grain from unfertilized plots. When N was applied at the rate of 100 pounds per acre, the concentration of protein in the grain reached 11.2% at the Dober site, but at all other locations the same N treatment produced grain with 9.5% protein or less.

With N applications ranging from 150 to 400 pounds per acre, the concentration of protein in the grain ranged between 9.6 and 15.8% (Table 13). It has been previously reported (Koehler, 1961) that the application of increasing increments of N which do not result in yield increase is usually found to produce a marked increase in the level of protein in the grain. This seemed to be the case at the Dober site where the application of 100 pounds of N caused only a small yield increase but a major increase in the percentage of grain protein. There was definite increase in protein content from 150 pounds of N on all locations except Cadle's where the 250 pound increment of N was required for a protein increase of more than 1%.

Hutcheon and Paul (1965) studied N and moisture relationship with wheat in the growth chamber. It was pointed out that high levels of N had a greater influence on the growth of straw than on grain. They further reported that the production of materials such as carbohydrates in the grain is more sensitive to adverse growing conditions than is the production of protein. Particularly, moisture stress alters grain protein content primarily through its action on yield of both grain and forage. When grown under conditions of low moisture stress which appear to favor production of carbohydrate material both in leaves and kernels, the wheat never contained more than 16% protein. With an increase in moisture stress, apparently less carbohydrate was formed and in this instance protein exceeded 16%. It appears that considerable moisture stress was needed in combination with excessive amounts of N to approach the level of 16% protein in the soft white wheat grown in the present experiments.

The test weight expressed in pounds per bushel was largely unaffected by the application of 100 pounds of N per acre, but N rates in excess of 100 pounds reduced the test weight markedly (Figure 3 and Table 14). It is apparent from Figure 3 that with increasing rates of N ranging from 100 to 400 pounds per acre the test weight decreased while the concentration of protein in the grain increased sharply. The average plot for the nine locations (Figure 3) in essence represents the general trend observed in the experiments. There were some deviations from the general pattern on the individual locations with respect to the response from application of 100 pounds of N. The statistical analysis showed a significant increase in test weight of grain from plots receiving 100 pounds of N per acre when compared to corresponding unfertilized plots at the Stapleton, Dromgoold and Pitchford sites. Only at the Dober site did the

Table 14. The effect of N application on test weight for the nine experimental locations.

Location Soil series (farm)	Variety	Test weight (pounds per bushel) on Rates of N application (lbs. /A) 0	100	150	250	400
Aloha (Reese)	Nugaines	61.8	61.0	58.5	57.1	56.9
Amity (Allen)	Nugaines	60.7	60.2	58.6	55.3	53.2
	Druchamp	a	58.4	57.0	53.7	53.2
Chehalis (Drew)	Nugaines	61.1	60.5	59.3	56.9	54.8
Laurelwood (Dober)	Nugaines	60.7	59.3	57.4	56.0	54.9
Newberg[1] (Pitchford)	Nugaines	57.9	59.9	a	a	57.1
Steiwer (Stapleton)	Druchamp	57.8	58.2	57.3	56.7	a
Wapato (Cadle)	Nugaines	60.6	61.8	61.4	61.2	60.7
Willakenzie (Dromgoold)	Druchamp	55.8	58.2	57.9	56.5	a
Woodburn (Busch)	Nugaines	62.1	61.3	59.6	55.8	53.6

a = not samples.

1 = The test weight was reduced by 1.4 lbs./bu by increasing the N rate from 100 to 200 at the Pitchford location.

test weight of the grain decrease significantly when 100 pounds of N per acre was applied. At the remaining sites the application of 100 pounds of N per acre produced no significant change in the test weight. Applications of N ranging from 150 to 400 pounds per acre decreased the test weight significantly (0.05 level) compared to the corresponding values for the 100 pound N treatments.

As already indicated in Figure 1 and Table 8 increasing increments of applied N beyond the optimum level resulted in lower yields; therefore, a plot of grain yield versus the test weight produces a linear relationship with a positive slope. This positive correlation is presented in Figure 4. It is apparent that when yields were reduced by the application of N rates greater than 100 pounds per acre, the test weight per bushel also declined. Therefore it is essential to apply the appropriate amount of N fertilizer in order to produce optimum yields of top quality wheat.

Relationship Among Wheat Varieties With Respect to Test Weight Per Bushel and Protein Concentration in the Grain

The comparative test weight and protein concentration for the three wheat varieties used in the experiments are summarized in Table 15. It is apparent from the table that the concentration of protein in Druchamp wheat was significantly greater than in Nugaines wheat. However, there was no significant difference between

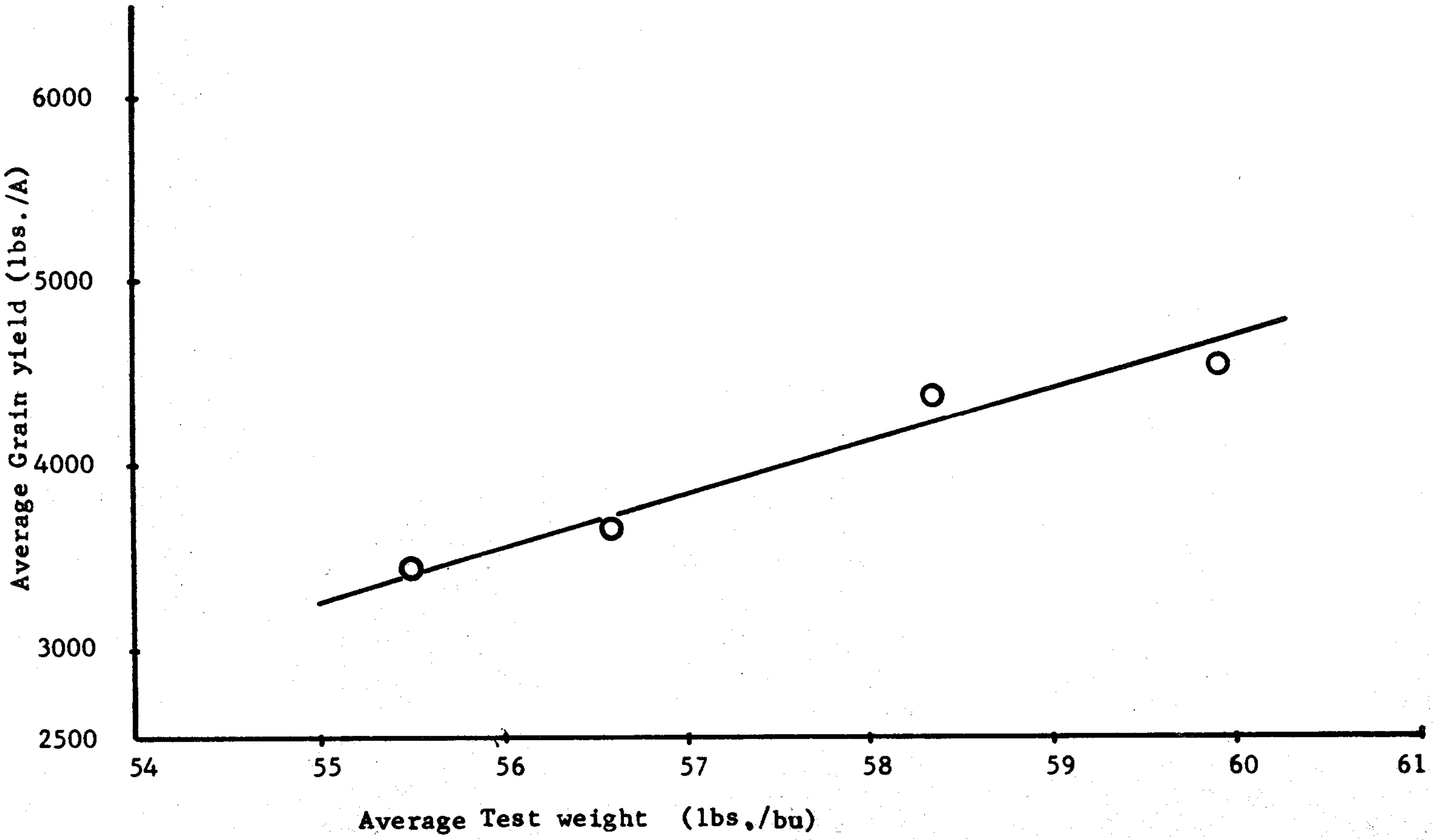

Figure 4. Linear relationship between average test weight and average yield for the nine experimental locations.

Table 15. Varietal comparisons for test weight and grain protein for the nine experimental locations.

Location Soil series (farm)	Nugaines Test weight (lbs./bu)	Nugaines Protein (%)	Druchamp Test weight (lbs./bu)	Druchamp Protein (%)	Gaines Test weight (lbs./bu)	Gaines Protein (%)
Aloha (Reese)	58.9B	11.0A	56.0A	12.6B	57.4A	10.9A
Amity (Allen)	58.4B	9.8A	57.0A	12.1B	56.3A	10.8A
Chehalis (Drew)	59.3B	10.8	57.6a	13.3	56.9A	11.6
Laurelwood (Dober)	57.3B	13.4	54.4A	14.3	56.5a	14.4
Newberg (Pitchford)	58.7B	11.9A	56.4A	14.0B	53.6A	11.6A
Steiwer (Stapleton)	59.6b	12.1A	57.4a	13.9B	56.6a	12.1A
Wapato (Cadle)	61.6B	9.6A	58.8A	12.2B	59.7A	9.9A
Willakenzie (Dromgoold)	60.0B	10.0A	58.3A	11.7B	58.9A	9.6A
Woodburn (Busch)	59.4B	10.1A	56.5A	13.3B	58.5B	10.2A

B is significantly higher than A at 0.01 significance level, b is significantly higher than a at 0.05 significance level.
All tests of significance are within a site.

