AN ABSTRACT OF THE THESIS OF

POJANEE LAOPIROJANA for the MASTER OF SCIENCE
(Name) (Degree)

in SOILS presented on December 12, 1969
(Major) (Date)

Title: EFFECTS OF RESIDUAL AND APPLIED NITROGEN ON NUGAINES WHEAT

Abstract approved: Redacted for Privacy
Steve Roberts

A study was made to evaluate the effect of different rates of N fertilization on Nugaines wheat. The variable N treatments provided different N regimes as a basis for evaluating potential diagnostic tests for assessing the N status of the wheat plant. The crop was grown in Lane county during the 1968 growing season on soil of the Malabon series.

To evaluate the treatment effects the yield of grain and dry matter, number of culms per foot of drill-row, leaf percentage, grain protein, test weight, and concentration and uptake of nutrients (N, P, K, Ca and Mg) were measured. The preliminary evaluation of the diagnostic tests for assessing the N status of the wheat plant were conducted by comparing the relative sensitivity of the above parameters to the different rates of applied N. First approximations of the critical levels were estimated from graphs of grain yield

against the various analytical measurements.

The application of N increased grain yield, dry matter production, the concentration of nitrate-N, N, P and K in the plant tops. The application of 200 pounds of N per acre decreased the test weight and increased the protein content of the grain. This same rate of N fertilization produced an increase in the number of culms per foot of drill-row and the plant leaf percentage.

The concentration of nitrate-N, total N, P, K, Ca, and Mg in the plant tops decreased with time irrespective of N treatment as the plants matured. The concentration of nitrate-N in the upper leaves was greater than the concentration of nitrate-N in the lower leaves at the boot stage of growth. The total uptake of these nutrients with time corresponded to increases in yield of dry matter.

A suitable approach for assessing the N status of the wheat plant appeared to be that of measuring the level of total N in the plant tops or the level of nitrate-N in the plant leaves during the latter part of April. At this time the critical level for total N in the plant tops was about 2.8% and the critical level for nitrate-N in the plant leaves was about 300 parts per million. Greater precision was attained in the measurement of total N concentration in plant tops than for the concentration of nitrate-N in the leaves.

The critical-level approach for dry matter production, culms per foot of drill-row, and leaf percentage appeared to have limited value for assessing the N status of the wheat plant.

Effects of Residual and Applied Nitrogen on Nugaines Wheat

by

Pojanee Laopirojana

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1970

APPROVED:

Redacted for Privacy

Assistant Professor of Soils
in charge of major

Redacted for Privacy

Head of Department of Soils

Redacted for Privacy

Dean of Graduate School

Date thesis is presented December 12, 1969

Typed by Donna L. Olson for Pojanee Laopirojana

ACKNOWLEDGEMENT

The author wishes to express sincere gratitude to Dr. Steve Roberts for his encouragement, counsel, and guidance during the investigation and preparation of this thesis, and his concern and enthusiasm for teaching which has inspired me.

Special acknowledgement and thanks are given to Dr. Murray D. Dawson for his suggestions and advice which were helpful in the completion of this thesis.

Sincere appreciation is also expressed to Dr. Max B. Williams for serving on my committee.

The friendship and cooperation of the graduate students, the staff and the faculty of the Department of Soils was greatly appreciated.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table		Page

LIST OF APPENDIX TABLES

Table		Page

EFFECTS OF RESIDUAL AND APPLIED NITROGEN ON NUGAINES WHEAT

INTRODUCTION

On a world-wide basis wheat is regarded as one of the most important agricultural commodities. It is possible to produce wheat under a wide range of climatic conditions, and consequently about eight billion bushels of wheat are harvested annually from nearly 575 million acres of the world's cropland. It is estimated that wheat provides nearly 20% of the total calories for the people of the world (Reitz, 1967) compared to rice which provides an estimated 21% of the total.

For the State of Oregon, agricultural and forest products are major sources of income. The return from the sale of wheat is of major economic importance among the 25 or more agricultural crops which are produced commercially in Oregon. The acreage and production of wheat in the State of Oregon and in the Willamette Valley for years 1960-67 and for 1967-68 are given in Table 1.

Although only about 20% of the wheat which is produced in the State is grown in the Willamette Valley (Table 1) of western Oregon, the average yield per acre in the Valley is higher and the production problems related to soil fertility are perhaps more numerous than for the other areas of the State.

Table 1. Wheat acreage and production in the State of Oregon and in the Willamette Valley area of the State.[a]

Area	Year or Yearly Average	Cropland Harvested Acres	Production Bushels
State of Oregon	1960-67	772,000	26,008,000
	1967-68	1,045,000	32,950,000
Willamette Valley	1960-67	111,450	5,528,000
	1967-68	150,800	6,638,000

[a]Acreage and production figures from Oregon State University, Agricultural Extension Service, 1968.

For wheat production in western Oregon, the recognized problems of soil fertility are those associated with soil acidity and nutrient deficiencies of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S). The expenditure for N represents a significant part of the total cost of fertilizer for wheat production. In view of these facts there appears to be ample justification for conducting research on the fertilization of winter wheat in western Oregon. But in order to bring about a major improvement in the yield of wheat, attention must also be directed toward the development of varieties with high yield potential, improvement in the cultural practices used to produce wheat, and the design of suitable programs to control weeds which compete with the crop for moisture and plant nutrients.

From previous experiments in western Oregon, it is apparent that adequate fertilization may increase the average for the yield of wheat but in order to increase the net-return to the grower, fertilizer must also be used more efficiently. More information is needed on the fertilization of wheat, especially with N, in order to improve the current fertilization practices.

In addition to the N supplied by fertilizer, wheat plants utilize N that is released by soil organic matter which contains a significant amount of N, a small part of which is mineralized during the growing season. But any attempt to relate the availability of residual N with the organic matter or total N contents of the soil has not been successful for most crops, especially wheat. Some of the N added to the soil as chemical fertilizer along with some of the N released from organic matter, may leach out of the soil in a humid climate; some may be fixed, and some may be volatilized to the atmosphere. Consequently soil test values which are based entirely on inorganic soil N have been of limited value. The crop removal of this element thus is greatly influenced by the soil conditions and by the other factors which influence the soil conditions and by other factors which influence the level of available N in the soil.

In general, varied crop rotations, and fertilization practices combined with inherent differences in soil make it difficult to develop a suitable system of soil testing for available N. In some areas a legume is included in the crop rotation to provide for succeeding crops of wheat. This brings about a significant reduction in the amount of N fertilizer required to produce the crop. For this reason, the tissue testing approach has been suggested as an indicator of the adequacy of the N supply for plant growth.

Tissue testing has been used for a variety of plant nutrients besides N. The concentration found within the plant reflects what the plant has obtained from the soil in relation to its growth up to the time of sampling the plant. The N status of the plant can be ascertained by comparing the existing N concentration with the concentration established as just deficient for growth (critical N level). Plants which have a concentration of N below the critical level are considered deficient in N.

At the present time there is insufficient background information for interpreting tissue tests for N on wheat. For example there may be some question concerning the stage of growth and the appropriate plant part to use as the basis of a tissue test for N. The factors affecting the level of N in a given tissue may require further study. The purpose of this experiment was to explore the possible use of plant tissue analysis as a diagnostic technique for predicting the N fertilizer requirements of winter wheat.

The objectives of this study were:

1. To determine the effect of different rates of applied N on the wheat plant in terms of yield, grain quality, plant morphology,

and nutrient uptake.

2. To compare the relative sensitivity of selected measurements to variations in the N fertility level.

3. To obtain some preliminary information on the critical levels in the wheat plant under reasonably defined conditions.

LITERATURE REVIEW

Fertilizer Requirements for Wheat

The importance of nitrogen (N), phosphorus (P) and potassium (K) fertilizers for wheat production have long been recognized. In a report by Snyder (1907) on some experimental work in Minnesota the application of P and K fertilizer was more advantegeous than the application of N alone or the application of a complete fertilizer. Hobbs (1953) working in eastern Kansas found that N fertilization greatly increased the yield of wheat when adequate P fertilizer was also applied. A study was made in Kansas by Williams and Smith (1954) on the effect of N fertilizer, alone and in combination with a complete fertilizer. They concluded that N alone did not increase the yield of wheat significantly, but increases in yield were noted when P was included in the fertilizer treatment. The inclusion of K in the treatment had no significant effect on the yield of wheat. Rankin (1947) reported work in North Carolina where increased yield resulted from N fertilization. Long and Eving (1949) demonstrated by a series of experiments in Tennessee that an average of 3.5 to 4 pounds of N is required to produce each additional bushel of wheat in the yield range where N is the limiting growth factor.

The Climatic Factor and Moisture Supply

Variations in yield of winter wheat as influenced by the environmental conditions have been observed in Kansas by Laude (1938). The seasonal conditions within a particular region ordinarily establish a general pattern of growth, plant development and wheat yield. Staple and Lathane (1954) also investigated the weather conditions which influence wheat yield in Canada. Their results showed that field crops responded similarly to a given set of weather conditions. Evaptranspiration was the most important single factor which influenced the yield of each crop. The two components, seasonal rainfall and stored moisture used, had nearly equal influence on yield.

Hunter (1958) conducted 133 fertilizer experiments with wheat in the Columbia Basin counties of Oregon. The response to N varied from location to location and was dependent upon such factors as soil depth, soil moisture, management practices, and other climatic factors. Lathane and Staple (1959) demonstrated in Saskatchawan, Canada that crops subject to moisture stress at an early stage of growth yielded well on all soils tested but that crops with moisture stress late in the season yield poorly on loam soil. When the soil level of soil moisture was maintained above 30% Fernandez and Laird (1959) concluded that moisture availability was not a limiting factor in grain yield under the condition of their experiment.

Nature of the Response to Fertilizer

Rhode (1964) studied the effect of N fertilization on components of wheat yield and other agronomic characteristics of winter wheat, and concluded that N fertilizer increased grain yield, plant height, and straw yield. McNeal and Davis (1954) observed that yield increases occurred as a result of increasing (a) the number of heads per unit area, (b) the number of kernels per head, or (c) the kernel weight. Wahhab and Hussain (1959) indicated on the experiments conducted in Pakistan that N fertilization at seeding increased the number of tiller per plant, number of kernels per head, and the yield of grain per acre. In this same study the application of N brought about an increase in the concentration of N in the plant tissue, a decrease in P concentration and a decrease in the concentration of K.

Wheat Quality

From the standpoint of nutritive value, protein is an important constituent of food and feed crops. In wheat, the quantity and quality of protein are major factors in determination of the quality of wheat flour and its suitability for making various bakery products. The protein content of wheat is greatly influenced by environmental factors particularly by available N.

Davidson and LeClerc (1917-18) concluded from their experiments in Kentucky and Nebraska that the protein content of wheat depends first upon the supply of available N for the plant and second upon the movement of nitrogeneous material into the grain. Russel, Smith and Pittman (1958) noted that yield and protein content of spring wheat grown on stubble fields in southern Alberta, Canada were affected by N fertilizer.

Baker (1950) and Blackett (1957) found that protein content was not increased by increasing N fertilizer rates, even though grain and straw yields were increased significantly. Peterson (1952) showed consistently that the application of N increased the yield and protein content in winter wheat grown in Utah. He also suggested that failure to obtain an increase in protein is likely attributed to the utilization of added N in the production of more grain and straw, thus leaving an insufficient amount to increase the protein content or the grain.

An increase in available soil N has generally been found associated with both an increase in protein content of wheat grain and yield of wheat unless other factors are limiting. In Tennessee the application of N at or near flowering has a greater tendency to increase the percentage of protein in the grain in contrast to earlier applications which may tend to stimulate dry matter production and grain yield (Long and Sherbakoff, 1951).

Bayfield (1936) found in his Ohio experiments that climate exerted the largest influence upon wheat quality. Heavy precipitation before heading period decreased protein content. He also found increases in percentage of wheat protein was associated with heavy soil and dark soil. Dubetz (1961) found that the protein content of spring wheat was not only limited by available N and moisture content, but it was also associated with soil type. He indicated that significant increases in grain yield and decreases in percentages of protein were obtained by increasing soil moisture content on a loam soil but not loamy sand.

Accumulation of Nitrogen by the Wheat Plant

In the plant, nitrogen's primary role is in N metabolism. It is a constituent of amino acids which form the essential units for protein synthesis. The wheat plant accumulates N very rapidly during the early stages of growth. As the plant matures and grain is produced, a large part of the N is translocated to the grain where, at harvest it is present in the form of protein.

Ames (1910) indicated on his experiment in Ohio that without exception application of N fertilizer increase the N content of the grain. The amounts of N, P and K in wheat plants were increased by addition of these elements. Knoweles and Watkins (1931) studied the wheat plant with respect to absorption of nutrients from the soil and the translocation of nutrients within the plant at selected stages of growth. They made no attempt to relate the chemical composition of the plant at the early growth stages and the final crop yield. They concluded that the percentages of nutrients in wheat plant tops decreased from the first sampling until maturity was reached.

Donean (1934) studied the N in relation to the composition, growth and yield of wheat in Washington and found that when limited quantities of available N were present in the soil, the addition of N fertilizer stimulated plant growth and caused an increase in yield and N content of the grain. The dry matter production and total N accumulation reached a maximum at the blooming stage of the wheat plant. A decrease in the amount of dry weight and N in the aerial part of the plant took place between the blooming stage and maturity. Olson (1923) concluded from his experiments that the percentage of N in the plant decreased with the progressive growth of plant. Further, the dominant direction of N movement was from the lowest to uppermost part of the plant, and N areas evidently translocated to the grain at very early stages of kernel formation. Rankin (1947) also investigated that the amount of N taken up by wheat is influenced by stage of growth of the wheat plants when N is supplied. Plants accumulate N rapidly in the first month after application and there was an increase in N uptake which corresponded to the period of greatest increase in dry weight. In Nevada, Haas and Miles (1952) indicated that N uptake by plants on low-nitrogen soil fell off rapidly after the plants reached the heading stage, but plants growing on high-nitrogen continued to accumulate N.

It is generally accepted that increased rates of N fertilization increase the nitrate-N content of most plants. But according to Gilbert et al. (1946) the concentration of nitrate-N in the plant is influenced by other factors besides the nitrate-N or total N present in the soil. Moeller and Therman (1966) studied the nitrate-N content of rye, wheat, and oat forages. They observed that the first cuttings contained the highest amount of nitrate-N and the later cuttings and regrowth cuttings were lower in nitrate-N.

Hanway and Englehorn (1958) investigated the nitrate-N accumulation in some Iowa crops and concluded that usually nitrate-N concentration was higher in lower portions of the stalk than in the upper portions, in the leaves or in the grain. The concentration of nitrate-N in all plant parts decreased as the plant matured. They also found that high nitrate-N contents in plants most likely occurred under drouth conditions, but high nitrate-N would accumulate in plants with adequate moisture, if the level of soil fertility was high. Crawford et al. (1961) also discussed on the experiment conducted in New York that the concentration of nitrate-N in stems of oat plants in field tests was higher than either leaves or the heads. The level of N fertilization, the species of plants, the part of the plant, the stage of maturity, and light intensity all affected greatly the concentration of nitrate-N in the plants. They also concluded that the time of N fertilization, the kind of N carriers, the placement of N fertilizer, and the addition of other plant materials had only small effects on the concentration of nitrate-N in plants.

Whitson, Wells and Vivian (1903) believed that under the same seasonal condition, the most important factor in causing variation in the composition of crop was the amounts of nitrate-N in the soil. But the work of Shaw and Walters (1911) and also that of LeClure and Yoder (1914) further showed that the soil is a minor factor in accounting for the variation in N content of wheat within the limit of these experiments was climate. Baldwin and Ketcheson (1958) concluded on the experiment conducted in Canada that N uptake of plants was dependent on both the texture and the reaction of the soil. Large penetrable aggregates brought about coarse rooting which resulted in diminished uptake of phosphate which was relatively immobile. The uptake of nitrate-N was largely unaffected as a result of its greater mobility (Wiersum, 1962).