Nugaines and Gaines varieties with respect to the concentration of protein in the grain. It is important to recognize that all of these comparisons are at a comparable rate of N fertilization and does not indicate the interaction, if any, between the N rates and the varieties.

In the case of variety test weight comparisons, the statistical analysis showed that Nugaines had significantly greater test weight than either Druchamp or Gaines (Table 15) at all the locations. Gaines wheat had the lowest test weight on all but the Busch site where its test weight was not significantly different from Nugaines wheat.

The protein and test weight data from the experiments indicate that in most instances one would expect the milling quality of Nugaines to be superior to that of the other two varieties, and it also had a slightly lower concentration of protein which should make it the most desirable of the three wheat varieties from which to obtain pastry flour.

Effects of N, P and K Fertilization on Levels of These Nutrients in Plant Tissues

Plant analysis was used to evaluate the uptake of the applied fertilizers by wheat plants. With adequate information concerning the critical levels for these nutrients in wheat plant tissue, the analytical data may also indicate whether the supply of available nutrients in the soil is sufficient for optimum growth of the crop. Unfortunately, the critical levels for N, P and K in wheat plants have not been established so it is not possible to interpret the data in this manner. Direct comparison of the nutrient concentration in plants from a fertilized versus non-fertilized plot may indicate whether fertilization enhanced the uptake of the nutrients under study. Where the nutrient in question is deficient, an increase in plant growth and in yield is anticipated if fertilization with the nutrient enhances the uptake of that nutrient by the crop. A chemical analysis of plant tissue at various stages of growth also provides a record of nutrient concentrations in a growing plant with time. It may be possible to follow the translocation of a nutrient from one plant part to another; for example, the translocation of N from the leaf to the grain of wheat.

Plant tissue from arbitrarily selected stages of growth (jointing and boot stages) were used for the chemical analyses and evaluation in these experiments. Possibly the analyses of samples representing other stages of growth may have provided additional information in explaining the correlations and yield responses obtained and discussed in the following section.

The N, P and K levels in the plant tissue at the jointing stage of growth were in all cases higher than the levels of the same nutrients in the plant tissue at the boot stage (Tables 16 and 18). The fertilizer treatments had a significant effect on the N, P and K content of plant tissues at the jointing stage. These differences in plant N concentration were significant at the boot stage of growth (Appendix tables 10 through 18). The N, P and K concentrations in the plant tissue on all the treatments decreased between jointing and heading. The decrease in the concentrations between the two stages must have been caused by either the translocation of N, P and K from vegetative tissues to the grain or by dilution with increased vegetative growth or both.

The application of N increased significantly the N concentration of the plant tissues at all locations at both stages of growth at which samples were taken (Figure 5 and Table 16). The concentration of leaf N in the plants representing the plots fertilized with N decreased from the jointing stage to the boot stage, but the leaf N in plants from non-fertilized plots increased during this period. Apparently the decline in the N concentration from jointing to the boot stage may be attributed to the development of the heads. It is well established that N and P are the first elements to enter the grain (Rannie, 1956); this may have been the case in decreasing concentrations of these elements in the vegetative tissues at the boot stage of growth.

Percentages of N in the plants which received N without P and K were generally greater than those which received a complete

Table 16. The effect of N application on N concentration of plant samples at jointing and boot stages of growth for the nine experimental locations.

Location Soil series (farm)	Stage of growth	% N concentration in plant tissue on rates of N (lbs./acre) 0	100	150	250	400
Aloha	Jointing	2.58	3.84	4.30	4.62	4.73
(Reese)	Boot	2.60	3.00	3.38	3.81	4.05
Amity (Allen)	Jointing	1.54	2.36	3.09	3.72	4.17
Chehalis	Jointing	1.82	2.68	3.41	4.18	4.23
(Drew)	Boot	2.46	3.05	3.43	3.79	4.33
Laurelwood	Jointing	2.31	3.31	4.01	4.39	4.55
(Dober)	Boot	2.82	3.19	3.50	3.74	3.89
Newberg[1] (Pitchford)	Jointing	1.51	2.22	a	a	3.61
Steiwer	Jointing	2.63	3.37	3.88	4.19	a
(Stapleton)	Boot	2.24	3.15	3.50	3.85	a
Wapato	Jointing	2.39	3.13	3.62	4.43	4.86
(Cadle)	Boot	2.25	2.67	2.88	2.94	3.26
Willakenzie	Jointing	2.25	3.31	4.12	4.26	a
(Dromgoold)	Boot	2.19	2.69	3.30	3.61	a
Woodburn (Busch)	Jointing	2.23	3.65	4.15	4.67	4.62

a = not determined.

1 = The N concentration in plant tissue increased by 0.68% by increasing the N rate from 100 to 200 at the Pitchford location.

Table 17. The effect of P and K application on P and K concentration in plant samples at the jointing and boot stages of growth for the nine experimental locations.

Location Soil series (farm)	P application rates (lbs./A)	P concentration in plant tissue at Jointing stage %	P concentration in plant tissue at Boot stage %	K application rates (lbs./A)	K concentration in plant tissue at Jointing stage %	K concentration in plant tissue at Boot stage %
Aloha	0	0.37	0.35	0	2.83	1.69
(Reese)	18	0.32	0.30	50	2.84	2.13
Amity	0	0.33	a	0	3.11	a
(Allen)	18	0.32	a	25	2.93	a
Chehalis	0	0.41	0.28	0	4.55	3.03
(Drew)	18	0.43	0.29	25	4.38	3.05
Laurelwood	0	0.39	0.31	0	4.02	3.18
(Dober)	18	0.39	0.31	25	3.99	3.28
Newberg	0	0.37	a	0	2.99	a
(pitchford)	18	0.39	a	25	3.20	a
Steiwer	0	0.43	0.31	0	4.14	2.80
(Stapleton)	36	0.43	0.31	25	3.37	2.89
Wapato	0	0.43	0.29	0	2.94	2.27
(Cadle)	18	0.42	0.30	25	3.02	2.30
Willakenzie	0	0.32	0.25	0	4.35	2.68
(Dromgoold)	36	0.38	0.26	25	3.62	2.62
Woodburn	0	0.37	a	0	3.62	a
(Busch)	18	0.41	a	25	3.48	a

a = not determined.

The values recorded in this table are averages on 150 pounds of N rate except for Pitchford location where the averages are on 200 pounds of N rate.

Table 18. Variety comparisons for N, P and K concentrations in plant samples at the jointing and boot stages of growth for the nine experimental locations.

Location Soil series (farm)	Stage of growth	Nugaines N (%)	Nugaines P (%)	Nugaines K (%)	Druchamp N (%)	Druchamp P (%)	Druchamp K (%)	Gaines N (%)	Gaines P (%)	Gaines K (%)
Aloha (Reese)	Jointing	4.1	.32a	2.7	4.1	.39b	3.1b	4.2	.36a	2.9
	Boot	3.3b	.31	2.2b	3.3b	.33	1.7a	3.0a	.33	2.1
Amity (Allen)	Jointing	3.2	.33	2.6A	2.9	.33	3.2B	3.2	.37	3.2B
Chehalis (Drew)	Jointing	3.5B	.43	3.9	2.6A	.39	3.4	3.1A	.40	3.4
	Boot	3.5b	.29	3.0b	3.5b	.31	2.6a	3.2a	.28	2.8
Laurelwood (Dober)	Jointing	4.0b	.38a	4.0	3.7a	.44b	3.8	4.0b	.43b	4.1
	Boot	3.6	.32	3.2B	3.8B	.37B	2.8A	3.4A	.29A	3.1B
Newberg (Pitchford)	Jointing	2.9	.39	3.1	3.1	.37	3.3	2.7	.37	3.5
Steiwer (Stapleton)	Jointing	4.3B	.37	3.7	3.9A	.42	3.6	4.1B	.42	3.9
	Boot	3.4	.39B	3.2	3.6B	.32A	2.9	3.2A	.30A	3.2
Wapato (Cadle)	Jointing	3.4a	.41	3.1	3.8b	.43	3.1	3.5a	.42	3.1
	Boot	2.9	.30	2.4b	2.9	.30	2.1a	2.8	.28	2.3b
Willakenzie (Dromgoold)	Jointing	4.5B	.35	4.2B	3.9A	.34	3.6A	4.4B	.35	4.3B
	Boot	3.4	.24	3.2B	3.2	.26	2.6A	3.3	.24	3.1B
Woodburn (Busch)	Jointing	3.9	.41	3.7	3.9	.41	3.7	4.1	.43	3.8

a = not determined.