Accumulation of Other Nutrients by the Wheat Plant

Various workers have shown that there is a reciprocal relationship between the amounts of N and P absorbed by plants as indicated by the percentages of these elements occurring within the plant. The effect of N on availability of P to plant may be divided into biological effects and chemical effects. Since both N and P are elements essential for plant growth, it would be expected that a deficiency of either element would limit growth of the above and below-ground portions of the plants. Woodford and McCalla (1936) suggested that the proportionately greater absorption of soil P by wheat may compensate for the low availability and uptake of N and S.

Smith, Kapp and Potts (1950) indicated that N fertilization increased the percentage of N but on the other hand significantly decreased both the percentages of P and K in the forage. Warder, Lathane, Hinman and Staple (1964) summarized their work on the effect of N and P fertilization on the yield and nutrient uptake of wheat in Canada. The use of N and P fertilizer increased the yield of wheat on both loam and clay soil which were deficient in P according to the soil test. The N and P fertilizing had no affect on the concentration of P in the grain, but fertilization did increase the total P uptake by the crop.

Grunes (1959) concluded from his study that the addition of N fertilizer has a marked effect on absorption of soil and fertilizer P by plants. The ammonium form of N appeared to increase absorption of P to a greater extent than did the nitrate-N form. Renie and Soper (1958), Arnon (1939) and Breon (1944) also believed that ammonium-N materially influenced plant absorption fertilizer P in the field study. Furthermore Miller and Ohlrogge (1958) pointed out that the band placement of N along with P greatly increased P uptake by corn. A variety of other factors may influence the effect of N on P uptake. For example, soil reaction (Yuen and Pollard, 1957), nature of complementary ion (Lehr and Vern Wesemael, 1956) and temperature (Willis et al., 1957 and Doormar et al., 1960) have all shown to modified the N effected on P uptake.

The growth rates and chemical composition of plants grown under greenhouse conditions with high fertilization rates have been studied by de Wit et al. (1963). They proposed that one of the factors regulating growth rate is the organic anion concentration which in turn is regulated by the inorganic cation and inorganic anion balance or ratio. They estimated the organic anion concentration by the difference in concentration between the inorganic cations and inorganic anions. Dijksnoorn (1958) and Noggle (1966) found that the K fertilizer had no effect on the total cation concentration, but did effect the relative proportion of the individual cations. They also reported that increasing N fertilization caused a decrease in the anionic concentrations of Cl, P and S in the plant and an increase in N. The net effect was an increase in the total anion concentration (Cl, P, and S) which in turn relatively greater than the increase in cations (K, Na, Mg and Ca). Therefore an increasing N level brought about certain decreases in the cation-anion ratio.

Tromp (1962) studied the mutual interaction in absorption of NH_4, K and Na in wheat plants and found that the K absorption is strongly inhibited by NH_4, while conversely K has little, if any, effect on the rate of NH_4 absorption. In spite of the fact that it has a distinct effect on the absolute magnitude of the K absorption rate, the nature of the relation between the K uptake rate and the K concentration is not influenced by ammonium-N.

MATERIALS AND METHODS

Experimental Location and Characterization of Soil

A soil fertility experiment with winter wheat was established at a site 0.5 mile south of the Eugene airport in Lane County of western Oregon. The data for chemical characterization of the soil at this experimental site (Table 2) were obtained by the routine analytical methods used by the Oregon State University Soil Testing Laboratory. A descriptive resume was provided by Parsons and Herriman for the soil at the experiment site, which was designated as the Malabon series (Appendix A).

Table 2. Summary of soil chemical analyses before fertilization.

Soil Series (Farm)	pH	N %	P ppm	K meq/100g	Ca meq/100g	Mg meq/100g
Malabon (Drake)	5.6 ± .14	0.144 ± .014	25.5 ± 3.87	1.56 ± .17	13.5	5.6

The Drake Farm on which the experiment was conducted has undulating topography, and the experiment was situated on a slightly convex surface. Based on the results obtained from chemical analysis, this soil is regarded as being slightly acid and high in "plant available" P. This soil is moderately fertile, well drained, and suitable for growing a variety of crops.

Experimental Design and Treatments

A randomized block design with three replications of six treatments was used for this field experiment; individual plots were five feet by 30 feet. Within each replication, each of the six different treatments was applied to paired plots. One plot of each pair served as the source of plant tissue for analytical purposes and the second plot was harvested for determining the yield of grain. The six treatment variables which consisted of five rates of N and an untreated control are shown in Table 3. The Nugaines variety of winter wheat which was seeded at a rate of 90 pounds of seed per acre was used as the indicator crop to evaluate the various fertility treatments.

Table 3. Key to the fertility treatments.

Treatment No.	Fall N Application lbs./A	Spring N Application lbs./A
1	F_0	S_0
2	F_{20}	S_{50}
3	F_{45}	S_{50}
4	F_{20}	S_{75}
5	F_{20}	S_{125}
6	F_{20}	S_{200}

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

Field Plot Technique

A chronological record of the field operations is presented in Table 4. The fallow field was disced and harrowed in preparation for seeding. The Nugaines wheat was seeded with a five-foot grain drill with seven-inch row spacing and it was equipped with a belt-type fertilizer applicator. With the belt-type applicator it was possible to place precise amounts of fertilizer in the drill-row along with the seed. The fertility treatment and chronological record of fertilizer application are shown in Tables 3 and 4, respectively.

Table 4. Chronological record of the field operations.

Source		Dates
Seeding		10-18-67
Karmex Spray applied		10-31-67
Soil sampling (Fall)		10-18-67
Fertilization (Fall)		10-18-67
Fertilization (Spring)		3-11-68
Soil & Plant sampling (Spring)	1	3-28-68
	2	4- 8-68
	3	4-19-68
	4	5- 1-68
	5	5-22-68
	6	7- 5-68
Harvest of grain		8- 7-68

The 20 pound rate of fall-applied N, P, K, and S were banded in the drill-rows with the seed at the time of seeding. A uniform application of 26 pounds of P per acre and 50 pounds of K per acre were applied to all plots in the form of concentrated superphosphate (52% P_2O_5 - 22.7% P) and muriate of potash (60% K_2O - 50% K). The 20 pound rate of N and 23 pound rate of S per acre were supplied by ammonium sulfate. This base application was supplemented by a broadcast application of ammonium nitrate to give 45 pounds per acre of fall-applied N. Gypsum was used as the source of S on plots that did not receive the fall application of N. Ammonium nitrate was applied in the spring in a broadcast application by hand to complete the N treatments.

A "Karmex" (3, 3-4 dichlorophenyl 1 methoxy 1 methylurea) spray treatment was applied at the rate of 1.9 pounds of active material per acre for grass control. A self propelled sprayer with a ten-foot boom was used for the Karmex application.

A self-propelled International Harvester combine with a 42-inch header was used to harvest the plots. For grain yield determination, an area 42 inches by 25 feet was harvested from the center of each plot. At the time of harvesting a 30 inch border was clipped at both ends of each plot and discarded in order to eliminate any border effect between plots. The grain harvested from each plot was weighed at the site. A subsample of grain was taken from each plot for protein and test weight determinations. The yield of grain was calculated and reported in pounds per acre. Test weight and grain protein were reported in pounds per bushel and percentage by weight, respectively.

Soil and Plant Sampling

Before seeding and fertilizing the plots, two sets of soil samples were collected from each of the three replications of the experiment. One set of soil samples was collected from the plow-layer and a second set of soil profile samples was collected by one-foot increments to a depth of four feet. In the spring, a similar set of soil samples was collected from soil profile of each plot in one replication, each time plant samples were collected (Table 4). The soil samples were brought to the laboratory for processing. Sub-samples were taken in order to determine the moisture content gravimetrically from the soil samples which were collected in the spring except for the third sampling (4-19-68) when moisture content was not determined. The rest of each soil sample was spread thinly for rapid drying at room temperature. When air dry, each sample was ground to pass a 14 mesh sieve to prepare them for analysis.

To characterize the original fertility status of the soil before fertilization, chemical analyses were then carried out on the soil samples which were collected in the fall. The average analytical value and indicated standard deviation for the samples from each of the three replications at this location were reported in Table 2. Samples collected in the spring were analyzed for nitrate-N and ammonium-N only (Appendix Tables 1 and 2).

Samples of wheat plant tissue were collected from all plots at six times during the growing season. On each of the six dates indicated samples of total tops of the wheat plants were clipped one inch above the ground from an area 24 inches x 21 inches (three drill rows). The samples of total plant tops were used to determine dry matter yield and the number of culm per foot of row. On the first five sampling dates, a second set of total top samples consisting of 30 to 40 plants were collected from 15 to 20 random locations within each plot. The separation of leaves and stems for these samples served as the basis for determining the leaf percentage. For the 5th sampling (5-22-68) the "flag" leaf plus one additional leaf (upper) were separated from the lower leaves. All the samples were then dried in a forced draft oven at 70°C. The oven dry weight of samples was determined, the yield of dry matter was reported in pounds per acre, and the percentage of leaves was calculated. All plant samples were ground in the dry state by means of an osterizer blender and then finely ground in a Wily mill to prepare them for analysis.

Soil Analysis

Soil samples were analyzed at the Soil Testing Laboratory of Oregon State University. The methods of analysis are listed in Table 5. Soil reaction was reported in pH units; soil moisture and total nitrogen (N) are reported as a percentage. Ammonium-N (NH_4-N), nitrate-N (NO_3-N) and "available" phosphorus (P) are reported in parts per million; calcium (Ca), magnesium (Mg), and potassium (K) are reported in milliequivalents per 100 g of soil.

Analysis of Plant Tissue and Grain

The methods of analysis used for the plant tissue are summarized in Table 6. The total above-ground plants were wet ashed with perchloric acid (Jackson, 1958) for determining P, K, Ca and Mg. The nitrate-N and total N in plant tissue were determined by the Kjeldahl method (Bremner, 1965-1966). The grain protein was determined at the Pendleton Branch Experiment Station by means of the protein analyzer as indicated in Table 6. Grain protein and all of the nutrients were reported as a percentage in the plant tissue except nitrate-N (NO_3-N) which was reported in parts per million. The total uptake of N, P and K were calculated as the product of the concentration present and the dry matter yield.

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

Test or Determination	Reference	Notes on the Method
Extractable P	Olson *et al.*, 1954	On 1:10 soil extract ratio using 0.5 N sodium-bicarbonate, adjusted to pH 8.5, extractable P was determined by the molybdenum blue colorimetric procedure using Bauch and Lomb "Spectronic 20" and spectrophotometer.
Extractable bases (Ca, Mg, K)	Schollenberger and Simon, 1945	On a single extraction 1:20 soil to extractant ratio) using 1 N ammonium acetate, adjusted to pH 7.0; K was determined by means of flame emission spectrophtometer; Ca and Mg were determined by atomic absorption.
Moisture content	Gardner, 1965	Gravimetric determination of water loss on oven drying at 105°C.
Nitrogen	Bremner, 1965 (modifed method)	Kjeldahl method
Ammonium nitrogen	Bremner, 1965	Steam distillation of ammonium and nitrate extracted with 2 N potassium chloride using 1:10 ratios of soil extractant.
Nitrate nitrogen	Bremner, 1966 (modified method)	
pH	Jackson, 1958	Determinations with glass electrode pH meter on a 1:2 soil water suspension.

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

Test or Determination	Reference	Notes on the Method
Ca, Mg, K	Brown et al., 1948	Analysis of the perchloric acid digest for K by flame emission and for Ca and Mg by atomic absorption.
Grain protein	Udy, 1956	Determine with Udy Model E Protein analyzer.
N	Johnson and Ulrich, 1959	Micro Kjehdahl procedure which included nitrate-N.
Nitrate-N	Bremner, 1965. Bremner, 1966. (modified method)	Analyze 20 ml of the filtrate from plant tissue by the identical procedure used for soil extracts (0.2 g of ground plant tissue with 50 ml of 2 N potassium chloride.)
P	Jackson, 1958	Molybdate-Vanadate colorimetric method was used to determine P in perchloric acid digest. The color intensity was measured on a Bauch and Lomb "spectronic 20" spectrophotometer.

Statistical Analysis

The statistical analysis of variance of the data was obtained on the 3300 computer at the computer center of Oregon State University with some additional calculations on a desk calculator. Selection was subjected to analyze by correlation and regression. The data is presented graphically or in tabular form.

RESULTS AND DISCUSSION

Climatic Conditions

For the 1968 growing season, the climatological records for the Willamette Valley indicate only minor deviations from the normal weather pattern (Table 7). Since the recorded yields of wheat followed the anticipated trend with the different ratio of applied N, it is doubtful that the climate factor had any unusual effect on the growth of the crop. For February, 1968, the mean monthly temperature and the total precipitation were above normal, but for March and April the precipitation was below normal. If one considers the climatological data for the period from January through July which includes the most important part of the 1968 growing season, the deviations from the normal appear largely insignificant. The excessive amount of precipitation in August, occurred after the wheat plants reached maturity. Consequently the unusual weather pattern in August had little effect on the crop, but it did interfere with harvesting operations.

Appendix Table 1 shows the marked decrease in the percentage of soil moisture in the profile to a depth of four feet as the growing season progressed. There was also a consistent decrease in moisture content from the surface to a depth of four feet at different periods of plant growth when soil samples were collected. Nitrate-N was also determined on the soil samples which were collected during the growing season.

Table 7. Climatological data for the Willamette Valley.[a]

		Jan.	Feb.	March	April	May	June	July	Aug.
Temperature	Normals	38.3	41.5	45.1	50.5	55.9	60.3	65.5	65.1
(°F)	1968	39.6	47.7	47.9	47.7	54.6	60.4	66.3	64.1
	Deviation	+1.3	+6.2	+2.8	-2.8	-1.3	+0.1	+0.8	-1.0
Precipitation	Normals	7.71	6.17	5.88	3.28	2.78	2.15	0.50	0.72
	1968	6.97	8.14	4.36	2.36	3.89	2.15	0.38	5.19
	Deviation	-0.74	+1.97	-1.52	-0.93	+1.11	0.00	-0.12	+4.47

[a]Climatological data figures from Environmental Science Services Administration, U. S. Department of Commerce.

From the limited number of soil samples collected, it was not possible to study the relationship between N treatment and soil moisture or residual soil nitrate-N. Some previous irrigation studies indicated that the yield of wheat produced on the soil of Chehelis series was not limited by the supply of available moisture (Rossner, 1968). The depth of rooting for most plants is unrestricted on the soil of either the Chehelis series at the site of Rossner's experiment or the Malabon series where the present experiment was conducted.

Yield of Grain and Dry Matter

The growth response of the wheat plant was studied in the field under different rates of N fertilization. The N treatments provided conditions where there was a possibility for N deficiency, for normal

N supply and for luxury consumption of N.

The N treatments used in the experiment and the corresponding values for the mean yield of grain are summarized in Table 8.

Table 8. The effect of N fertilization on grain yield of Nugaines wheat at the Drake Farm, 1968.

Spring Applied N lbs./A	Average Grain Yield lbs./A	Percent Yield Increase
0	3660	100
50	4710	129
50[a]	4920	134
75	5340	146
125	6190	169
200	5590	153
LSD .05	669	---

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

The maximum grain yields were achieved at 125 pound of N per acre applied in the spring. The yield of grain decreased when 200 pounds of N per acre was applied in the spring. Statistical treatment of the data on yield of grain by an analysis of variance (Appendix Table 9) showed that N significantly (0.01 probability) increased the yield on the order of 29 to 69% above the untreated control.

The average dry matter yield which was recorded for each of the sampling data indicated is reported in Figure 1 and in Appendix Table 3. At the early stages of growth, soon after the spring N application, the differences in dry matter yield as affected by N

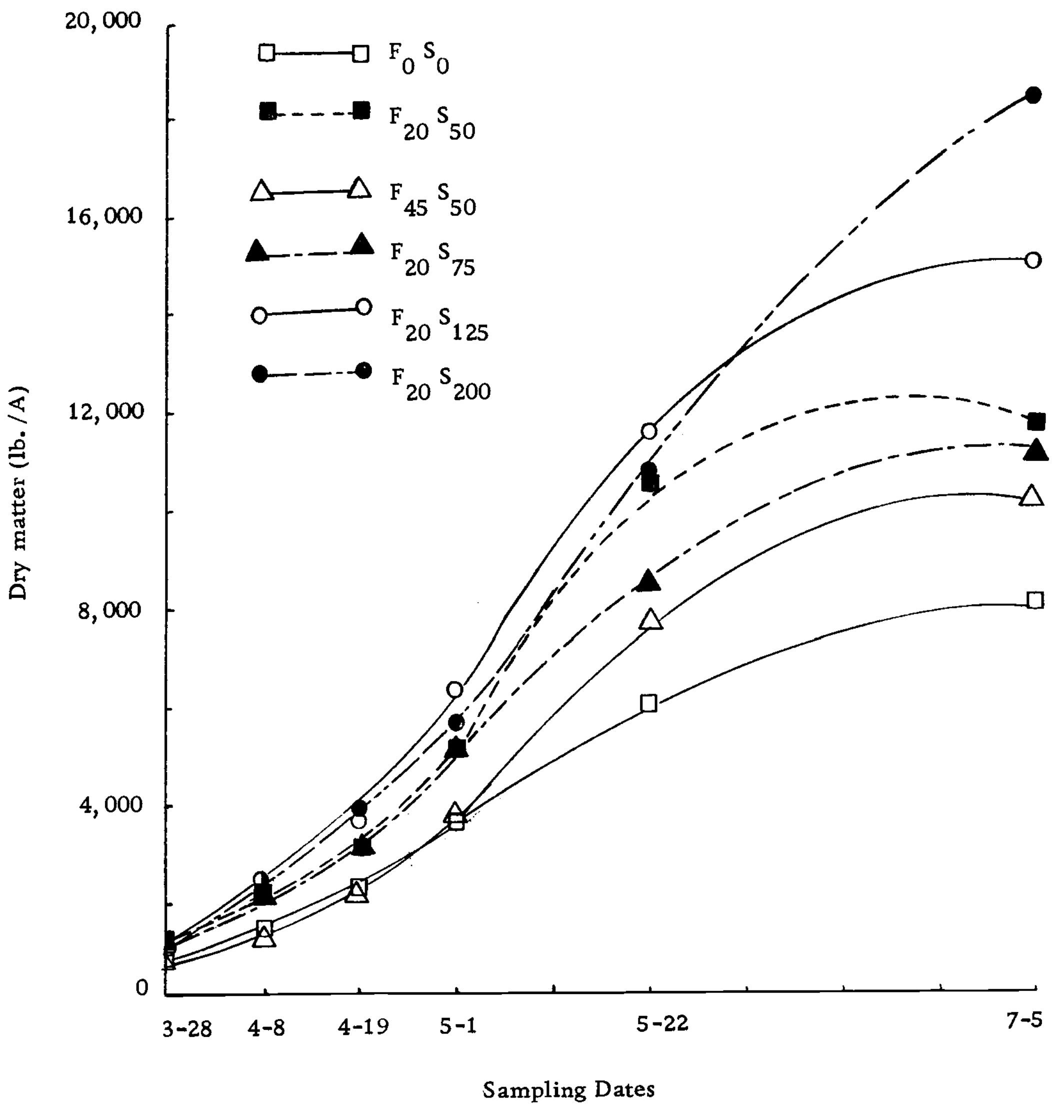


Figure 1. Dry matter of wheat at different time of sampling.

levels were hardly discernable. But one month after fertilization the dry matter yield from plots which received the N treatments was 40 to 59% greater than the untreated control plot (0.01 level). The treatments do not show the effect from the N fertilization after the second period of sampling but toward the fourth sampling (5-1-68) definite trends began to emerge and large treatment effects were observed at the "boot" stage (5-22-68). The maximum amount of dry matter occurred at the soft dough stage (7-5-68) which showed dry matter yield increased significantly (0.01 level) at all N levels 25 to 124% over the untreated control (Appendix Table 10).

In the Willamette Valley, soil tests for P and K have been used extensively as a basis for fertilizer recommendations on winter wheat. Since there are no recognized soil tests for N and S, certain minimum applications of these nutrients are recommended each time a crop of wheat is grown. Although soil tests for P and K indicated that the supply of P and K was adequate, a uniform application of P, K and S was applied to all plots. Where wheat is grown on non-irrigated fields and there is no significant carry-over of N fertilizer from the previous crop the usual recommendation calls for the application of 20 pounds of N per acre in the fall followed by an application ranging from 100 to 150 pounds of N per acre in late February or before mid March. These recommended rates of N fertilization in combination with N release from organic matter are considered adequate to produce wheat yields of 100 bushels per acre or more in the absence of other yield limiting factors (Fertilizer recommendation sheet 9, Oregon State University Agricultural Extension Service).

When wheat is grown in a rotation following a legume crop of course the recommendation is scaled down considerably. The data from this experiment appear to support the N fertilizer recommendation for the winter wheat in the Willamette Valley. The application of 125 pounds in the spring produced a yield of 6190 pounds (103 bushels) per acre which was the highest yield produced by any of the N treatments. The plot to which 200 pounds of N per acre was applied gave the highest yield of dry matter (18,250 pounds per acre) but caused a depression in grain yield. One explanation for the highest production of dry matter and yet a depression in yield was proposed by Hutcheon and Paul (1966). They suggested the application of an excessive amount of N may stimulate the vegetative growth and reduce the available water supply for filling the grain in the heads. The high level of N had more influence on straw production than on yield of grain.

The three plots which received the lowest applications of N including both plots with 50 pounds of N per acre and 75 pounds of N per acre gave significant increases in yield of grain and dry matter over the unfertilized plot. The dry matter yield of 45 pounds of N per acre in fall and 50 pounds of N in spring produced less dry matter than the wheat which received either 50 pounds of N per acre in spring or 75 pounds of N per acre in spring because the heavy N application in fall decreased the number of tillering resulting in low dry matter yield (Rankin, 1947).

Morphology of the Wheat Plant

It was of interest to study the morphological changes which commonly occur in the wheat plant as a result of N fertilization. The number of culms per foot of drill-row and the weight percentage of leaf were examined since other workers indicated that these characteristics were influenced by N fertilization. It was assumed that perhaps a unique set of morphological properties exist which was indicative of an optimum supply of N for growing the crop. The number of normal sized culms per foot of drill row are reported in Table 9 and the percentage of leaf material on the total plant tops is presented in Table 10 for several different sampling dates.

The data indicate a decrease in culm numbers as the growing season progressed. But actually the decrease in number of culm probably originates from the fact that as the plants increase in height many of the unusually small culms are excluded from the recorded count. In a practical sense from the standpoint of grain yield only the culms which mature and produce normal heads are of interest.

Table 9. The effect of N fertilization on the number of culms per foot of drill-row at different times of plant sampling.

Spring Applied N lbs./A	Number of culm per foot of drill-row at different dates of sampling				
	3-28-68	4-8-68	4-19-68	5-1-68	5-22-68
0	41	70	55	44	33
50	67	68	60	53	46
50[a]	57	47	51	39	36
75	45	72	60	53	42
125	56	71	63	67	62
200	57	73	76	64	57
LSD .05	-	-	-	13	12

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

Table 10. The effect of N fertilization on leaf percentage of wheat plants at different times of plant sampling.

Spring Applied N lbs./A	Average % leaf (by wt) at different dates of sampling				
	3-28-68	4-8-68	4-19-68	5-1-68	5-22-68
0	58.22	55.63	48.53	35.40	20.15
50	63.21	51.84	47.87	35.32	18.99
50[a]	64.64	54.04	56.58	34.01	18.31
75	62.82	55.26	45.97	37.25	18.62
125	61.28	54.82	55.98	39.53	22.23
200	61.82	57.80	53.09	42.12	25.71
LSD .05	-	-	6.72	4.09	2.04

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

The data show that culm development for the early spring growth was affected very little by the rate of N fertilization. For the culm counts which were taken on 5-1-68 and 5-2268 the pattern of the N response begins to emerge. The statistical analysis of variance for the culm counts which were taken on these two dates are presented in Appendix Table 11.

The application of N produced a trend toward increase in the number of culms per foot of row which were significant at 1% level probability. The two highest rates of N used in the experiment, 125 and 200 pounds of N per acre produced a significantly greater number of culms than the control or any other low N-applied treatments particularly on 5-22-68. But there was no significant difference between the culm counts for the two highest rates of N (LSD 0.05 level). Rankin (1946) and Hobb (1953) found that when N was applied in the spring, increase in yield resulted from increase in tillering and increase in the number of kernels per head. Apparently for any given planting pattern there is an upper limit beyond which tillering may not be increased by the application of additional amounts of N fertilization.

The obvious trend for the percentage of leaf is that as the wheat grows toward maturity, leaf percentages by weight decrease as a result of the translocation of nutrients to the stem and eventually to the grain. The first detectable effect of N fertilization on the percentage of leafy material on the plant was observed at the early stage of growth just two weeks after spring application of N (3-28-68). Also at this stage the N fertilizer appeared to stimulate the vegetative growth but the differences were not statistically significant.

The statistical analysis of variance (Appendix Table 12) showed that on 4-19-68 and 5-1-68 there were significant differences (0.05 level) in leaf percentage which were related to the N treatments. And these differences were also highly significant (0.01 level) at a later date of sampling (5-22-68 or "boot" stage). The highest rate of applied N (200 pounds of N per acre) for the last date on which leaf measurements were taken, produced the highest percentage of leaves. As mentioned earlier, this treatment also resulted in the highest dry matter yield (Figure 1), but the yield of grain was lower than for the treatment consisting of 125 pounds of N per acre. Wheat plants from the control plot or from three plots which received N at the rates of 50, 50 (split application) or 75 pounds of N per acre showed some similarity with respect to percentage leaf. But the plants subjected to the aforementioned treatments had a significantly lower (0.05 level) percentage of leaf than plants which were fertilized with the two highest rates of N. The pattern of grain yield followed nearly the same trend with N rates as did the changes in leaf percentage.

Wheat Quality

The term "quality" as used for wheat refers to suitability of the processed grain for specified uses (such as bread, cookies, pastries, macaroni) rather than to the quality of seed for seeding purposes. Two important measures of quality considered in this study were test weight and grain protein content, the weight of the grain contained in a Winchester bushel which has a volume of 2150.42 cubic inches is known as "test weight". Some investigators (cited by Shenk, 1968) concluded that the "bushel weight" or "test weight" was not a precise measure of the flour yielding potential of wheat but instead was only a very general indicator for this quality. Quantity and quality of protein and its usefulness have probably received more attention than any other aspect of the wheat kernel. Usually protein content in wheat grain range from 9% to 16% but usually about 11 to 13%. In Canada, for example, wheat of all grades is sold on an f.a.g. (fair average quality) protein basis. It is desirable to produce flours with different percentages of protein content depending upon the particular purposes for which the flour is to be used.

The rate of N fertilization has a marked effect on both protein content and the test weight as indicated by Figure 2 and Appendix Table 4. Statistical analysis of both tests are contained in Appendix

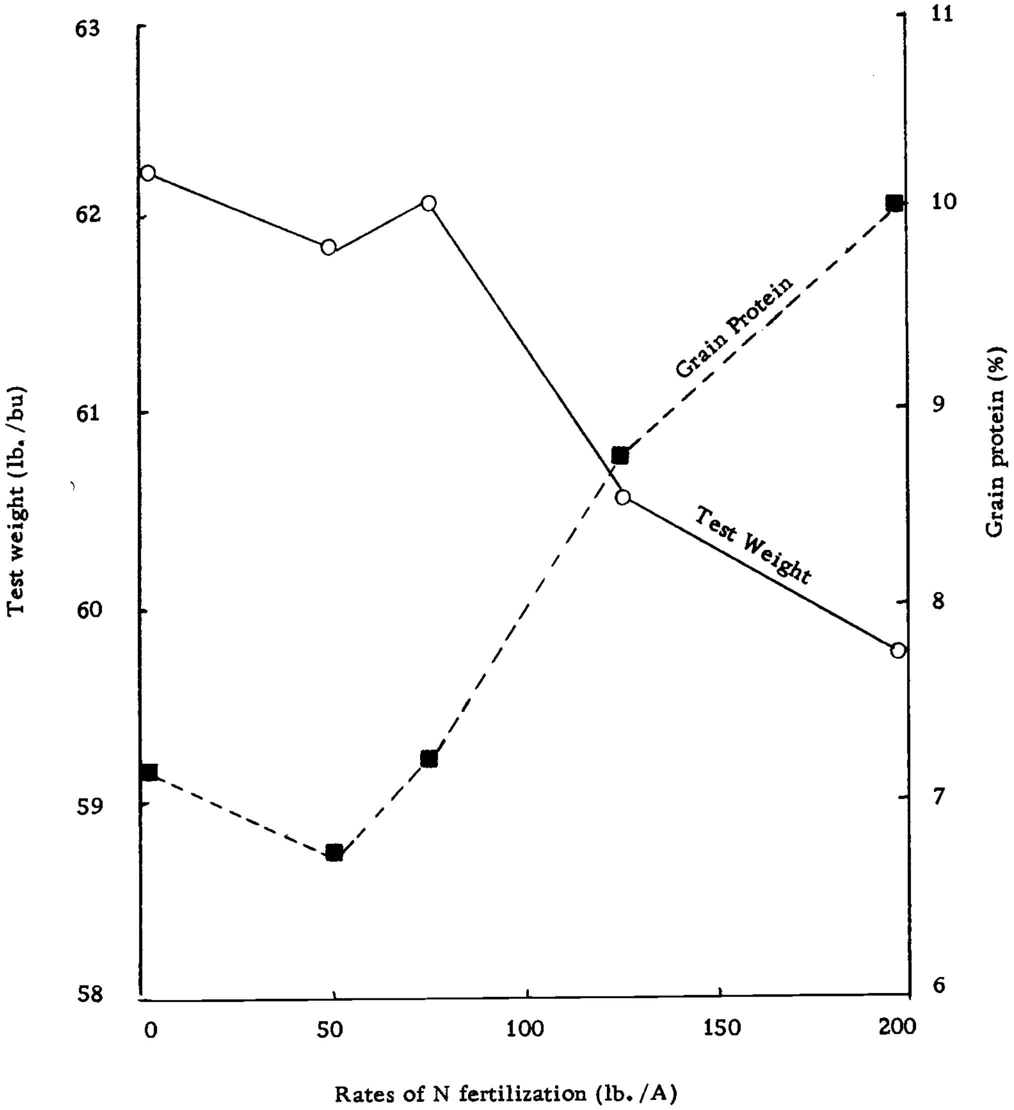


Figure 2. Relationship between N application, average test weight, and average grain protein.

Table 9. The analysis of variance showed that the highest rate of N increased the protein content significantly at 1% level probability. But statistically (LSD 0.05) the level of protein in the grain from the untreated control plot was equivalent to the grain protein associated with the low rate of N fertilization.

Many research workers in other parts of the United States and other countries have reported increases in protein content of wheat as a result of N fertilizer. In general, the research reports from other areas indicate that typically N fertilization increases the grain protein of wheat which is similar to the response pattern for the Pacific Northwest (Koehler, 1961). But some reports indicate the low rates of N application may actually result in small decreases in protein content as was true for this study when only 50 pounds of N per acre was applied. These typical responses almost always occur where there are relatively large increases in yield, and are most likely the result of a dilution effect (Koehler, 1961).

High rates of N fertilization produce a marked shift in the relationship between yield of grain and protein content. For example, an increase in N fertilization from 125 to 200 pounds per acre decrease the yield but produced the highest protein content. These results support the finding of Hunter _et al_. (1961) and Fernandex and Laird (1959) who reported there were rather marked increases in protein content associated with higher N fertilizer rates where yields were not correspondingly increased.

The statistical analysis of variance for test weight (Appendix Table 9) showed that test weight was not affected by low rate of N applications (up to 75 pounds of N per acre) but was significantly reduced with high rates of fertilization (125 and 200 pounds per acre). The test weight decrease may be because in general, early N-application under the circumstances prevailing in the experiment, probably cause an increase in the number of kernels per head. Such a condition precludes adequate nutrition for the kernels. That is necessary for better development over untreated plots. However, even if the average weight of kernels is decreased kernels would probably have stimulated to increase their weight by utilizing the early application of N.