B is significantly higher than A at 0.01 significance level and b is significantly higher than a at 0.05 significance level.

All tests of significance are within a site.

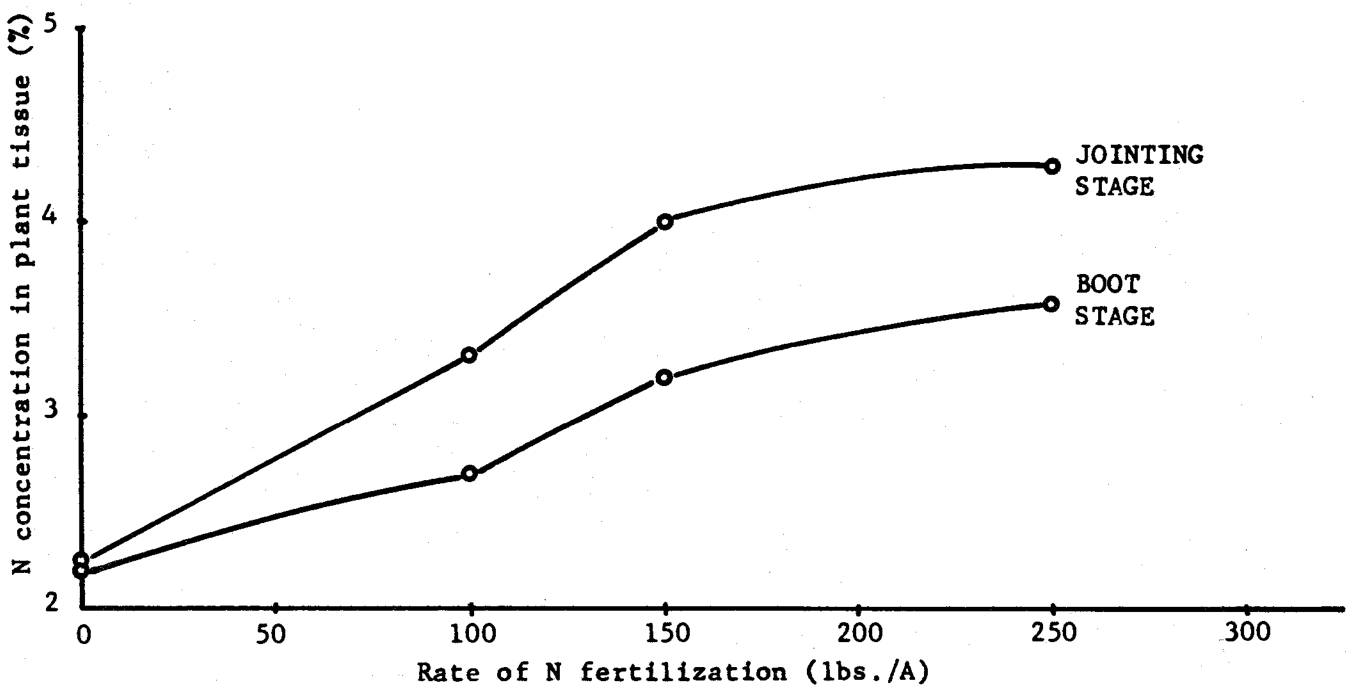

Figure 5. The effect of N application on the N concentration in plant tissue from jointing and boot stages of growth for Dromgoold location.

N, P and K fertilizer, but this difference was not statistically significant (Appendix tables 10 through 18). Apparently the NPK combination stimulated growth of the plants which resulted in the dilution of the N concentration or there was an increased ion competition as a result of fertilizer combination. Dewit et al. (1963) found that the increased uptake of Cl supplied by the fertilizer KCl decreased NO_3 uptake. However, this would be an effect of small magnitude because of the limited addition of Cl in these experiments.

Simple correlation by linear regression analysis was used to study the relationship of both yield and test weight to plant N. The correlation coefficients reveal that plant N at the jointing stage is significantly correlated with both yield and test weight for some of the experiments (Appendix tables 19 through 27). The correlation between plant N and yield was significant at the Stapleton, Dromgoold, Reese and Cadle sites; these correlations were not significant at the remaining sites (Figure 6). This was due to the fact that rates of N in excess of those required to produce optimum yields were used. In all cases the increasing increments of applied N increased the concentration of N in the plant tissue (Figure 5).

The negative correlation between plant N and test weight, as shown in Figure 7, was significant at 0.01 level (Appendix tables 19 through 27). It was apparent (Figure 7) that the test weight of the grain was decreased markedly as the plant N concentration went

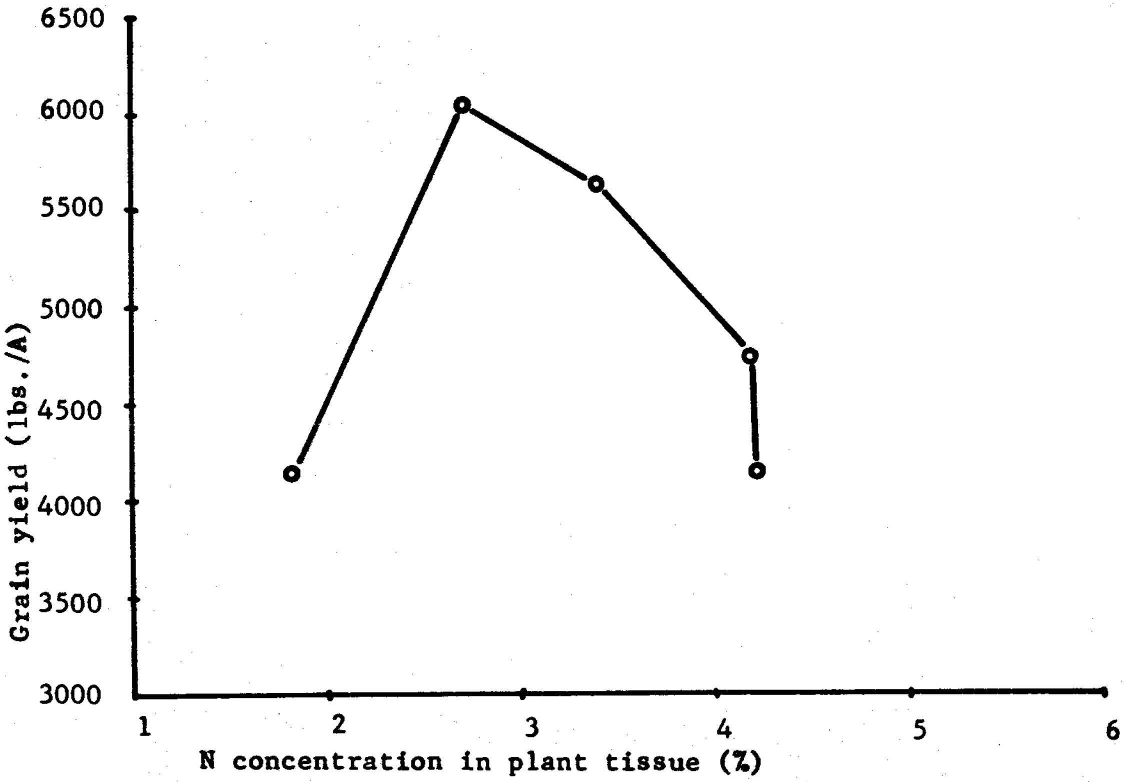

Figure 6. Correlation between yield and N concentration in plant tissue from jointing and boot stages of growth for Drew location.