Bayfield (1936) has presented data which show wheat strength and quality are influenced most by climate and secondary factors are soil and variety. He concluded that the supply of nutrients available to the plant is probably the most important soil factor regulating the amount of protein. In Canada, Hopkins (1935) reported that an increased amount of precipitation during the period of growth especially in May-June lowered the protein content, while high temperatures in July or August, on the other hand, did not raise the protein content significantly. Considering this experiment the precipitation is increased during the month of May (Table 7) but may be had only little effect on the protein content. Protein content of the grain could be controlled by N supply and moisture stress in growth chamber experiments. In the range of 11 to 16% protein content could be increased concurrently with yield but protein content above 16% was realized only where a growth factor such as moisture was below optimum for maximum yield (Hutcheon and Paul, 1966).

In summary, increasing the rate of N fertilization beyond optimum level resulted in lower yield and test weight. Therefore it is essential to apply the appropriate amount of N fertilizer to wheat in order to produce maximum yield and top quality.

Nitrogen in the Wheat Plant

Small amounts of nitrate-N are found in most growing plants and under favorable growing conditions nitrate-N is rapidly converted to amino acids and proteins. Under certain environmental conditions nitrate-N may accumulate in plants. It was confirmed by Crawford (1961) and is generally accepted that increasing the level of N fertilization also increases the concentration of nitrate-N in plant tissue. It was also pointed out by Crawford (1961) that the concentration of nitrate in most plants decreases as the plant approaches maturity. The concentration of nitrate-N in the leaf, stem, and total plant tops (above-ground) of the wheat plant is shown in Figures 3, 4 and 5 and in Appendix Table 5.

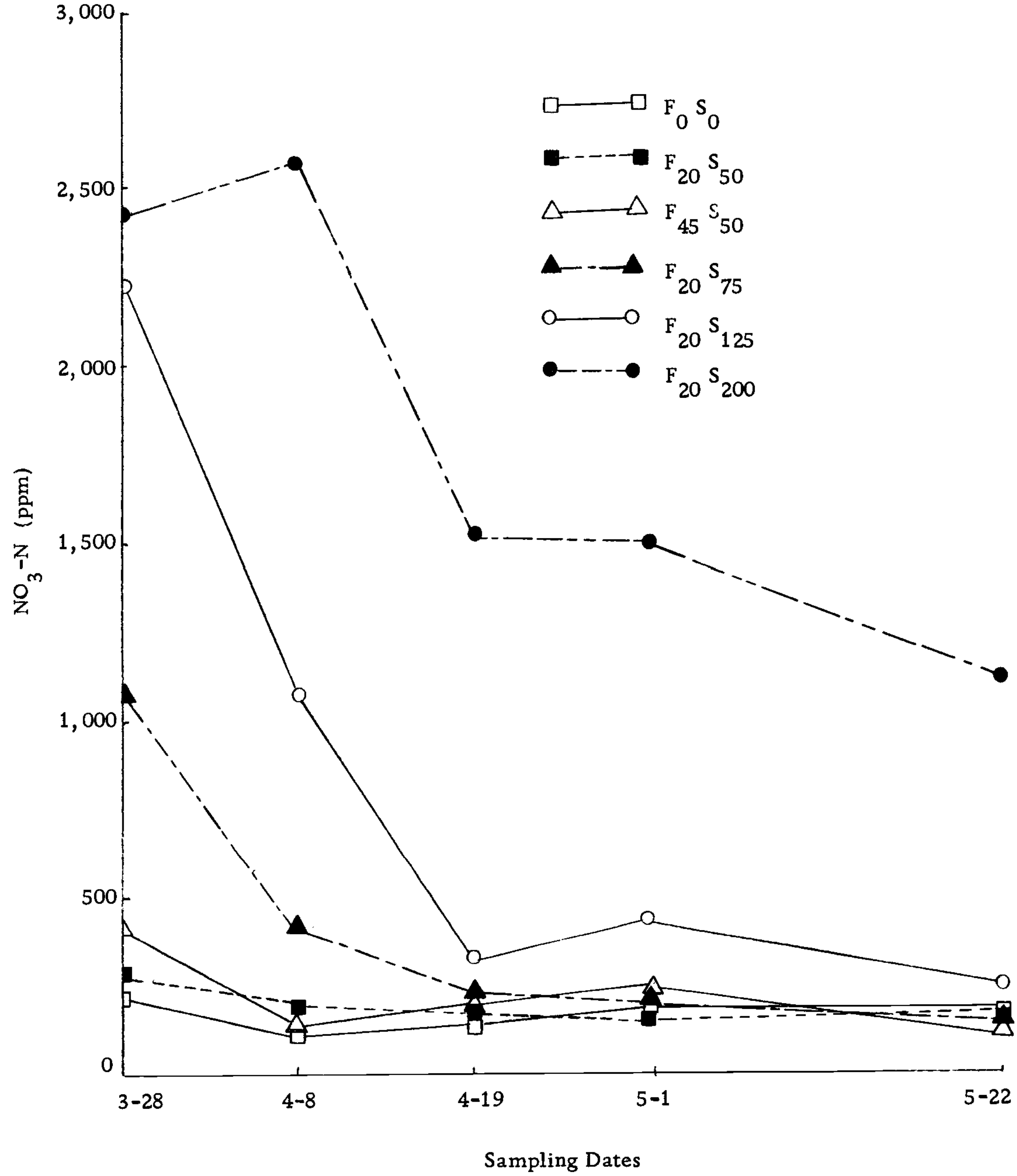


Figure 3. Comparison of average nitrate-N levels in wheat leaves at various times of sampling.

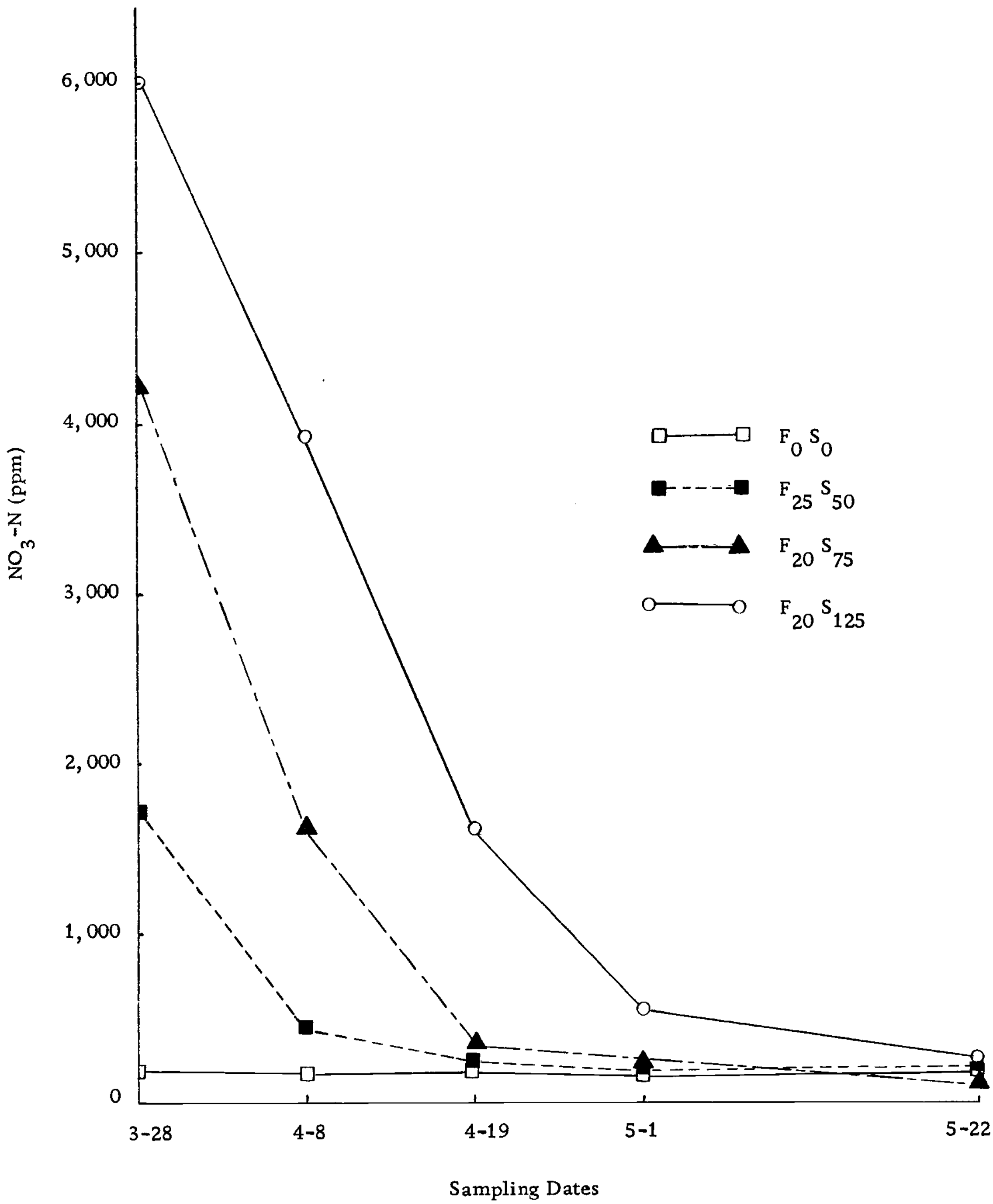


Figure 4. The concentration of nitrate-N in the stem of the wheat plant at different times of sampling.

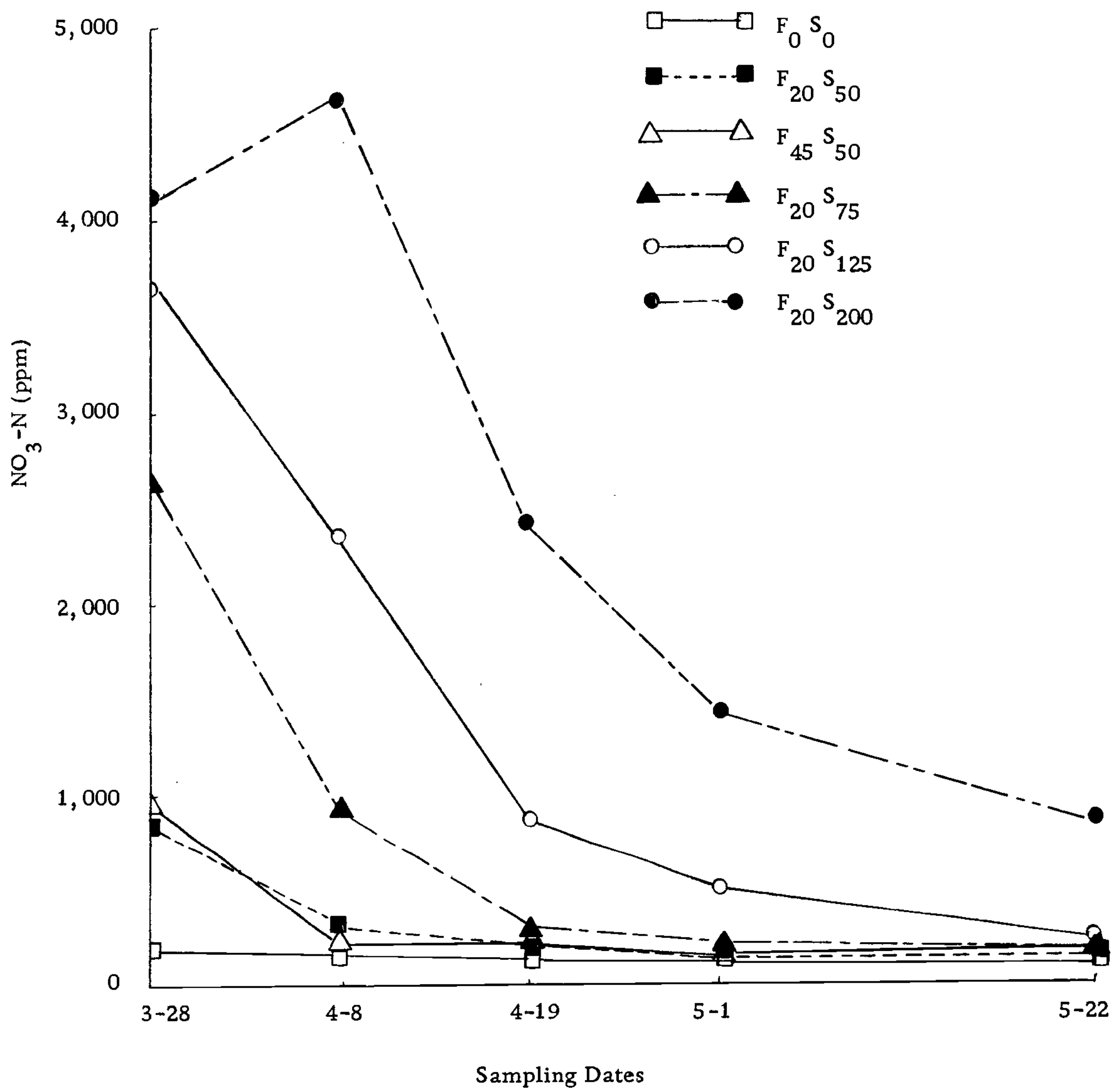


Figure 5. The concentration of nitrate-N in total tops of the wheat plant at different sampling dates.

The concentration of nitrate-N in the leaf,stems and total tops of the wheat plant follow a trend toward decrease with time as the growing season progresses. For each of several successive sampling dates the concentration of nitrate-N in the stems was higher than the concentration of nitrate-N in the leaves irrespective of the N treatment. The results of this study agree with the previous work by Hanway and Englehorn (1958), which indicated that the concentration of nitrate-N in the stems may be greater than in either leaves or grain. It was concluded that this decrease in the concentration of nitrate-N in the wheat plant may result in part from the decline in available N in the soil or from a dilution of the nitrate-N already present in the plant resulting from an increase in dry matter.

Figure 6 shows a comparison of the concentration of nitrate-N in the upper leaves and lower leaves of the plant as affected by N fertilization. The concentration of nitrate-N in upper leaves is higher than the concentration of nitrate-N in lower leaves at the "boot" stage of growth (5-22-68). It appears that nitrate-N is largely translocated from the old leaves to younger leaves. This seems to support the idea that the average concentration of nitrate-N in the total plant tops decreases as the plants mature (Moeller and Therman, 1966).