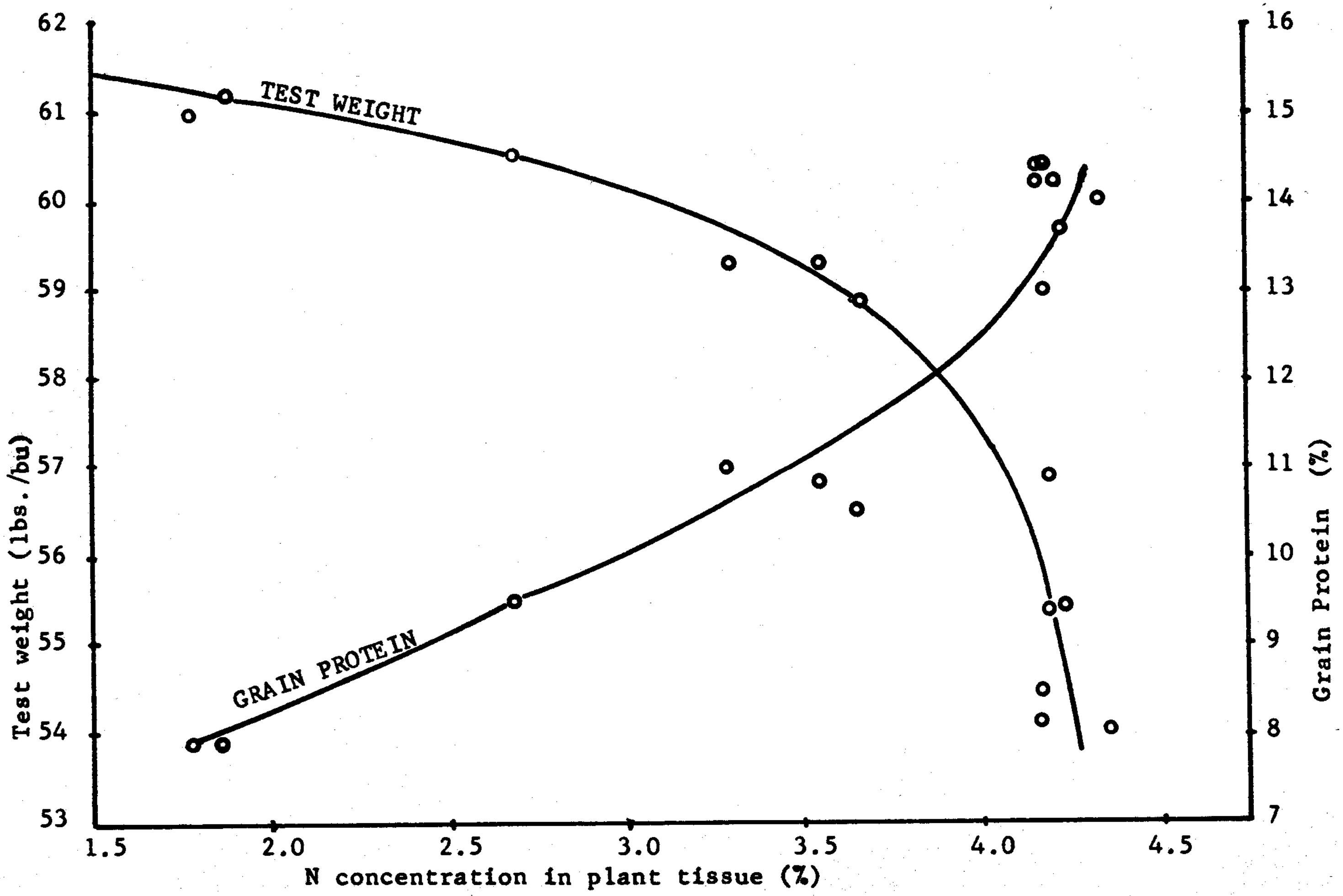

Figure 7. Relationship between N concentration in plant samples from jointing stage, test weight and grain protein for Drew location.

beyond 3.5% at the jointing stage of growth. This decrease in test weight reflects a decrease in grain quality for baking and milling that resulted from high rates of N applications.

In contrast to the N effects, P and K fertilization did not change significantly the P and K concentrations in the plant tissues at the two growth stages sampled (Table 17). Failure of applied P and K to increase the concentrations of these nutrients in the plant tissues usually indicates that a major yield response is not likely and this effect was observed in these experiments. The lack of response to P and K in these experiments may be explained by the high soil test values for these nutrients at some locations and the suboptimum yields caused by certain limiting factors at other locations. The levels of P and K found in these samples might be considered above the critical levels for the yields obtained. The absence of an increase in yield from P and K indicated that there was little advantage in P and K fertilization, but at the same time there was no evidence of a detrimental effect resulting from these applications.

The applications of N consistently increased the concentration of P and K in the plant tissues at both the jointing and the boot stages of growth (Appendix tables 1 through 9). The effect of N on K (Figure 8) was more marked than the effect on P. In both cases the increase in respective concentration in the plant tissues were found to be statistically significant at 0.05 level (Appendix tables 10

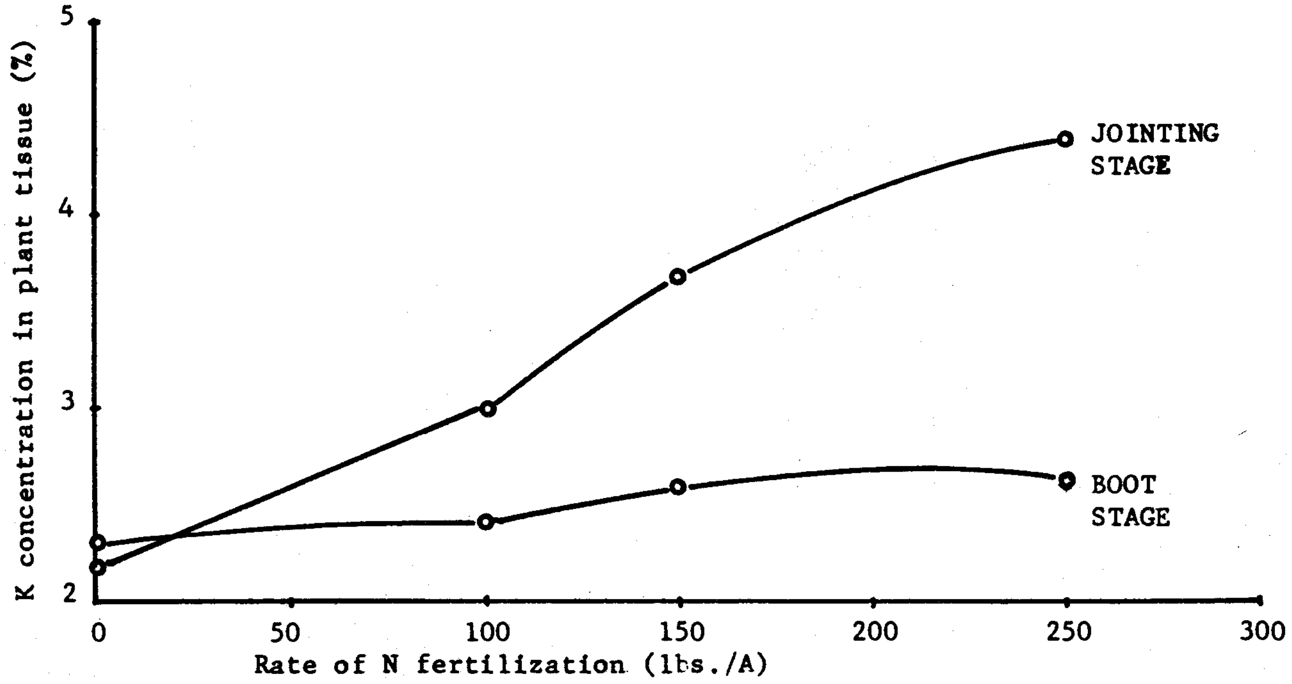

Figure 8. The effect of N application on K concentration in plant tissue from jointing and boot stages of growth for Dromgoold location.

through 18) at the jointing stage of growth. In some cases the increase in K concentration in the plant tissues was significant at the boot stage too. Apparently the intake of P by the wheat plants occurs rapidly at the early stages of growth and this minimizes any treatment effects on P uptake that may be detected at the boot stage of growth. The increased uptake of P as a result of N fertilization may have resulted from N increasing the availability of soil P or from the stimulation of root development thereby promoting root exploration into a greater volume of soil (Grunes et al., 1958).

The marked increase in the concentration of K which was related to the application of excessive rates of N might be attributed to the "Ionic Balance" phenomenon in the plants (Noggle, 1966; Dijkshoorn, 1958; and Dewit et al., 1963). The uptake of anionic nitrate-N may have been accompanied largely by K cations. Jackson and Kronstad[1] observed that the concentration of Ca and Mg in semi-dwarf wheat was comparatively constant whether the plants were growing on acid or on calcareous soils. The uptake of K appears to fluctuate much more widely than either Ca or Mg.

In short the plant analyses and subsequent evaluation of the data supports the idea that N is a predominant factor which regulates the growth, yield and nutrient content of wheat under the growing conditions in western Oregon.

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[1] Personal communication.

Relationship of Wheat Varieties With Respect to N, P and K Concentrations in the Plant Tissue

Results of variety comparisons for N, P and K concentrations in the plant tissue at the jointing and the boot stages of growth are summarized in Table 18. The N concentration in the plant tissue from Nugaines variety at the jointing stage of sampling was found to be significantly greater than that for the Druchamp variety at Dober, Drew, Stapleton, Cadle and Dromgoold sites. At the other four locations the absolute concentrations of N in the plant tissue for Nugaines were still higher than Druchamp but the difference was not statistically significant. There was less difference between varieties at the boot stage of growth. The differences were significant only at the Reese and Drew sites. Nugaines and Gaines, however, did not show any appreciable difference in the N concentrations of the plant tissue.

The P concentration in the plant tissue was comparable for the three varieties at most of the locations. At the Stapleton site the plant P concentration of Nugaines at the jointing stage was found to be significantly greater than that for Druchamp but at the Reese site the converse was true. The differences were not significant at the other locations.

The K content of the plant tissue from Nugaines plots was significantly greater than that for Druchamp at Reese, Dober, Drew, Cadle, and Drumgoold sites at the boot stage samples. The differences were significant for jointing stage samples only at the Dromgoold site. At the Allen site the K concentration in the plant tissue at the jointing stage samples showed Druchamp significantly greater than Nugaines. Differences do exist in the concentration of nutrients found in the tissue of different wheat varieties, but most of these differences are not sufficiently large to warrant extensive consideration for the purposes of this study.