The relationship between the rate of N applications and nitrate-N content in various parts of the wheat part are shown in Figures 3,

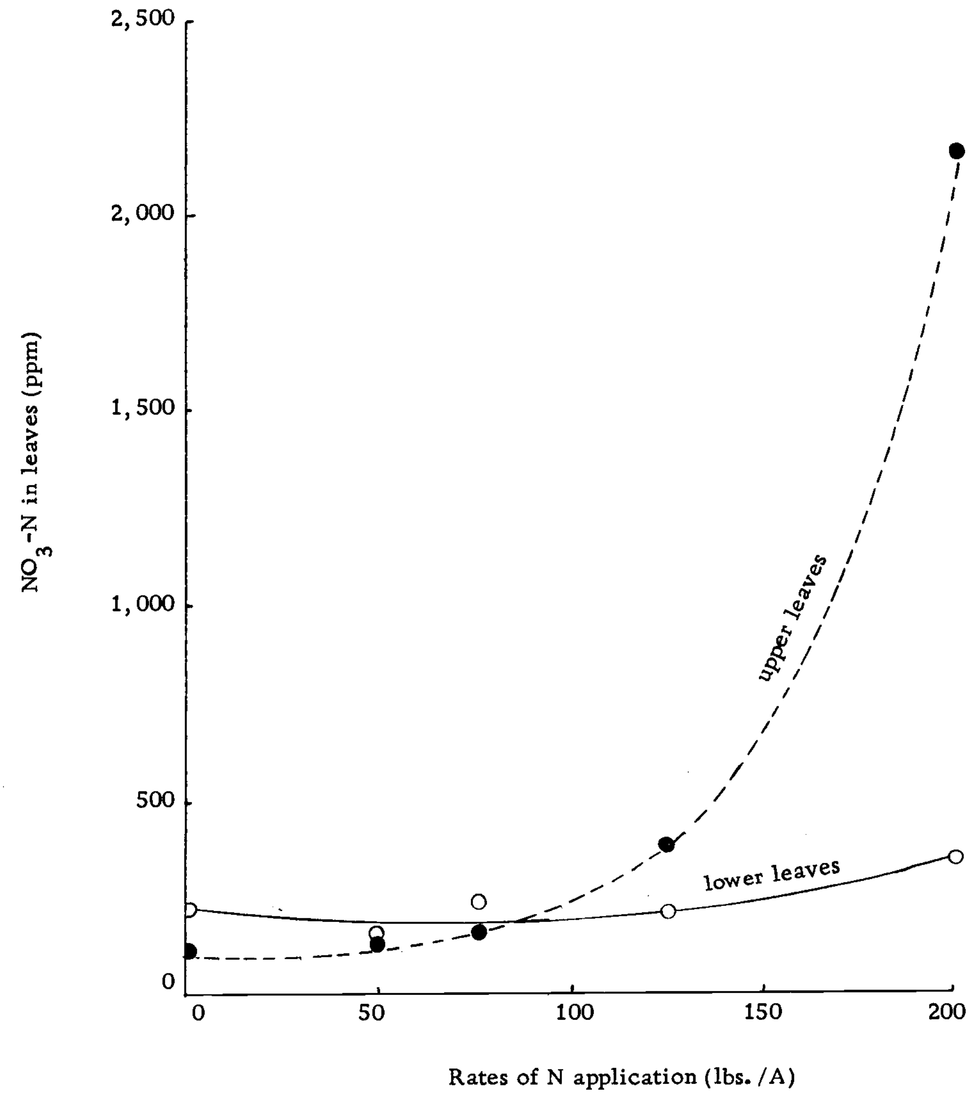


Figure 6. Relationship between the concentration of nitrate-N in the two uppermost leaves and the lower leaves of the wheat plant on 5-22-68.

4 and 5. The concentration of nitrate-N in the leaves, stems and total tops of the wheat plant increased as the level of N fertilization increased. The analysis of variance for the concentration of nitrate-N in the leaves, stems, and in the plant tops on each sampling date are shown in the Appendix Tables 13, 14 and 15. There were highly significant treatment effects (0.01 level of probability) in the concentration of nitrate-N during the life cycle of wheat plants when samples were taken. The highest nitrate-N concentration in any part of the plant parts occurred in conjunction with the highest rate of applied N at the various stages of plant growth.

At the time the second series of plant samples were collected, the concentration of nitrate-N in the plant tissue from plots treated with 200 pounds of N per acre was greater than the nitrate-N concentration recorded for series of samples. It appeared that the effect of the high N treatment on increasing the nitrate-N concentration of the plant tissue was not fully expressed in the first series of samples taken (Appendix Table 5).

Many factors appear to influence wheat tissue nitrate-N concentrations. The data in this study show that (1) the level of N fertilization, (2) the part of the plant selected for analysis, and (3) the stage of maturity at the time of sampling all affect the measured concentration of nitrate-N. Variations in the time of N application, the placement of N fertilizer and the addition of other plant nutrients were not included in this study but ordinarily these factors have only a small effect on the concentration of nitrate-N in the wheat plant (Crawford et al., 1961). Nitrate accumulation in plants growing in the field also has been associated in the most cases with drouth conditions. But in this study, the progressive decline in the concentration of nitrate-N with the advance of plant maturity probably indicates the wheat plants were not subjected to any severe moisture stress (Appendix Table 1).

The concentration of Kjeldahl total N in the plant tops at various stages of plant growth are recorded in the Appendix, Table 6. while total uptake of N appears in Appendix Table 7. The relationships between the N concentration, the total N uptake in the plant tops and the rate of N fertilizations at each stage of plant growth are shown in Figures 7 and 8, respectively. The concentration of N and total N uptake increased in direct proportion to the rate of N applications at almost all stages of growth.

Figure 8 shows a progressive increase in the accumulation of total N in plant tops from spring seedlings (first sampling) up to the soft dough stage (last sampling) for all treatments. It has been observed that the percentage of N in the total plant top decreased steadily for all treatments over this same period (Figure 7). The consistent trend toward increase in the accumulative uptake of N indicated that the decrease in the concentration of N with time was

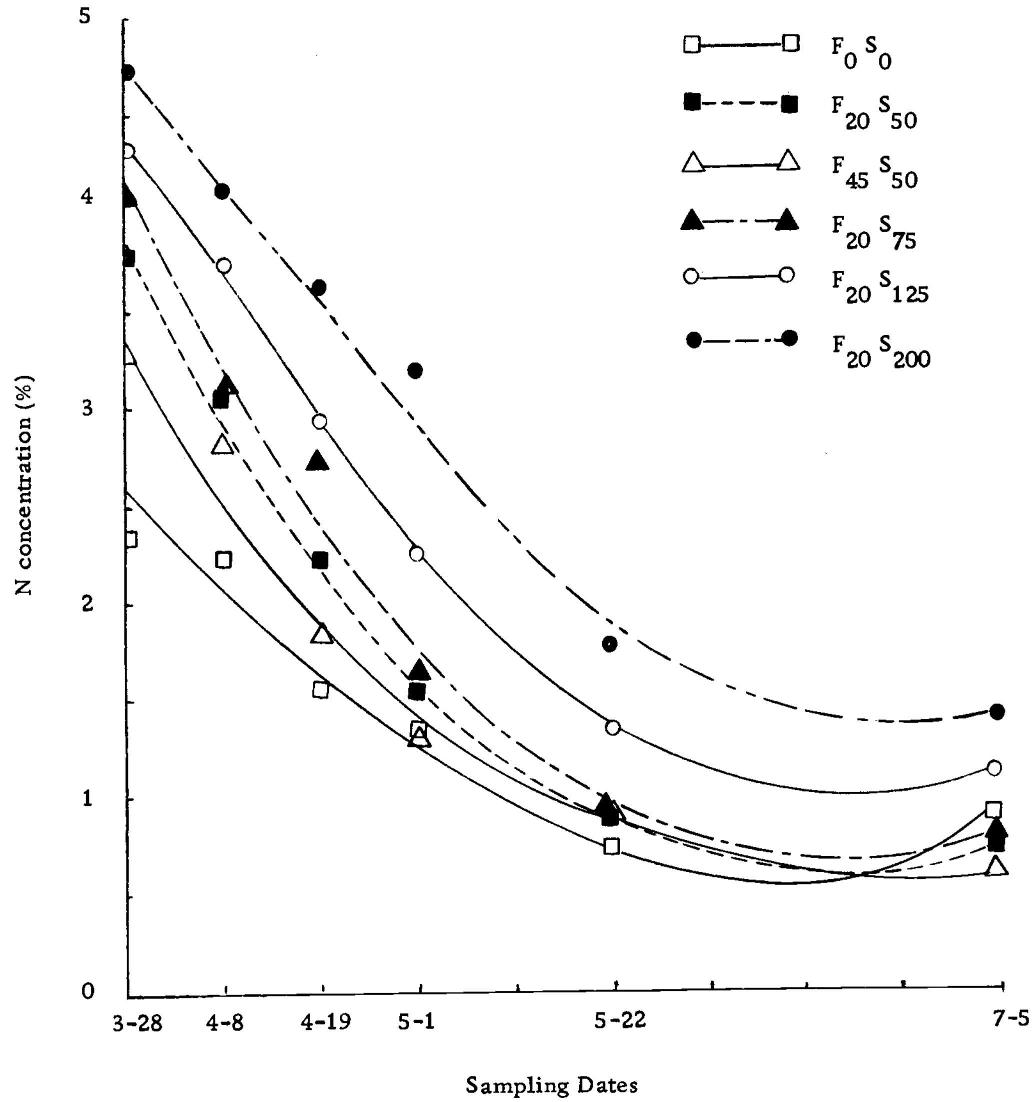


Figure 7. Total N in plant tops on different dates of sampling.

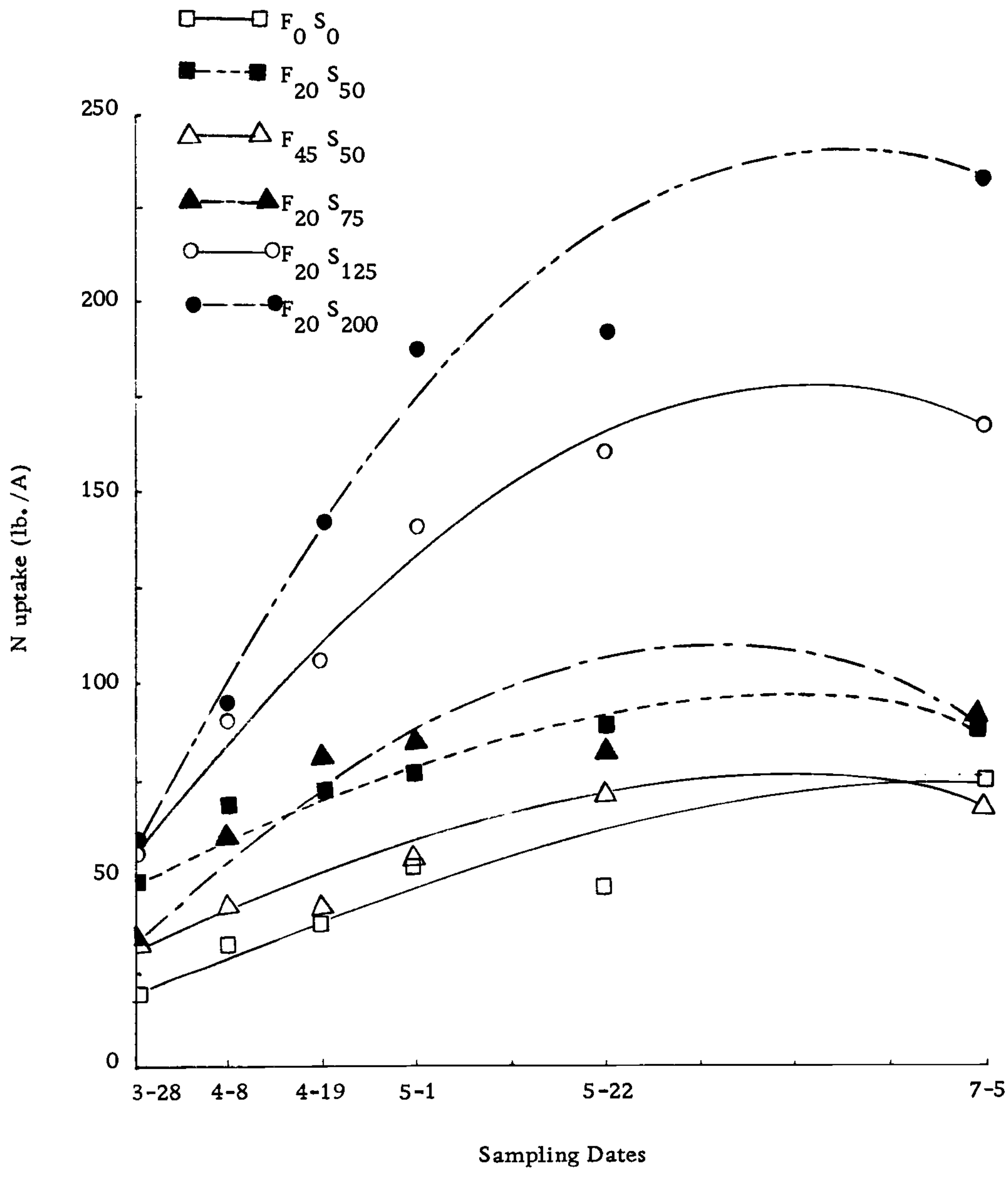


Figure 8. Accumulative total N uptake on different sampling dates.

associated with increase in dry matter production.

The statistical analysis of variance of N concentration and total N uptake of wheat plants for all sampling dates is reported in Appendix Tables 16 and 17. The treatment effects of applied N were highly significant (0.01 level of probability) for the entire period of sampling when either N concentration or total N uptake were considered. At most sampling dates there appeared to be little difference in the concentration of plant N or the total N uptake between the 50 pound or 75 pound/acre nitrogen fertilizer treatments. However, the quantity of N taken up by plants after heading was three times as great on the high N fertilizer plots compared with the control (Figure 8 and Appendix Table 7). The wheat plants which were subjected to high rates of applied N continued to accumulate total N over an extended period compared with plants which were growing under the low N regime. A similar observation was noted by Allison and Stering (1949) who concluded that the more fertile soils not only supply larger quantities of N to the crop at early stages of growth but maintain an available supply of N for uptake by the wheat plant at the later stages of growth.

Uptake of Other Nutrients

Various workers have found a relationship between the uptake of N in plants and the uptake of other plant nutrients (Grunes *et al.*, 1959). In order to study similar effects in this experiment, the concentration of P, K, Ca and Mg were determined in the plant tissue and reported for each sampling date (Tables 11 and 12) while total uptake of P and K in the tops of the wheat plants are shown in Figures 9 and 10. Calculations for total plant P and K appear in Appendix Table 8.

The most dramatic feature of the data on uptake of P, K, Ca and Mg by the wheat plant is the reduction with time in the concentration of these nutrients in the plant tissue (Tables 11 and 12). The shift in concentration of all nutrients including N follows a similar trend. The plants were actively accumulating N, P and K during most of the growing season but nutrient uptake did not keep pace with the production of dry matter. The net effect was dilution of the concentration of these ions in the plant.

The data for accumulation of K (Figure 10), unlike N and P (Figure 9), seemed to indicate a loss of K from the plant tops after 5-22-68 (boot stage of growth). The comparable loss of K from the total top of the corn plant was indicated by Sayre (1948). His data indicated a 15% loss in K from the point of peak uptake at silking time until the plant matured. The loss was largely unaccounted for, but it was suggested that K may have been washed from the leaves or that K may have moved from the tops to the roots. The loss of K from the top of wheat plants by either or both of these mechanisms

Table 11. The effect of N fertilization on the concentration of P and K in wheat plant tops at different sampling dates in 1968.

Spring Applied N lbs./A	Average P and K Concentrations (%) at Different Dates of Sampling											
	P Concentration						K Concentration					
	3-28	4-8	4-19	5-1	5-22	7-5	3-28	4-8	4-19	5-1	5-22	7-5
0	0.40	0.20	0.26	0.24	0.15	0.16	3.19	3.03	1.71	1.51	1.46	0.90
50	0.43	0.40	0.32	0.25	0.13	0.19	4.68	4.00	3.32	2.08	1.44	0.49
50[a]	0.40	0.40	0.32	0.24	0.14	0.14	4.15	3.88	2.87	1.96	1.34	0.52
75	0.41	0.38	0.43	0.25	0.18	0.14	4.55	4.25	3.92	2.67	1.38	0.88
125	0.57	0.44	0.44	0.30	0.18	0.14	4.76	4.81	3.83	1.85	1.97	0.95
200	0.42	0.49	0.41	0.40	0.19	0.15	4.69	5.39	4.37	3.86	2.10	1.29
LSD 0.05	-	0.05	-	-	N.S.	-	-	0.89	-	-	0.38	-

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

\- not analyzed statistically.

Table 12. The effect of N fertilization on concentration of Ca and Mg in wheat plant tops at different dates of sampling in 1968.

Spring Applied N lbs. /A	Average Ca and Mg Concentration (%) at Different Times of Sampling											
	Ca Concentration						Mg Concentration					
	3-28	4-8	4-19	5-1	5-22	7-5	3-28	4-8	4-19	5-1	5-22	7-5
0	0.13	0.16	0.12	0.13	0.10	0.06	0.080	0.067	0.066	0.054	0.055	0.057
50	0.15	0.16	0.13	0.12	0.09	0.08	0.085	0.074	0.058	0.055	0.053	0.050
50[a]	0.14	0.15	0.12	0.15	0.10	0.09	0.081	0.068	0.063	0.051	0.050	0.052
75	0.17	0.20	0.11	0.12	0.10	0.07	0.094	0.082	0.071	0.053	0.043	0.048
125	0.19	0.20	0.16	0.12	0.14	0.06	0.109	0.085	0.075	0.062	0.067	0.055
200	0.18	0.21	0.18	0.16	0.13	0.11	0.102	0.086	0.082	0.075	0.058	0.062
LSD .05	-	N.S.	-	-	0.025	-	-	N.S.	-	-	N.S.	-

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

-Not analyzed statistically.

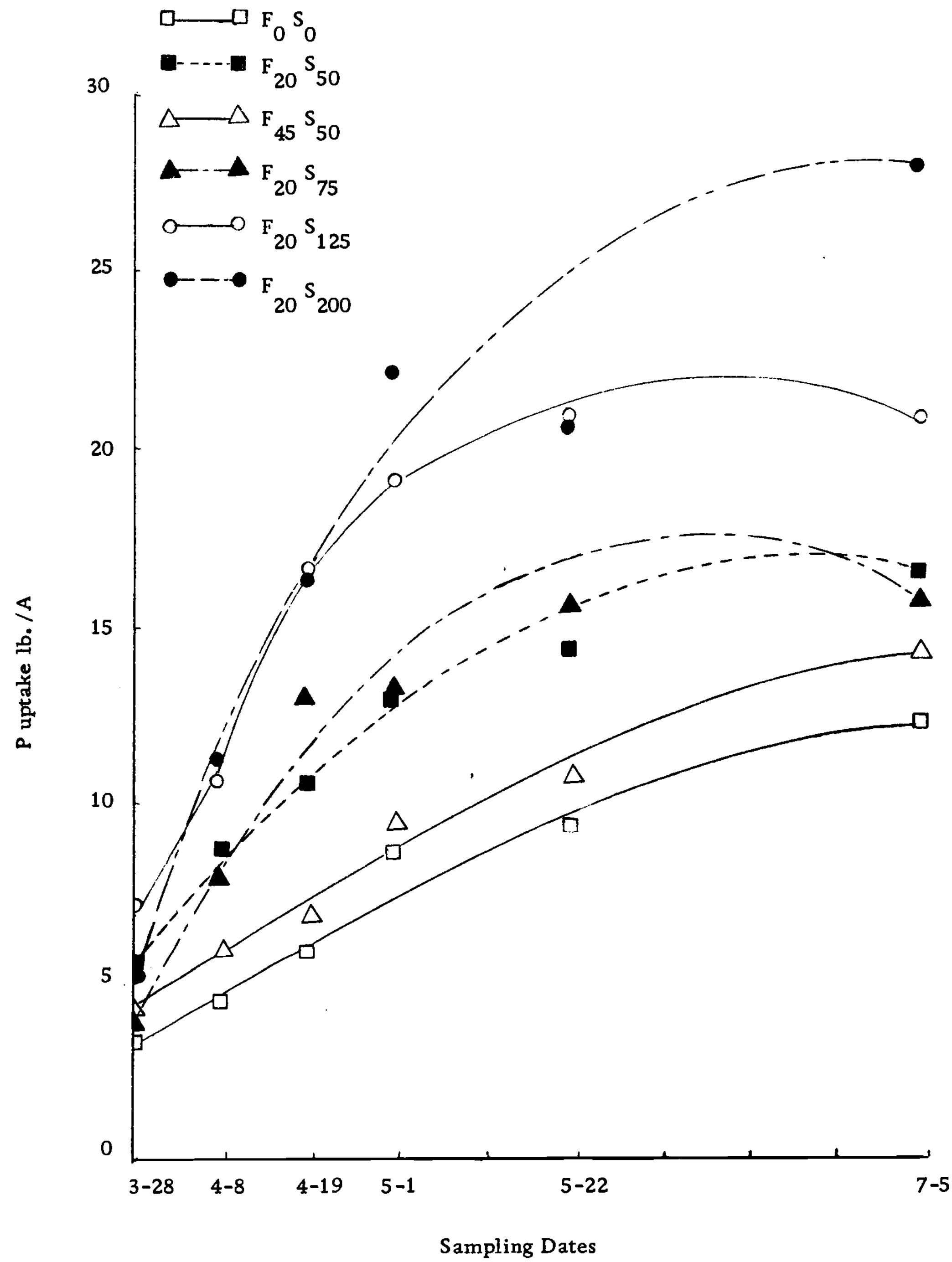


Figure 9. Accumulative P uptake by the wheat plant for different sampling dates.

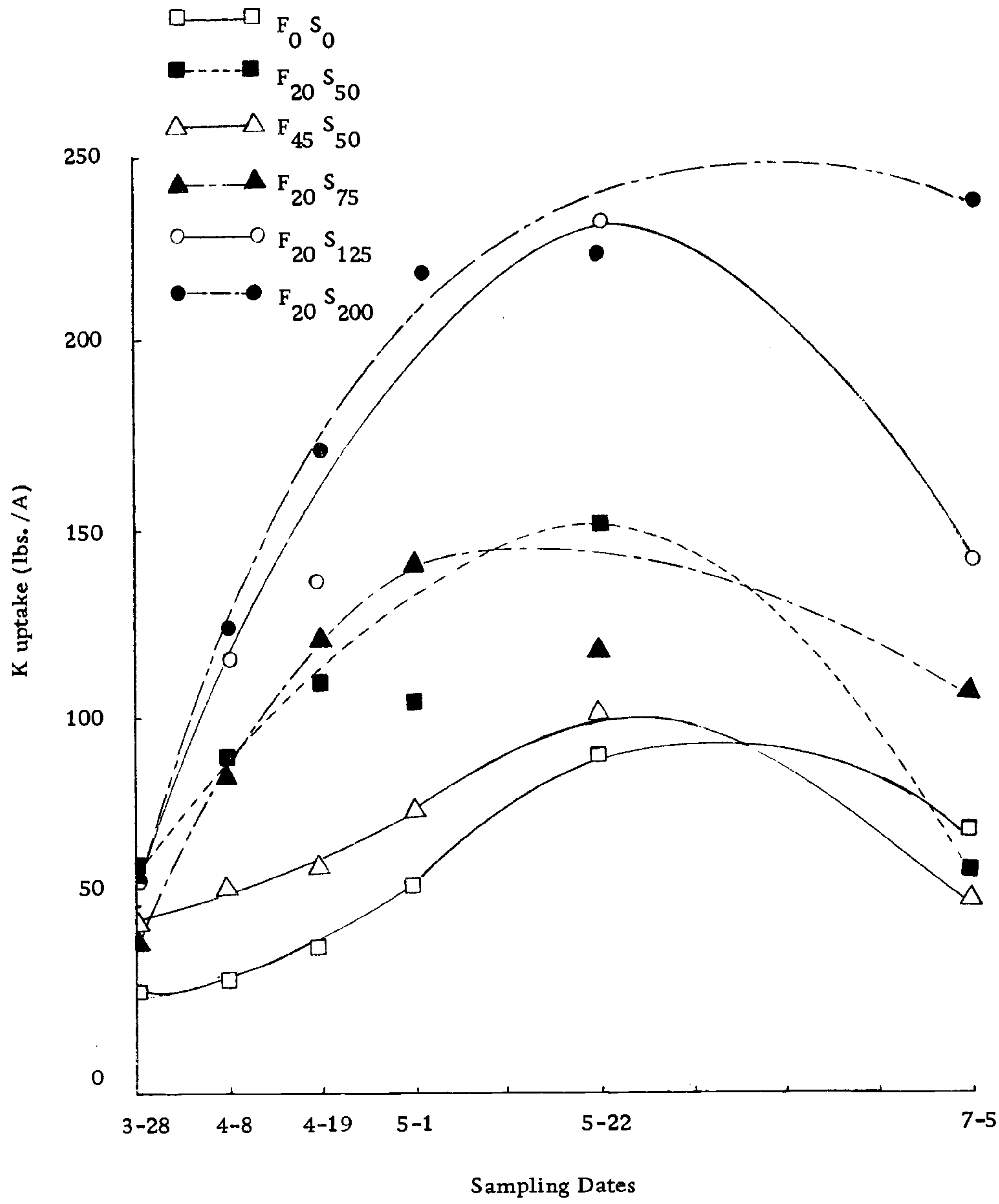


Figure 10. Accumulative uptake of K by the wheat plant on different sampling dates.

is a distinct possibility.

The statistical analysis for the concentration of P, K, Ca and Mg at the second sampling (4-8-68), at the fifth sampling (5-22-68), and the total uptake of these nutrients at the final sampling (7-5-68) are shown in Appendix Tables 18 and 19. The concentration of P and K were significantly increased by the N treatments (0.01% level of probability) on 4-8-68 and only the K concentration was increased significantly by N application at the booting stage (5-22-68).

Grunes et al. (1958) concluded that N fertilization increased uptake of P and K by promoting plant root growth which in turn increased the root foraging power. The net effect is that in the initial growth phases, P absorption occurs more rapidly than plant growth, and therefore P concentration is higher for N-fertilized plants. This explanation may be equally applicable whether N fertilizer is applied in the fall at seeding time, or in the spring.

It has been previously (Russell et al., 1954) reported N fertilization either in the fall or in the spring increased the P concentration of plants in the early part of the growing season, but that later in the season the N effect on P concentration was not noticeable. Russell's group attributed the increased P concentration to a possible effect of N on increased root growth, and also to possible effect of the ammonium ion over nitrate ion. They thought that later in the season the similarity of P concentrations was due in part to the increase in the dry matter production resulting from N fertilization. They also stated that later in the season a possible predominance of the nitrate ion over the ammonium ion in the soil may have been the cause of similarity of P concentrations, whether or not N fertilizer was applied earlier.

The mechanism whereby N increases P uptake may be explained as a direct chemical effect or by the indicated physiological effects. The direct effects include increases in the solubility of P; due to the presence of N salts (Jacob and Hill, 1953), or to residual acidity (Yuen and Pollard, 1957). The indirect effects include increases in anion-cation ratio in the plant (McCalla and Woodferd, 1938), in root proliferation (Miller and Ohlrogge), in cation exchange capacity of roots (McLean, 1957), or in root efficiency (Grunes _et_ _al_., 1958).

Some evidence indicates that the marked increase in the concentration of K which is associated with the high rates of N fertilization might be related to the "Ionic Balance" phenomenon in the plant (Dijknoorn, 1958; Dewit _et_ _al_., 1963; and Noggle, 1966). If one accepts the theory of cation-anion balance in salt accumulation, one may further postulate that K serves as the balancing cation for the accumulation of the nitrate anion. Conditions which favor nitrate accumulation may then also enhance K uptake.

There was a trend toward increased concentrations of Ca and

Mg in the wheat plants at the time of the second sampling significantly as a result of the N treatments although the treatment effects were not statistically significant. The concentration of Ca but not Mg was significantly increased at the "boot" stage (5-22-68) by the application of either 125 or 200 pounds of N per acre.

In the case of other constituents like P and K, significant correlation was found between the K percentage levels in the wheat plant at jointing stage and the final yield of grain (Figure 11). No correlation was found on P to the final yield in this stage (Figure 11). The correlation between these nutrient concentrations and N concentration are shown in Appendix Table 20. The P and K concentration show significant correlation with the N concentration at most stages of plant growth except at the soft dough stage (Appendix 20) at which time the P and K concentrations had decreased greatly from the levels recorded earlier in the season.

Sensitivity of the Different Diagnostic Approaches for Assessment of Nitrogen Status of the Wheat Plant

Plant Analysis

Plant analysis has been used extensively to study the uptake of nutrients by wheat plants, but unfortunately, the critical levels for specified nutrients in wheat plants have not been established precisely. It is also possible that the critical levels of nutrients may

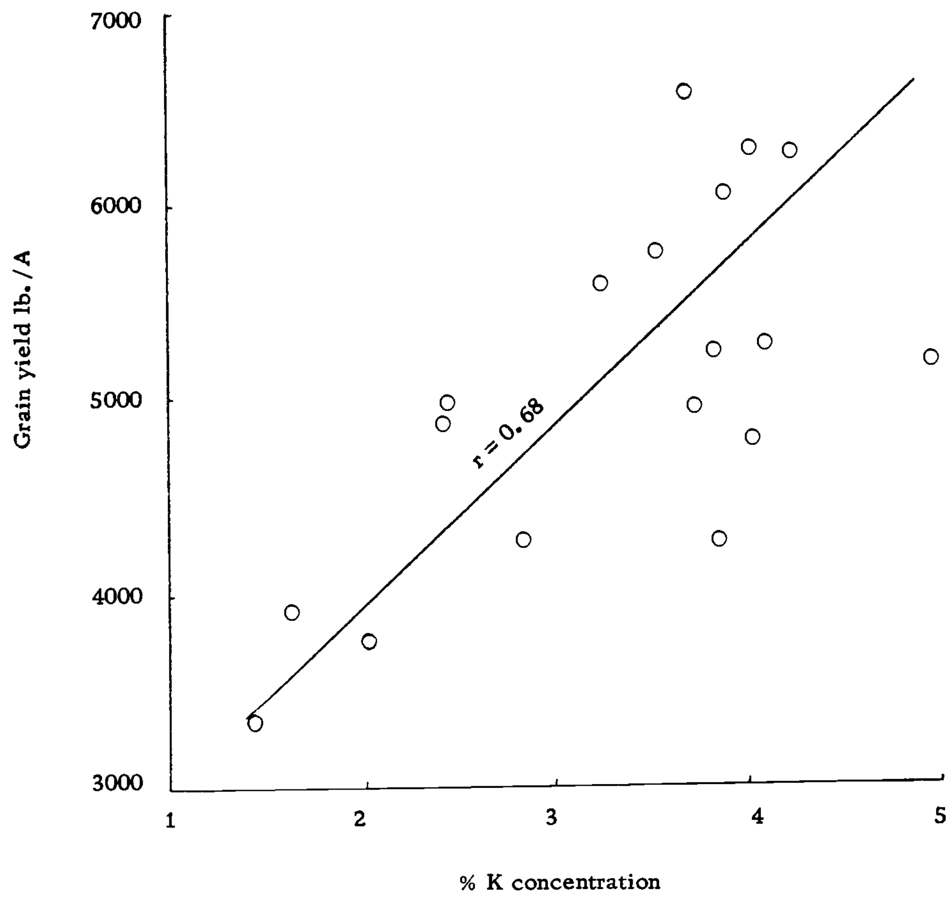


Figure 11. Relationship between K concentration in plant top and grain yield on 4-19-68.

fluctuate considerably depending upon the wheat variety and the climatic conditions where the crop is grown. The data which is presently available on critical levels must be verified, prior to its acceptance for use in Oregon.

In this study wheat plants were grown under different levels of N fertilizer. To obtain additional information on the critical level of N, different parts of the wheat plant were sampled and analyzed for N. A summary of the data used to compare the sensitivity of some of the different analytical approaches used in the study is presented in Table 13.

The data for chemical analysis indicated that the accumulation of N in the plant tissue was very sensitive to changes in the level of applied N. It was noted in Appendix Tables 13, 14 and 15 that the concentration of nitrate-N in the plant tissue was significantly affected by N fertilization on all dates of sampling. In relative terms the N treatments increased the nitrate-N concentration of the wheat plants from 3 to 46 fold over the untreated control plants (Table 13). There was a low degree of precision for measuring the nitrate-N in the plant tissue as evidenced by the coefficients of variation in Table 13 ranging from 13 to 37%. Apparently the accumulation of nitrate-N in plant tissue is influenced by many factors other than the rate of N application. For example, Gonke and Keeney (1956) published data for nitrate-N in the corn plant which was determined by the same

Table 13. Sensitivity of nitrate-N level in the plant tissue to variation in the supply of available nitrogen.