Other Nutrients in the Plants

Samples of plant tissue from the Nugaines variety with a selected fertilizer treatment were analyzed for Ca, Mg, Mn, Zn, and Fe and these results are reported in Table 19 for each of the nine experiments. The treatment was always the optimum fertilizer combination formed by using 150 or 200 pounds of N with 18 or 36 pounds of P and 25 pounds of K per acre. Under a wide range of soil test values for Ca and Mg there was a very small range of concentrations for these elements in the plant tissue. Although wheat may respond to the application of lime one would anticipate that these soils were adequately supplied with Ca and Mg for the nutrition of wheat plants.

In western Oregon studies in plant nutrition with respect to Mn have dealt with the problem of toxicity, particularly in the poorly drained, lowland soils (Jackson *et al.*, 1966). In the study with

Table 19. Levels of Mn, Zn, Fe, Ca and Mg in Nugaines plant samples from jointing and boot stages of growth for the nine experimental locations.

Location Soil series (farm)	% Mn at jointing	% Mn at boot	% Zn at jointing	% Zn at boot	% Fe at jointing	% Fe at boot	% Ca at jointing	% Ca at boot	% Mg at jointing	% Mg at boot
Aloha (Reese)	.005	.004	.002	.002	.01	.007	.26	.39	.11	.19
Amity (Allen)	.013	a	.002	a	a	a	.23	a	.08	a
Chehalis (Drew)	.013	.012	.002	.002	.01	.008	.16	.17	.12	.16
Laurelwood (Dober)	.003	.005	.002	.002	.01	.02	.21	.27	.09	.16
Newberg (Pitchford)	.003	a	.002	a	.005	a	.10	a	.08	a
Steiwer (Stapleton)	.011	.013	.003	.003	.01	.01	.19	.18	.12	.15
Wapato (Cadle)	.003	.003	.002	.002	.014	.007	.13	.15	.12	.17
Willakenzie (Dromgoold)	.012	.011	.002	.002	.016	.008	.20	.28	.12	.15
Woodburn (Busch)	.007	a	.002	a	.012	a	.18	a	.11	a

a = not determined.

Analyses are made on 150 pounds N rate with optimum P and K levels for all but Pitchford location where the N rate is 200 pounds.

bush beans, concentrations of Mn below 500 ppm seemed to indicate little if any problem of toxicity. The concentrations of Mn in the tissue of wheat plants in the experiments were extremely low and it appeared that Mn toxicity was not a factor at any of these experimental sites.

In western Oregon Fe deficiency has seldom been considered but a deficiency of zinc, has been identified in restricted areas for certain crops, exclusive of wheat. Recent work by Jackson et al. (1967) on the response of sweet corn to zinc fertilization indicates that the presence of 25 ppm zinc in the leaf tissue indicated the plants were adequately supplied with zinc.

SUMMARY AND CONCLUSIONS

A series of experiments designed to obtain a better evaluation of the effects of N, P and K fertilizers on the production of wheat in western Oregon, were initiated in the fall of 1966 and were carried through the summer of 1967. Nine locations were selected to represent the conditions under which wheat is produced in western Oregon and to provide a range in yield, nutrient content, test weight and protein content of the three wheat varieties Nugaines, Gaines and Druchamp.

The soils of the experimental sites included two of the most productive soils in the Willamette valley (Chehalis and Woodburn series) and the Steiwer and Willakenzie series which represent large areas of hill soils in western Oregon. The other selected sites represented Aloha, Amity, Laurelwood, Newberg and Wapato series.

The experiments were designed as a randomized block design, using treatment combinations on rates of N, P and K. The treatments were replicated three times at each of the nine locations.

Measurements on yields, test weight, protein content of the grain and N, P and K contents of the plant tissues at two stages of growth (jointing and boot stages) were taken. The results obtained were analyzed statistically to evaluate the effects of various treatments.

The 1967 growing season had an unusually mild winter and hot-dry summer. These climatic conditions resulted in a below average response to applied fertilizer. Also competition from grass was above average and stripe and leaf rusts were serious problems throughout western Oregon. These factors created conditions which undoubtedly reduced yield and responses. Had moisture been available at these locations prior to kernel development higher yields might have resulted from more efficient utilization of the fertilizer applied.

The analyses of the results obtained from the experiments have led to the following conclusions:

1. There was a substantial response to 100 pounds of N per acre at all the sites except one. The yield increases were found to be highly significant statistically.

2. Applications greater than 150 pounds of N per acre depressed yields when compared with 100 pounds of N per acre at all but two sites.

3. Relative yields and yield increases varied from location to location. This related to the cropping and fertilization history together with the differences in soil types.

4. Highly significant positive correlation between yield and plant N was found on all the locations.

5. There was a significant yield response (0.05 level) to applied P at one location and yield increases indicative of a response at five additional sites. Apparently the level of available P before fertilization at the experimental sites was adequate for the yield obtainable in these experiments, and this fact was substantiated by the high values for soil test P obtained at many of the sites.

6. Potassium application was also not effective in increasing yield. Again, the high soil test values indicated that the supply of soil K was adequate for the wheat crop.

7. Nitrogen application significantly increased protein content of the grain. Druchamp was significantly higher in protein content compared to either Gaines or Nugaines. It is important to note that the concentration of N in the plant at the jointing stage was lower in Druchamp than in either Gaines or Nugaines, yet the concentration of protein in the grain was higher for Druchamp.

8. Nitrogen application significantly decreased test weight at all the locations. Test weight produced a significant negative correlation with N in plant tissue.

9. The N application significantly increased the concentrations of N, P and K in the plant at the jointing stage and at the boot stage of growth with the exception of plant P at the boot stage which was unaffected by N application.

10. P and K applications had no effect on the P and K levels

in the plant tissue which could be detected at the two stages of growth when samples were collected.

11. Nugaines was the highest yielding variety at seven of the experimental sites and two of these were hill soils on which one may anticipate the superiority of Druchamp. Druchamp was the highest yielding variety at the two remaining sites and one of these was also a hill soil. Gaines was not the highest yielding variety at any of the sites. The superiority of Nugaines over Gaines with respect to yield was probably related to the greater rust resistance of Nugaines.

12. Test weight was significantly higher for Nugaines compared to either Gaines or Druchamp at all the locations.

At this point it should be emphasized that a seasonal distribution of precipitation and temperature would undoubtedly alter the expression of the treatment's effect evaluated in this study. The evaluation of NPK application and the varietal comparisons should be conducted over a period of years so that the results obtained would more nearly reflect the effect of average climatic conditions.

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APPENDIX

APPENDIX

DESCRIPTION OF SOIL SERIES

The Aloha series is a member of the Aquic Xerochrepts members of a fine silty, mixed mesic family. Typically, the soils have a thin, dark brown A horizon, and a mottled, firm dark-yellowish brown, medium textured B horizons. The solum is medium acid. The soils are somewhat poorly drained with slow surface runoff and moderately slow internal drainage and permeability. Most of these soils are cultivated. Orchards, berries, grain, hay and pasture are major crops.

The Amity series is a member of a fine silty, mixed mesic family of Argixerolls. These soils have very dark grayish brown silty A2 horizons and grayish brown or light olive brown silty clay loam Bt horizons with mottling. These soils are somewhat poorly drained. Runoff and internal drainage are slow. The Amity soils are used for small grain, grass seed, hay and pasture. Some cannery crops are grown with artificial drainage.

The Chehalis series consists of well drained moderately fine textured alluvial soils occurring in the Reddish Brown Lateritic zone and developed in mixed recent alluvium derived from sedimentary rocks and basic volcanic materials. The Chehalis soils characteristically have very dark grayish brown silty clay loam A1 horizon and dark brown silty clay loam AC and C horizons. The Chehalis soils where cleared and protected from overflow are used, in general, for field crops of grain, grasses, legumes, alfalfa, vegetables, berries, filberts and orchards.

The Laurelwood series comprises Mollic Normudalf members of a fine silty, mixed mesic family. Typically, the soils have a dark brown A horizon containing concretions and dark brown to yellowish brown moderately fine textured, strongly structural Bt horizons that overlie dark reddish brown fine textrued burred horizons. The solum is medium acid. These soils are well drained with slow surface runoff and medium internal drainage. Permeability is moderate. Orchards, berries, grain, hay and pasture are the major crops on these soils.

The Newberg series is a member of the coarse loamy mixed mesic family of Fluventic Haploxerolls. Newberg soils typically have very dark grayish brown or dark brown sandy loam or loam A and AC horizons and dark brown moderately coarse textured stratified C horizons. The solum is medium or slightly acid. Newberg soils are somewhat excessively drained. Surface runoff is slow, internal drainage is moderately rapid and permeability is rapid. These soils are mainly used for vegetable crops, fruit production and pasture.

The Steiwer series is a member of the fine loamy mixed mesic family of Typic Haploxerolls. The soils have a dark brown A horizon and dark brown to dark yellowish brown, moderately fine textured B horizon that overlie sedimentary rock. The solum is medium acid. The soils are well drained with medium surface runoff and moderate internal drainage. Permeability is moderately slow. Improved pasture, small grain and few prune orchards are important uses.

The Wapato series comprises Typic Haplaquolls, members of a fine silty, mixed, non-calcareous, mesic family. Typically the soils have very dark greyish brown A horizons with distinct mottles in the lower part and mottled, dark grayish brown, moderately fine textured B horizons. The solum ranges from slightly acid in upper part to medium acid in lower part. This is poorly drained with slow surface runoff and slow internal drainage. Permeability is slow or moderately slow. Most of these soils are cultivated. Hay and pasture are the major crops. When drained, beans and small grains are also raised.