Parameter	Date of Measurement	Range of Parameter	Fold Increase of Treated Over Control	Probability Level of Treatment Effect	C.V. %	Estimated Critical Level
NO_3-N in	3-28-68	200-2410	12.0	0.01	19.4	900
leaves	4- 8-68	110-2580	23.5	0.01	23.2	500
ppm	4-19-68	130-1350	10.4	0.01	16.7	300
	5-1-68	160-1320	8.3	0.01	37.0	300
Upper	5-22-68	110-1880	17.1	0.01	19.2	250
Lower	5-22-68	140-350	2.5	0.01	22.0	-
NO_3-N in	3-28-68	190-6920	36.4	0.01	25.1	4200
stems	4- 8-68	170-7800	45.9	0.01	24.4	2000
ppm	4-19-68	150-3130	20.9	0.01	26.1	600
	5- 1-68	90-1890	21.0	0.01	12.6	200
	5-22-68	100-860	8.6	0.01	31.2	-
NO_3-N in	3-28-68	200-4150	20.8	0.01	22.0	2300
plant tops	4- 8-68	140-4770	34.1	0.01	21.7	1250
ppm	4-19-68	140-2160	15.4	0.01	15.3	400
	5- 1-68	120-1650	13.8	0.01	17.4	250
	5-22-68	120-910	7.6	0.01	16.0	-

analytical method, and their coefficient of variation was about 35 to 40%.

It seems that there were consistent variations in the nitrate-N concentration irrespective of the plant part analyzed or of the sampling date. There was little indication that any specified sampling date was consistently superior to the others from the standpoint of improved precision of measurement.

The data for yield of grain was plotted versus the nitrate-N in selected plant parts in the plant tops as shown in Figures 12, 13, 14, 15, 16 and 17. A curve or line was arbitrarily fitted to the data points on the graph to indicate the general relationship between the two variables. The plant N data obtained prior to 5-1-68 appeared more useful for estimating the critical levels for the wheat plant than the data obtained at the later samplings.

The critical levels of plant N were estimated at 5700 pounds per acre which was 95% of the mean yield produced by the maximum yielding treatment for the experiment (Ulrich and Hills, 1967). The point of intersection of the curve on the graph and the 95% yield level was regarded as the first approximation of the critical level. The estimated critical levels are recorded in Table 13. The observed critical levels changed markedly with time. For example, the estimated critical level for nitrate-N concentration in the wheat leaves approached 900 parts per million on 3-28-68, but was estimated at

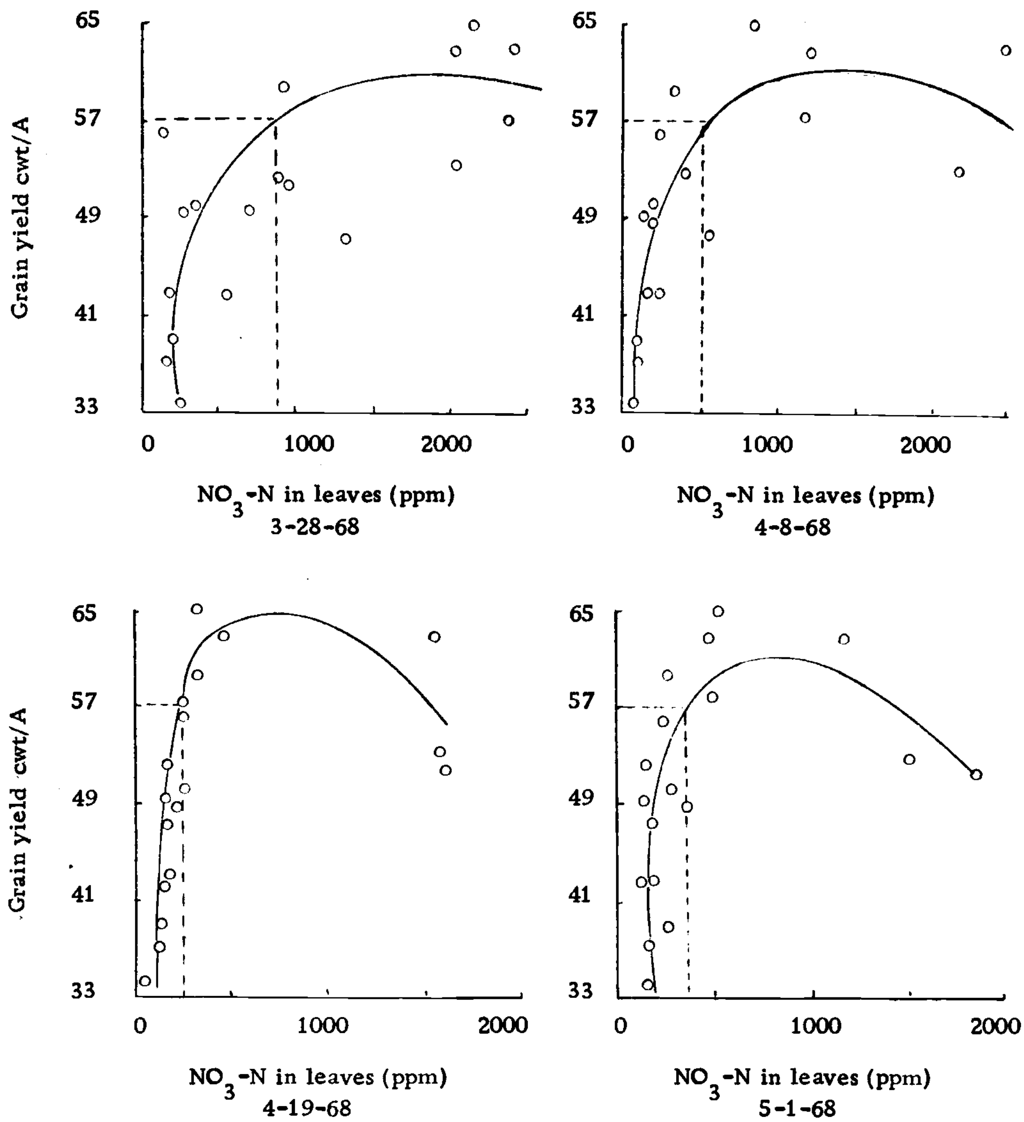


Figure 12. The relationship between nitrate-N in leaves and grain yield at the indicated dates.

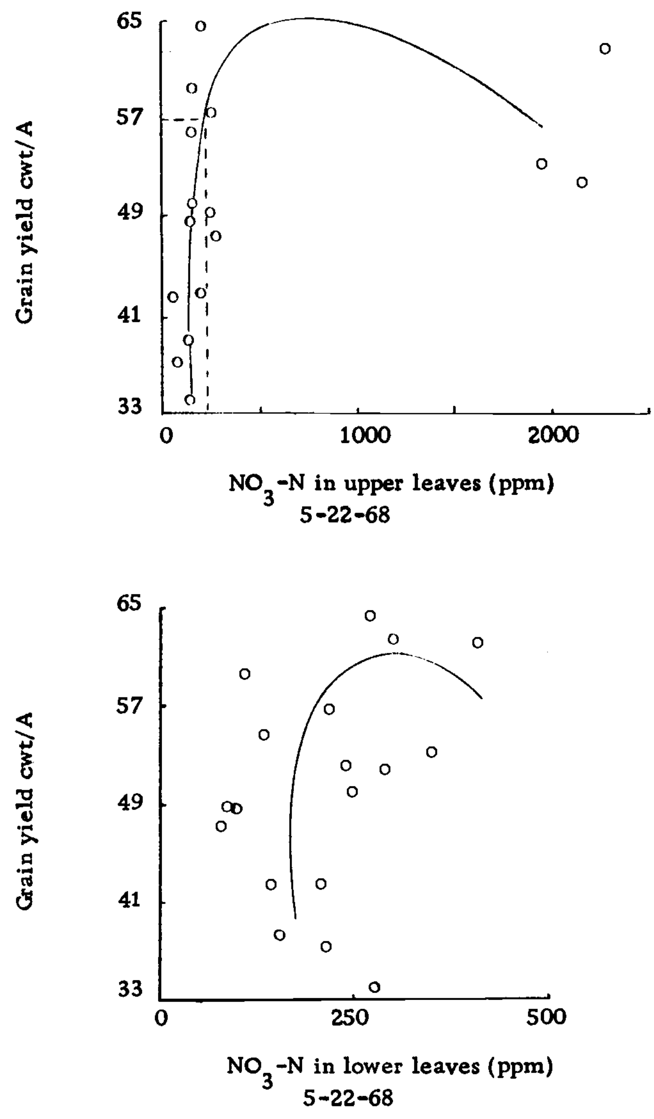


Figure 13. The relationship between nitrate-N in upper and lower leaves and grain yield on the indicated dates.

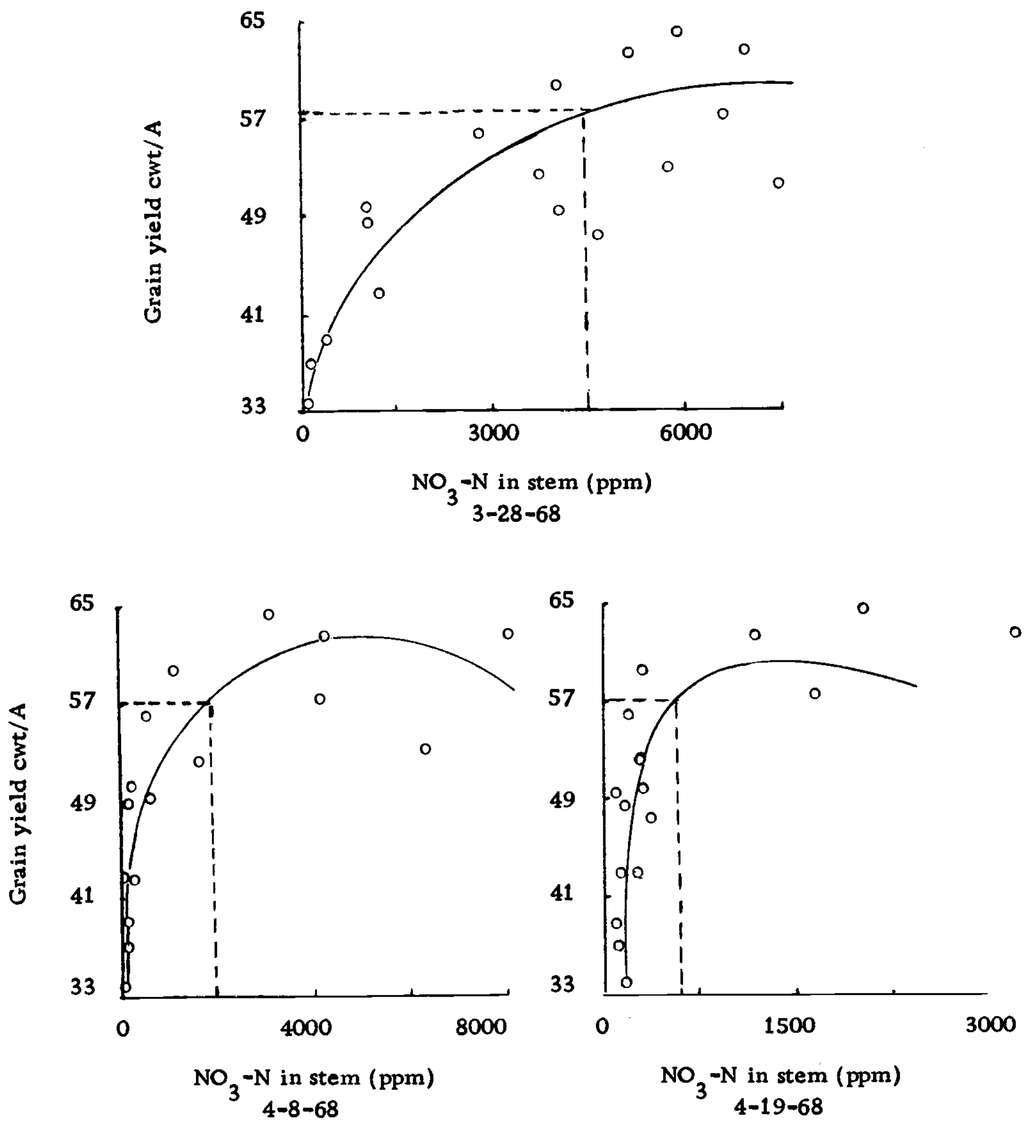


Figure 14. The relationship between nitrate-N in the stem and grain yield at the indicated dates.

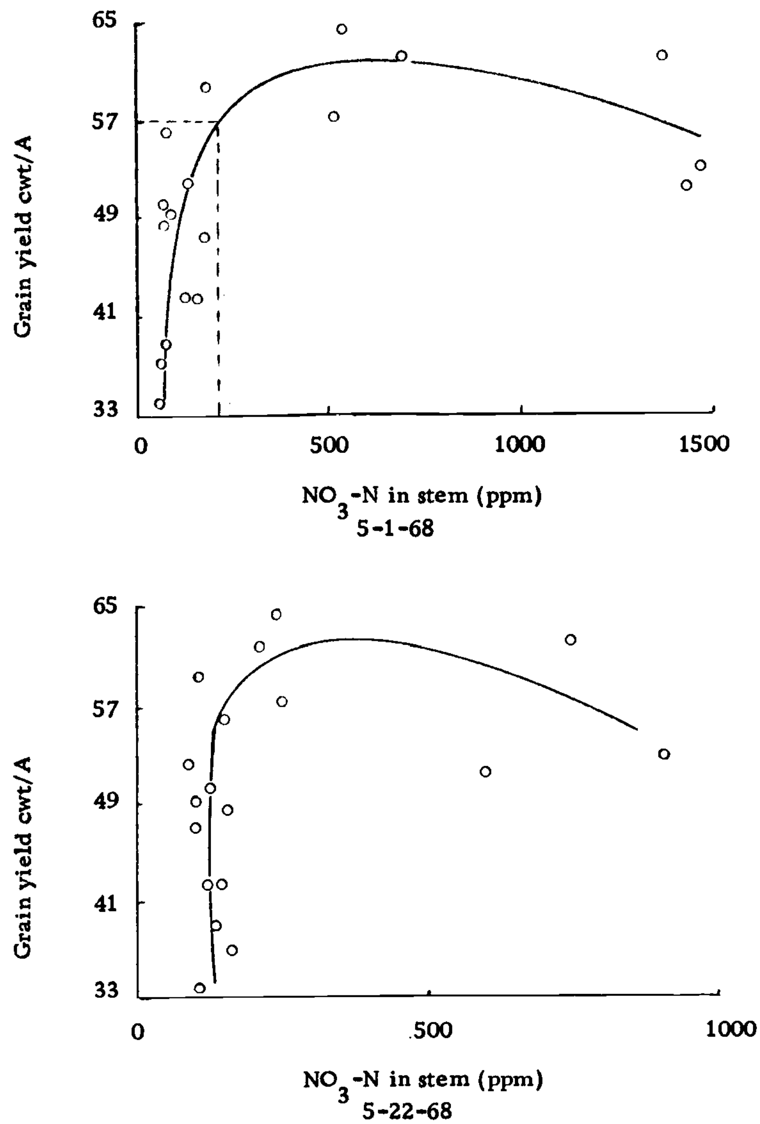


Figure 15. The relationship of nitrate-N in the stem and grain yield at the indicated dates.