The Willakenzie series is a member of the fine loamy mixed mesic family of Ultic Haploxeralfs. The soils typically have a dark brown A horizon and dark brown, moderately fine textrured Bt horizons, overlying sandstone or siltstone at depths of less than 40 inches. The solum is medium acid in the upper part and strongly acid in the lower part. The soil series is well drained with moderate surface runoff and moderate internal drainage. Permeability is moderately slow. Most of these soils have been cleared and are used for orchards, small grain, hay and pasture.

The Woodburn series is a member of a fine silty, mixed mesic family of Acquic Argixerolls. These soils have a very dark grayish brown silt loam A horizon, and dark brown silty clay loam or heavy silt loam Bt with mottles and very firm and brittle consistency in the lower part. The reaction is slightly or medium acid. These soils are moderately well drained. Runoff and internal drainage are medium and permeability of B3 horizons is slow. Berries, orchards, cannery crops, grain, hay and pasture are the principal crops raised on these soils.

Appendix Table 1. The effect of fertilization on the yield, test weight, grain protein and N, P and K concentrations in plant samples from jointing and boot stages of growth for the Reese location.

Treatment lbs./A of N P K	Yield (lbs./A)	Test weight (lbs./bu)	Grain protein (%)	Chemical analyses for plant samples from: Jointing stage N (%)	P (%)	K (%)	Boot stage N (%)	P (%)	K (%)
0 0 0	2267	61.8	9.1	2.58	.35	2.52	2.60	.42	2.62
100 18 50	4462	61.0	9.3	3.84	.33	3.33	3.00	.30	2.33
150 0 0	3678	57.6	a	4.14	.36	2.78	3.35	.37	1.63
150 0 50	3965	59.0	a	4.13	.38	2.94	3.42	.34	2.05
150 18 0	3977	58.4	a	3.81	.31	2.88	3.46	.30	1.75
150 18 50	4098	58.9	11.0	4.14	.32	2.73	3.29	.31	2.20
150 18 50 (No fall N)	4136	58.4	a	4.10	.40	3.16	3.29	.31	2.05
150 18 50 (broadcast)	4139	59.2	a	4.15	.38	3.48	3.55	.32	2.15
250 18 50	3839	57.1	12.7	4.62	.43	3.40	3.81	.34	1.95
400 18 50	3834	56.9	12.6	4.73	.37	3.60	4.05	.34	2.17
150 18 50 (Druchamp)	3945	56.0	12.6	4.05	.39	3.05	3.32	.33	1.70
150 18 50 (Gaines)	3387	57.4	10.9	4.17	.36	2.88	2.96	.33	2.05

a = not determined.

All recorded values are average over three replications.

Appendix Table 2. The effect of fertilization on the yield test weight, grain protein and N, P and K concentrations in plant samples from jointing stage of growth for the Allen location.

Treatment lbs. /A of N P K	Yield (lbs. /A)	Test weight (lbs. /bu)	Grain protein (%)	Chemical analyses for plant samples from Jointing stage		
				N (%)	P (%)	K (%)
0 0 0	2382	60.7	7.4	1.59	.29	2.18
0 18 25	3464	60.3	-	1.49	.33	2.65
100 18 25	5358	60.2	7.5	2.36	.28	2.12
150 0 0	5568	58.9	-	2.96	.33	3.20
150 0 25	5088	58.3	-	3.20	.32	3.22
150 18 0	5102	58.9	-	3.01	.31	3.00
150 18 18	5405	58.4	9.8	3.19	.33	2.64
250 18 25	3653	55.3	13.2	3.72	.34	3.32
400 18 25	2529	53.2	14.1	4.17	.39	3.79
100 18 25 (Druchamp)	4734	58.4	10.2	2.55	.31	3.03
150 18 25 (Druchamp)	4138	57.0	12.1	2.87	.33	3.22
250 18 25 (Druchamp)	2500	53.7	14.5	3.36	.35	3.50
400 18 25 (Druchamp)	2069	53.2	15.4	3.92	.36	3.55
150 18 25 (Gaines)	4170	56.3	10.8	3.18	.37	3.23

- not determined.
All recorded values are average over three replications.

Appendix Table 3. The effect of fertilization on the yield, test weight, grain protein and N, P and K concentrations in plant samples from jointing and boot stages of growth for the Drew location.

Treatment lbs./A of N	P	K	Yield (lbs./A)	Test weight (lbs./bu)	Grain protein (%)	Chemical analyses for plant tissues from: Jointing stage N (%)	Jointing stage P (%)	Jointing stage K (%)	Boot stage N (%)	Boot stage P (%)	Boot stage K (%)
0	18	0	3774	61.2	7.9	1.87	.35	2.61	2.45	.31	2.65
0	0	0	4140	61.0	7.9	1.77	.31	2.34	2.48	.29	3.05
100	18	0	6038	60.5	9.5	2.68	.38	3.27	3.05	.30	3.10
150	0	0	5781	59.3	11.0	3.28	.41	3.57	3.37	.28	2.95
150	18	0	5342	59.3	10.8	3.54	.43	3.92	3.50	.29	3.03
150 (No Fall N)	18	0	5757	58.9	10.5	3.65	.44	3.90	3.34	.30	3.15
250	18	0	4730	56.9	13.0	4.18	.45	4.10	3.79	.29	2.95
400	18	0	4290	55.3	14.3	4.20	.42	4.55	4.12	.31	3.03
400	18	25	3778	54.4	14.4	4.15	.28	4.43	3.79	.28	2.95
400	36	25	3764	54.1	14.3	4.15	.49	4.38	4.07	.30	3.05
400	53	25	4313	55.4	13.7	4.20	.48	4.23	4.32	.29	2.95
550	53	25	3392	54.1	14.0	4.33	.50	4.80	4.22	.31	2.98
150 (Gaines)	18	0	4067	56.9	11.6	3.06	.40	3.40	3.17	.28	2.75
150 (Druchamp)	18	0	4274	57.6	13.3	2.62	.39	3.38	3.47	.31	2.63

All recorded values are average over three replications.

Appendix Table 4. The effect of fertilization on the yield, test weight, grain protein and N, P and K concentrations in plant samples from the jointing and boot stages of growth for the Dober location.

Treatment lbs. /A of			Yield	Test weight	Grain protein	Chemical analyses for plant tissues from					
						Jointing stage			Boot stage		
N	P	K	(lbs. /A)	(lbs. /bu)	(%)	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
0	0	0	3490	60.7	9.1	2.31	.34	2.73	2.82	.30	3.04
100	18	25	3790	59.3	11.2	3.31	.35	3.62	3.19	.30	3.21
150	0	0	3369	56.8	--	4.05	.37	3.92	3.41	.32	3.08
150	0	25	3696	57.7	--	4.03	.41	4.08	3.49	.31	3.33
150	18	0	3499	57.3	--	4.00	.39	4.20	3.51	.30	3.27
150	18	25	3793	57.3	13.4	3.95	.38	3.98	3.59	.31	3.22
150 (No Fall N)	18	25	3617	57.6	--	4.05	.39	4.30	3.45	.30	3.38
250	18	25	2904	56.0	14.6	4.39	.39	4.13	3.74	.31	3.26
400	18	25	2572	54.9	15.8	4.55	.38	4.40	3.89	.31	3.08
150 (Druchamp)	18	25	2689	54.4	14.3	3.74	.44	3.80	3.77	.37	2.82
150 (Gaines)	18	25	3619	56.3	14.4	3.98	.43	4.07	3.44	.29	3.14

-- not determined.

All recorded values are average over three replications.

Appendix Table 5. The effect of fertilization on the yield, test weight, grain protein and N, P and K concentrations in plant samples from jointing stage of growth for the Pitchford location.

Treatment lbs. /A of N	P	K	Yield (lbs. /A)	Test weight (lbs. /bu)	Grain protein (%)	Chemical analyses for plant tissues from Jointing stage: N (%)	P (%)	K (%)
0	0	0	1946	57.9	8.3	1.51	.32	1.58
100	18	25	4363	59.9	9.5	2.22	.33	2.73
200	0	0	3538	58.8	-	2.79	.35	2.81
200	0	25	3397	57.8	-	2.88	.40	3.27
200	18	0	3625	58.6	-	3.01	.40	3.17
200	18	25	3681	58.7	11.9	2.93	.39	3.13
200 (No Fall N)	18	25	3470	57.3	-	3.20	.40	3.53
400	0	0	2762	58.1	-	3.68	.40	3.41
400	18	25	3000	55.9	-	3.63	.42	3.47
400	36	25	2497	57.4	-	3.52	.41	3.42
200 (Gaines)	18	25	2842	56.4	11.6	3.08	.37	3.25
200 (Druchamp)	18	25	2707	53.6	14.0	2.70	.37	3.50

- not determined.

All recorded values are average over three replications.

Appendix Table 6. The effect of fertilization on the yield, test weight, grain protein and N, P and K concentrations in plant samples from jointing and boot stages of growth for the Stapleton location.

Treatment lbs./A of N	P	K	Yield (lbs./A)	Test weight (lbs./bu)	Grain protein (%)	Chemical analyses for plant tissues from: Jointing stage N (%)	Jointing stage P (%)	Jointing stage K (%)	Boot stage N (%)	Boot stage P (%)	Boot stage K (%)
0	0	0	2041	57.8	8.6	2.63	.42	2.51	2.24	.36	2.50
100	36	25	3554	58.2	12.3	3.37	.37	2.69	3.15	.32	2.97
150	0	0	2889	57.4	--	3.85	.47	4.27	3.45	.30	2.87
150	0	25	3077	57.5	--	3.83	.39	3.16	3.52	.30	2.83
150	36	0	3336	57.0	--	3.83	.44	4.02	3.48	.31	2.73
150	36	25	3493	57.4	13.9	3.84	.42	3.58	3.61	.32	2.94
150 (broadcast)	36	25	3075	56.5	--	3.89	.43	4.22	3.46	.32	2.85
150 (No Fall N)	36	25	3014	56.6	--	4.03	.49	4.27	3.51	.30	3.02
250	36	25	3262	56.7	15.7	4.19	.44	4.40	3.85	.31	2.86
150 (Nugaines)	36	25	3147	59.6	12.1	4.25	.37	3.70	3.37	.39	3.23
150 (Gaines)	36	25	2808	57.4	12.1	4.05	.42	3.92	3.16	.30	3.20

-- not determined.

All recorded values are averages over three replications.

Appendix Table 7. The effect of fertilization on the yield, test weight, grain protein and N, P and K concentration in plant samples from jointing and boot stages of growth for the Cadle location.

Treatment lbs. /A of			Yield (lbs. /A)	Test weight (lbs. /bu)	Grain protein (%)	Chemical analyses for plant tissues from					
						Jointing stage			Boot stage		
N	P	K				N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
0	0	0	2432	60.6	9.0	2.39	.42	2.66	2.25	.33	2.25
100	18	25	3856	61.8	9.0	3.13	.41	2.88	2.67	.30	2.37
150	0	0	4272	61.5	-	3.50	.43	2.90	2.90	.29	2.27
150	0	25	4187	61.0	-	3.62	.42	3.00	2.80	.30	2.20
150	18	0	4372	61.4	-	3.74	.43	2.97	2.88	.31	2.27
150	18	25	4621	61.6	9.6	3.44	.41	3.05	2.92	.30	2.40
150 (No Fall N)	18	25	3213	61.0	-	3.80	.38	3.28	2.91	.28	2.50
250	0	0	4585	60.4	-	4.29	.42	3.13	3.20	.33	2.28
250	18	25	4179	61.2	11.3	4.43	.44	3.95	2.94	.31	2.27
400	18	25	4510	60.7	11.6	4.86	.44	3.06	3.26	.32	2.33
150 (Druchamp)	18	25	4780	58.8	12.2	3.81	.43	3.12	2.92	.30	2.07
150 (Gaines)	18	25	3022	59.7	9.9	3.47	.42	3.05	2.83	.28	2.27

- not determined.

All recorded values are averages over three replications.

Appendix Table 8. The effect of fertilization on the yield, test weight, grain protein and N, P and K concentrations in plant samples from jointing and boot stages of growth for the Dromgoold location.

Treatment lbs. /A of			Yield (lbs. /A)	Test weight (lbs. /bu)	Grain protein (%)	Chemical analyses for plant tissues from					
						Jointing stage			Boot stage		
N	P	K				N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
0	0	0	1876	55.8	8.8	2.25	.31	2.20	2.19	.27	2.28
100	36	25	3824	58.2	9.6	3.31	.33	2.98	2.69	.29	2.40
150	0	0	3966	57.6	-	4.27	.33	4.30	3.41	.25	2.67
150	0	25	3982	57.8	-	4.22	.31	3.68	3.30	.25	2.63
150	36	0	4175	58.0	-	4.10	.41	4.40	3.29	.26	2.68
150	36	25	4251	58.3	11.7	3.90	.34	3.55	3.21	.26	2.60
250	36	25	3643	56.5	14.1	4.26	.44	4.39	3.61	.25	2.62
150 (Gaines)	36	25	4058	58.9	10.0	4.43	.35	4.28	3.25	.24	3.12
150 (Nugaines)	36	25	4659	60.0	9.6	4.45	.35	4.22	3.44	.24	3.18

\- not determined.

All recorded values are averages over three replications.

Appendix Table 9. The effect of fertilization on the yield, test weight, grain protein and N, P, and K concentrations in plant samples from jointing stage of growth for the Busch location.

Treatment lbs. /A of A	P	K	Yield (lbs. /A)	Test weight (lbs. /bu)	Grain protein (%)	Chemical analyses for plant tissues from Jointing stage N (%)	P (%)	K (%)
0	0	0	4198	62.1	7.9	2.23	.31	2.40
100	18	25	5605	61.3	9.2	3.65	.39	3.07
150	0	0	5127	59.8	-	4.16	.38	3.73
150	0	25	5110	59.7	-	4.32	.36	3.30
150	18	0	5074	59.4	-	4.15	.41	3.52
150	18	25	4958	59.4	9.9	3.89	.41	3.65
150 (No Fall N)	18	25	5093	59.9	10.1	4.23	.39	3.59
250	18	25	3989	55.8	12.6	4.67	.41	3.70
400	18	25	3422	53.6	13.1	4.62	.38	3.93
150 (Druchamp)	18	25	4410	56.5	13.3	3.93	.41	3 73
150 (Gaines)	18	25	4343	58.5	10.2	4.05	.43	3.78

- not determined.

All recorded values are average over three replications.

Appendix Table 10. Analysis of variance table for Reese location.

Source of variation	d. f.	Yield	Test weight	Mean square for variables tested					
				Plant analysis at jointing			Plant analysis at boot		
				N	P	K	N	P	K
Rep.	2	303617	0.5003	0.2585	0.0014	0.0611	0.0455	0.0031	0.0702
Treat.	11	918758	8.3716**	0.8525**	0.0025	0.2536	0.4221**	0.0036	0.2268
N(1)	1	7227038**	0.8817	2.3563**	0.0008	1.0004	0.7994**	0.0228**	0.1204
N(2)	1	1276900	34.6136**	2.8505**	0.0001	0.0318	1.3417**	0.0044	0.1003
N(3)	1	36721	26.7668**	3.7997**	0.0153**	1.8113**	2.4680**	0.00002	0.0068
P	1	139968	0.3758	0.0752	0.0075	0.0091	0.0007	0.0085*	0.0533
K	1	12848	2.5201	0.0784	0.0005	0.0001	0.0070	0.0001	0.5633*
Px K	1	20667	0.5201	0.0850	0.0008	0.0721	0.0833	0.0008	0.0008
Error	22	295234	0.7822	0.0456	0.0014	0.1508	0.0277	0.0011	0.0764

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 11. Analysis of variance table for Allen location.

Source of variation	d. f.	Mean square for variables tested				
		Yield	Test weight	Plant analysis at jointing		
				N	P	K
Rep.	2	145656	0.720	0.133	0.0006	0.033
Treat.	13	4714503**	20.853**	1.813**	0.0022	0.801**
N(1)	1	12185201**	0.212	1.329**	0.0009	0.170
N(2)	1	12275687**	16.254**	8.393**	0.0024	2.494**
N(3)	1	11033271**	124.245**	9.169**	0.0141**	3.287**
P	1	11101	0.000	0.003	0.0004	0.047
K	1	23497	0.853	0.134	0.00001	0.088
PxK	1	459817	0.000	0.002	0.0007	0.106
Error	26	429140	0.353	0.050	0.0008	0.051

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 12. Analysis of variance table for Drew location.

Source of variation	d.f.	Yield	Test weight	Mean square for variables tested: Plant analysis at jointing N	P	K	Plant analysis at boot N	P	K
Rep.	2	3031949	0.584	0.002	0.018	0.105	0.041	0.0001	0.0145
Treat.	13	995656	20.429**	2.351**	0.008	1.397**	1.040**	0.0003	0.0728
N(1)	1	86611220**	0.720	1.491**	0.005	1.248**	0.671**	0.00001	0.1252
N(2)	1	29866225**	9.025*	6.105**	0.023**	3.612**	2.140**	0.0009	0.0123
N(3)	1	2030625	29.470**	5.991**	0.015*	2.301**	1.678**	0.00005	0.0001
N(4)	1	4238642**	131.290**	6.043**	0.016*	7.253**	5.638**	0.00001	0.0111
N(5)	1	4530299**	44.327**	2.744**	0.026**	3.466**	1.698**	0.00072	0.0002
P	1	486019	0.041	0.105	0.003	0.285	0.007	0.00030	0.0752
K	1	393216	1.127	0.003	0.00002	0.370*	0.170*	0.00082	0.0004
Error	26	573074	1.197	0.020	0.0025	0.119	0.039	0.0006	0.0634

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 13. Analysis of variance table for Dober location.

Source of variation	d. f.	Yield	Test weight	Mean square for variables tested: Plant analysis at jointing N	P	K	Plant analysis at boot N	P	K
Rep.	2	38537	3.121	0.025	0.0016	0.024	0.028	0.0022	0.0618
Treat.	10	575048**	18.473**	1.088**	0.0027	0.616*	0.356**	0.0012	0.0744*
N(1)	1	1667	3.227**	1.500**	0.0002	1.670**	0.205*	0.00002	0.0451
N(2)	1	71911	28.81**	5.760**	0.0061*	0.006	0.980**	0.0005	0.0380
N(3)	1	4315432**	33.076**	3.367**	0.0009	1.176**	1.051**	0.0001	0.0015
P	1	235480	0.000	0.012	0.00001	0.025	0.032	0.0001	0.0039
K	1	62064	0.750	0.003	0.0007	0.002	0.019	0.00001	0.0080
PxK	1	100650	0.480	0.001	0.0024	0.110	0.00003	0.00041	0.0690
Error	20	58243	0.202	0.015	0.0012	0.088	0.031	0.00041	0.0124

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 14. Analysis of variance table for Pitchford location.

Source of variation	d.f.	Mean square for variables tested: Yield	Test weight	Plant analysis at jointing: N	P	K
Rep.	2	711981	0.120	0.019	0.0029	0.495
Treat.	11	1256753**	7.972**	1.105**	0.0032	0.617**
N(1)	1	87628335**	6.202*	0.752**	0.0002	1.984**
N(2)	1	602952*	0.723	4.313**	0.0152**	3.522**
N(3)	1	1275205**	11.520**	5.423**	0.00001	1.918**
P	1	316261	1.027	0.022	0.0022	0.041
K	1	13669	0.521	0.000	0.0016	0.137
PxK	1	45757	0.801	0.023	0.0027	0.193
Error	22	83080	0.933	0.028	0.0011	0.070

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 15. Analysis of variance table for Stapleton location.

Source of variation	d.f.	Yield	Test weight	Mean square for variables tested: Plant analysis at jointing			Plant analysis at boot		
				N	P	K	N	P	K
Rep.	2	553806	1.168	0.098	0.0001	0.017	0.017	0.0011	0.040
Treat.	10	4790177**	2.262	0.639**	0.0034	1.230**	0.515**	0.0009	0.124
N(1)	1	3433754**	0.327	0.814**	0.0028	0.050	1.251**	0.0020	0.350**
N(2)	1	644006*	1.868	2.828**	0.0047	5.375**	2.684**	0.0036*	0.049
N(3)	1	723223*	1.834	1.035**	0.0022	2.722**	0.948**	0.0004	0.007
P	1	558576*	0.270	0.0001	0.0001	0.022	0.010	0.0005	0.0004
K	1	89269	0.163	0.001	0.0080	1.771**	0.031	0.0003	0.0022
PxK	1	721	0.083	0.001	0.0024	0.337	0.004	0.0001	0.0444
Error	20	122648	1.256	0.035	0.0032	0.092	0.026	0.0005	0.0324

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 16. Analysis of variance table for Cadle location.

Source of variation	d.f.	Yield	Test weight	Mean square for variables tested: Plant analysis at jointing			Plant analysis at boot		
				N	P	K	N	P	K
Rep.	2	1849854**	0.622	0.137	0.0007	0.0068	0.3232	0.0006	0.0043
Treat.	11	1349533*	2.200	1.201**	0.0010	0.0641	0.1961	0.0007	0.0330
N(1)	1	2999094**	1.927	0.836**	0.0003	0.0726	0.2688	0.0017	0.0204
N(2)	1	5943844**	0.123	2.723**	0.0004	0.1820*	0.7000	0.0009	0.0025
N(3)	1	1351851*	1.742	8.914**	0.0043*	0.1176*	0.9520	0.0009	0.0001
P	1	10952	1.027	0.014	0.0005	0.0020	0.0123	0.00001	0.0168
K	1	20172	0.101	0.018	0.0008	0.0223	0.0352	0.00003	0.0033
PxK	1	83500	0.440	0.159	0.0003	0.0005	0.0161	0.0003	0.0300
Error	22	276544	0.653	0.050	0.0006	0.0270	0.0503	0.0004	0.0304

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 17. Analysis of variance table for Dromgoold location.

Source of variation	d. f.	Yield	Test weight	Mean square for variables tested: Plant analysis at jointing N	P	K	Plant analysis at boot N	P	K
Rep.	2	363323	1.623	0.016	0.003	0.016	0.023	0.0003	0.1348
Treat.	8	1848193**	3.734**	1.574**	0.006*	1.805**	0.587**	0.0004	0.2595**
N(1)	1	48735000**	2.40*	1.675**	0.0008	0.905**	0.375**	0.0004	0.0204
N(2)	1	6102547**	0.003	7.535**	0.003	7.710**	3.016**	0.0003	0.3701**
N(3)	1	1192	2.703*	0.549**	0.013**	1.276**	0.454**	0.0002	0.0067
P	1	148296	0.608	0.227**	0.009*	0.0008	0.034	0.0007	0.0002
K	1	2581	0.188	0.092	0.007	1.6133**	0.028	0.00001	0.0019
PxK	1	533	0.021	0.006	0.003	0.041	0.0005	0.00001	0.0258
Error	16	99350	0.375	0.023	0.0013	0.064	0.039	0.00024	0.0258

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 18. Analysis of variance table for Busch location.

Source of variation	d.f.	Mean square for variables tested: Yield	Test weight	Plant analysis at jointing: N	P	K
Rep.	2	101923	0.714	0.013	0.007	1.065
Treat.	10	12331763**	9.297**	1.270**	0.003	0.575*
N(1)	1	2969474**	0.960	2.940**	0.008**	0.680*
N(2)	1	248170	17.640**	7.067**	0.006**	2.646**
N(3)	1	8348379**	13.861**	3.758**	0.001	1.285**
P	1	12352	0.403	0.147	0.004*	0.013
K	1	30100	0.013	0.008	0.0002	0.068
PxK	1	41184	0.003	0.130	0.0002	0.241
Error	20	212685	0.364	0.039	0.0007	0.091

**F value significant at 1% level.

*F value significant at 5% level.

Appendix Table 19. Simple correlation coefficients between the following variables: yield, test weight, and N, P, K concentrations in plant samples from jointing stage of growth for the Allen location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	0.52**	-0.16	-0.31*	-0.22
Test weight		1.00	-0.80**	-0.63***	-0.76**
N			1.00	0.60**	0.71**
P				1.00	0.62**
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.

Appendix Table 20. Simple correlation coefficients between the following variables: yield, test weight, and N, P, K concentrations in plant samples from jointing stage of growth for the Dromgoold location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	0.69**	0.80**	0.20	0.66**
Test weight		1.00	0.43*	-0.14	0.33
N			1.00	0.38	0.91**
P				1.00	0.54**
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.

Appendix Table 21. Simple correlation coefficients between the following variables: yield, test weight, and N, P, K concentrations in plant samples from jointing stage of growth for the Drew location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	0.38*	-0.09	-0.37*	-0.17
Test weight		1.00	-0.78**	-0.51**	-0.68**
N			1.00	0.66**	0.87**
P				1.00	0.69**
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.

Appendix Table 22. Simple correlation coefficients between the following variables: yield, test weight, and N, P, K concentrations in plant samples from jointing stage of growth for the Reese location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	-0.30	0.50**	0.12	0.34*
Test weight		1.00	-0.67**	-0.35*	-0.17
N			1.00	0.33*	0.47**
P				1.00	0.42**
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.

Appendix Table 23. Simple correlation coefficients between the following variables: yield, test weight, and N, P, K concentrations in plant samples from the jointing stage of growth for the Cadle location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	-0.07	0.50**	0.45**	0.36*
Test weight		1.00	-0.08	-0.26	-0.28
N			1.00	0.38*	0.44**
P				1.00	-0.06
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.

Appendix Table 24. Simple correlation coefficients between the following variables: yield, test weight, and N, P, K concentrations in plant samples from the jointing stage of growth for the Stapleton location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	0.20	0.41*	0.05	0.25
Test weight		1.00	-0.01	-0.46**	-0.35*
N			1.00	0.06	0.66**
P				1.00	0.49**
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.

Appendix Table 25. Simple correlation coefficients between the following variables: yield, test weight, N, P, K concentrations in plant samples from jointing stage of growth for the Pitchford location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	0.42**	0.04	0.10	0.16
Test weight		1.00	-0.21	-0.23	-0.40*
N			1.00	0.66 **	0.76**
P				1.00	0.61**
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.

Appendix Table 26. Simple correlation coefficients between the following variables: yield, test weight, and N, P, K concentrations in plant samples from jointing stage of growth for the Busch location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	0.68**	-0.08	0.07	-0.08
Test weight		1.00	-0.62**	-0.19	-0.39*
N			1.00	0.48**	0.61 **
P				1.00	0.75**
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.

Appendix Table 27. Simple correlation coefficients between the following variables: yield, test weight, and N, P, K concentrations in plant samples from jointing stage of growth for the Dober location.

	Variables				
	Yield	Test weight	N	P	K
Yield	1.00	0.64**	-0.34**	-0.19	-0.18
Test weight		1.00	-0.74**	-0.48**	-0.60**
N			1.00	0.37*	0.83**
P				1.00	0.49**
K					1.00

**Significant at 0.01 level.
*Significant at 0.05 level.