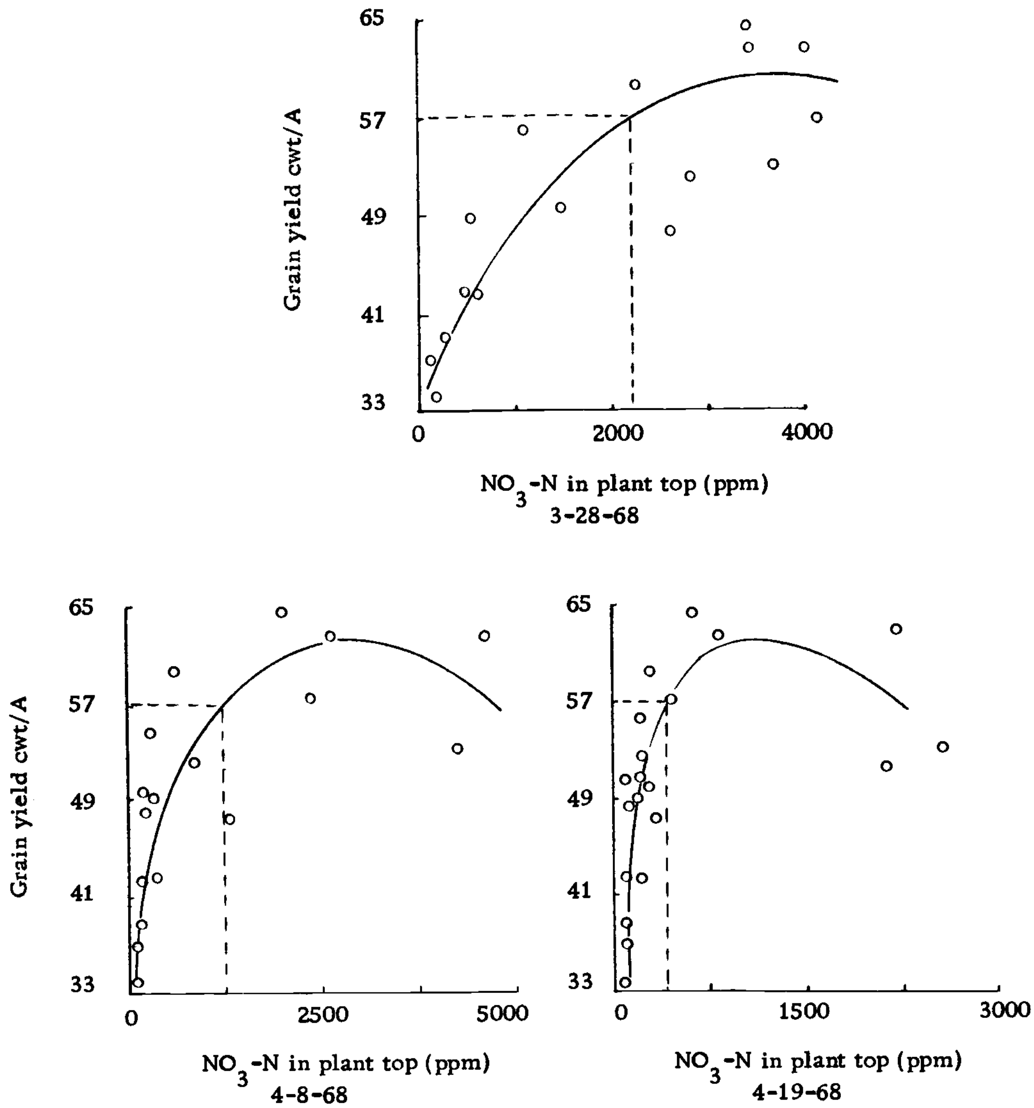
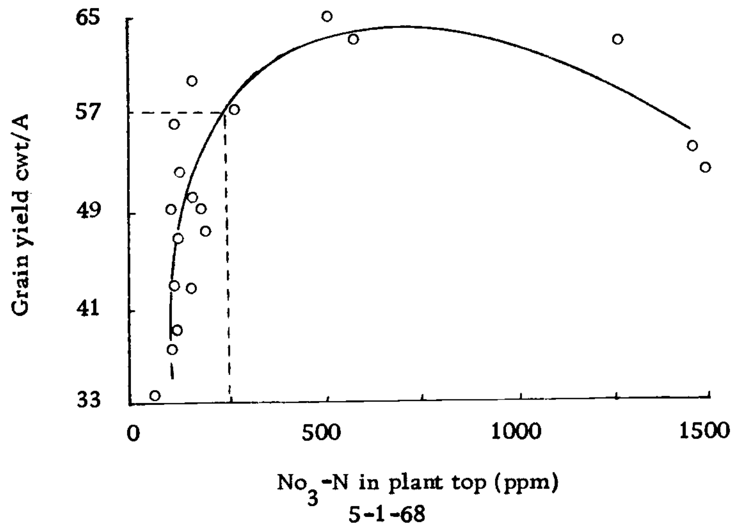


Figure 16. The relationship between nitrate-N in the plant top and grain yield at indicated dates.



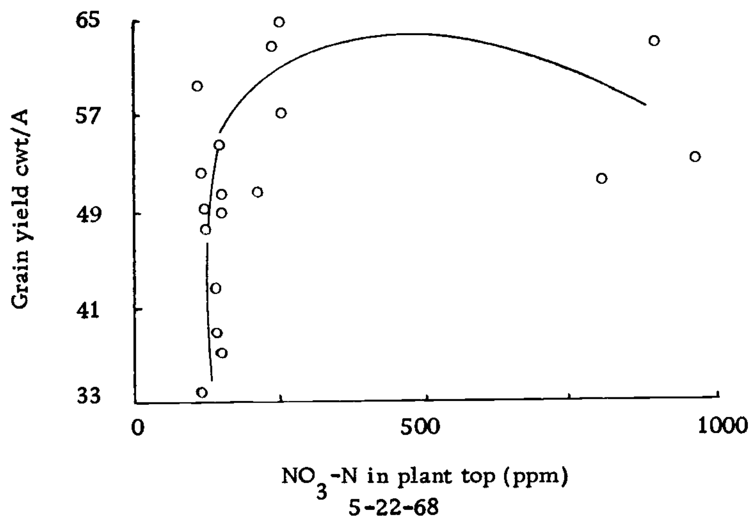


Figure 17. The relationship between nitrate-N in the plant top and grain yield at indicated dates.

about 300 parts per million on 4-19-68 and 5-1-68.

The analytical data for the leaves appeared the most suitable for estimating the critical level of nitrate-N. The graph of grain yield versus nitrate-N in the leaves indicates that approximately four to six weeks may be required after fertilization with N before the full effect of the treatment appears in the analytical data.

There was insufficient evidence obtained in this study to explain why some data points to the right of the critical level also occurred below the optimum yield level of 5700 pounds per acre. It was assumed that some factor other than supply of available N was limiting the yield of grain. At least two data points with high level of plant N and yields below the optimum resulted from yield depression suggesting an excessive amount of N fertilizer.

The upper leaves (flag leaf plus the leaf immediately below) maintained a much wider range in concentration of nitrate-N than did the lower leaves even as late as the "boot" stage of growth (Appendix Table 5 and Figures 6 and 13). The upper versus lower leaf comparison possibly indicates some advantage in selecting the upper leaves for diagnostic purposes, particularly at the advanced stages of growth.

The nitrate-N concentration in the stem of wheat followed the same pattern of change in concentration with time as the nitrate-N in the leaves, but the initial critical levels were much higher (Table

13). The estimated critical level for the nitrate-N concentration in the stem reached 4200 parts per million on 3-28-68 and dropped back to nearly 600 and 200 parts per million on 4-19-68 and 5-1-68, respectively.

The estimated critical level of nitrate-N in the plant top as expected follows a trend which is intermediate between the nitrate-N concentration in leaves and in the stems. The critical level nitrate-N in the total top was estimated at 2300 parts per million on 3-28-68, and at only 250 parts per million on 5-1-68. Archarya and Jadav (1957) pointed out that in the case of cereal crop like wheat it would appear to be more suitable to analyze the whole above-ground portion of the plant, instead of analyzing only certain tissues like the stem or particular leaves.

A summary of the data on the total N in the plant tops is presented in Table 14. The relationships between the total N concentration, total N uptake and grain yield which were used for evaluation of critical levels are shown in Figures 18, 19, 20 and 21. The concentration of total N in the plant tops followed a trend toward decrease with time which was also noted for nitrate-N. On all sampling dates the maximum percentage of N in the total plant tops from plots treateded with N was consistently about twice the level found in plants from the untreated control plots (Table 14). The coefficients of variation which ranged from 7.2 to 13.8% for the determinations

Table 14. Sensitivity of level in the total plant top to variations in the supply of available nitrogen.

Parameter	Date of Measurement	Range of Parameter	Fold Increase of Treated Over Control	Probability Level of Treatment Effect	C. V. %	Estimated Critical Level
N concen-	3-28-68	2.36-4.76	2.0	0.01	7.2	4.40
tration	4- 8-68	2.23-4.12	1.9	0.01	11.6	3.35
%	4-19-68	1.60-3.68	2.3	0.01	8.3	2.80
	5- 1-68	1.36-3.20	2.4	0.01	11.8	1.50
	5-22-68	0.78-1.79	2.3	0.01	13.8	1.00
	7- 5-68	0.68-1.40	2.1	0.01	12.2	-
N uptake	3-28-68	20-59	3.0	0.01	22.9	47.0
lbs./A	4- 8-68	34-95	2.8	0.01	20.0	85.0
	4-19-68	37-145	3.9	0.01	30.0	100.0
	5- 1-68	50-181	3.6	0.01	18.3	100.0
	5-22-68	49-191	3.9	0.01	17.2	100.0
	7- 5-68	76-257	3.4	0.01	15.6	100.0

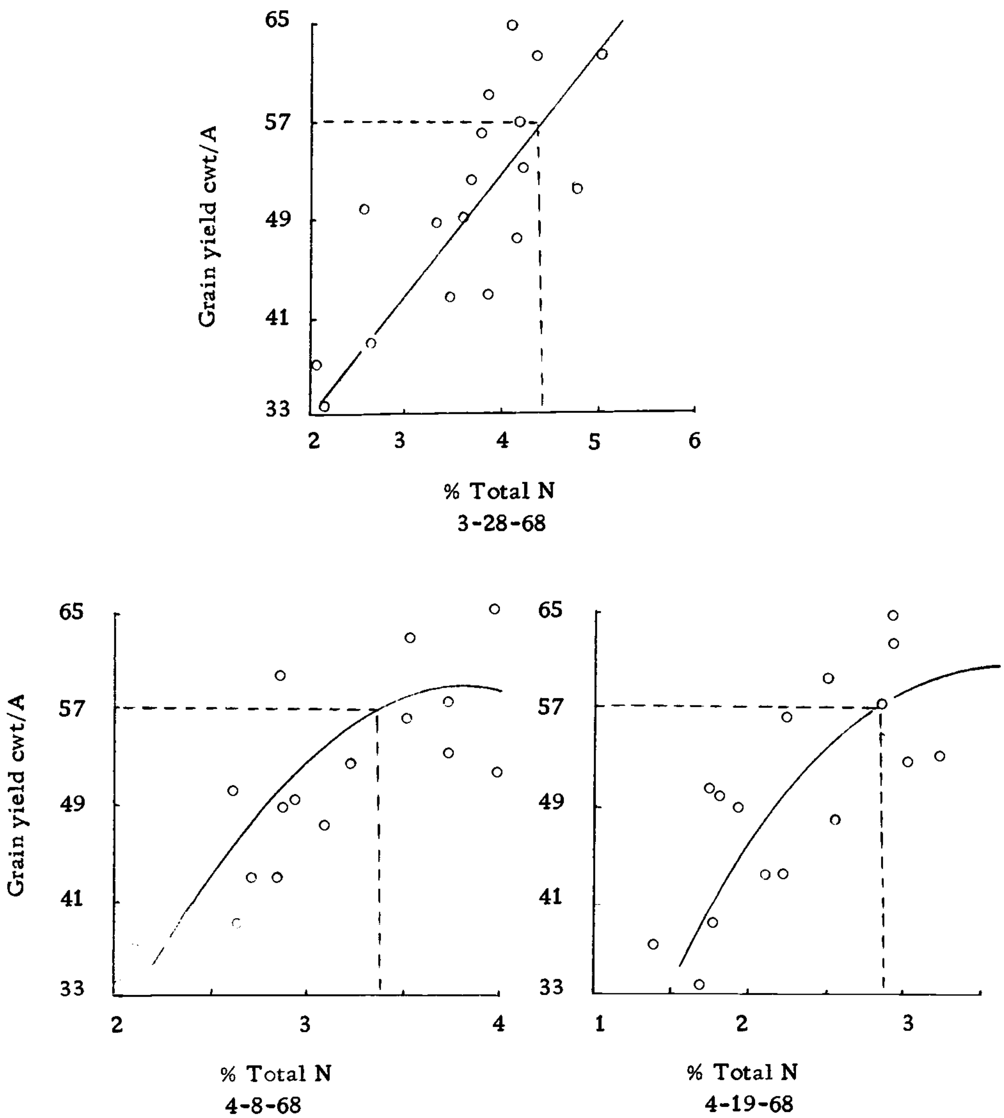


Figure 18. The relationship between total N concentration and grain yield at the indicated dates.

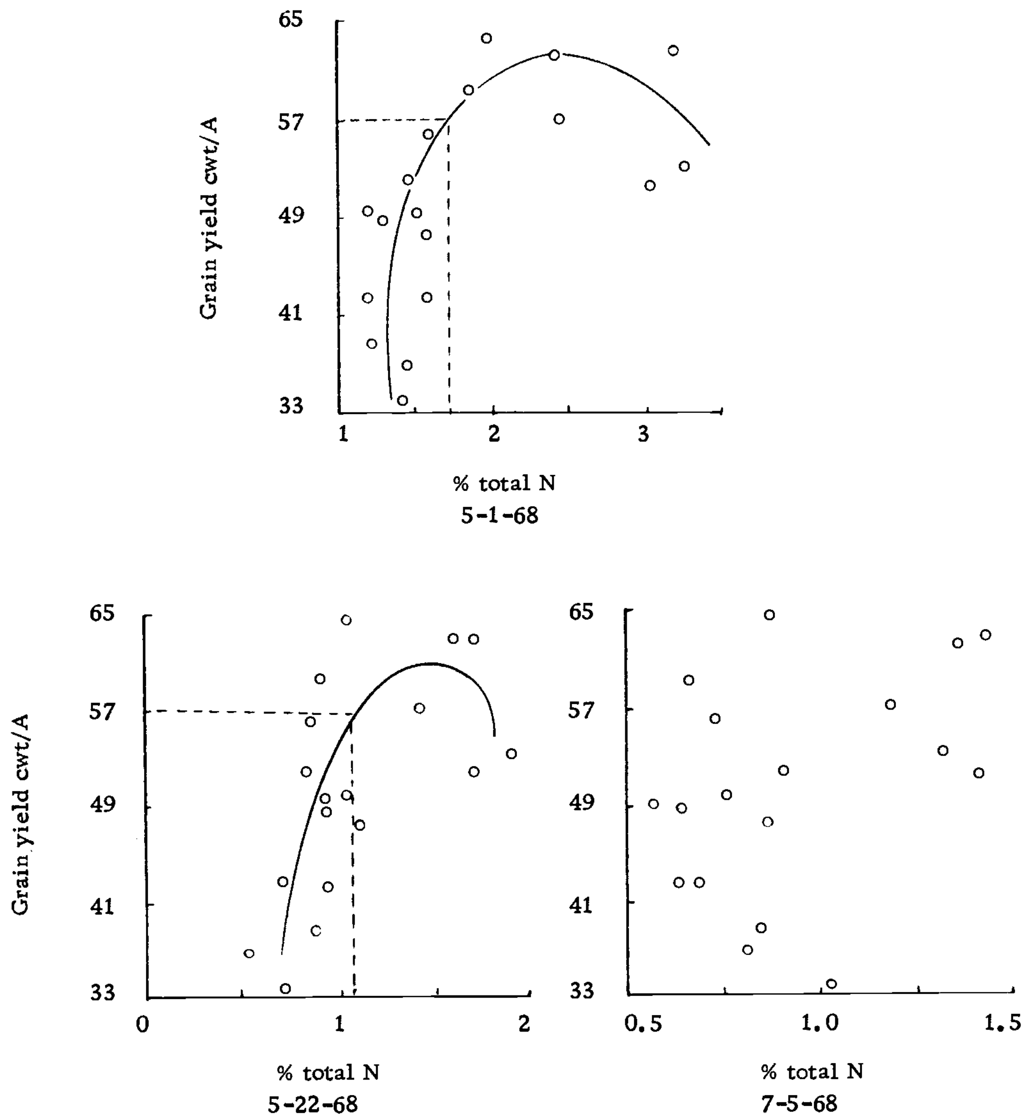


Figure 19. The relationship between total N in the plant tops and grain yield at the indicated dates.

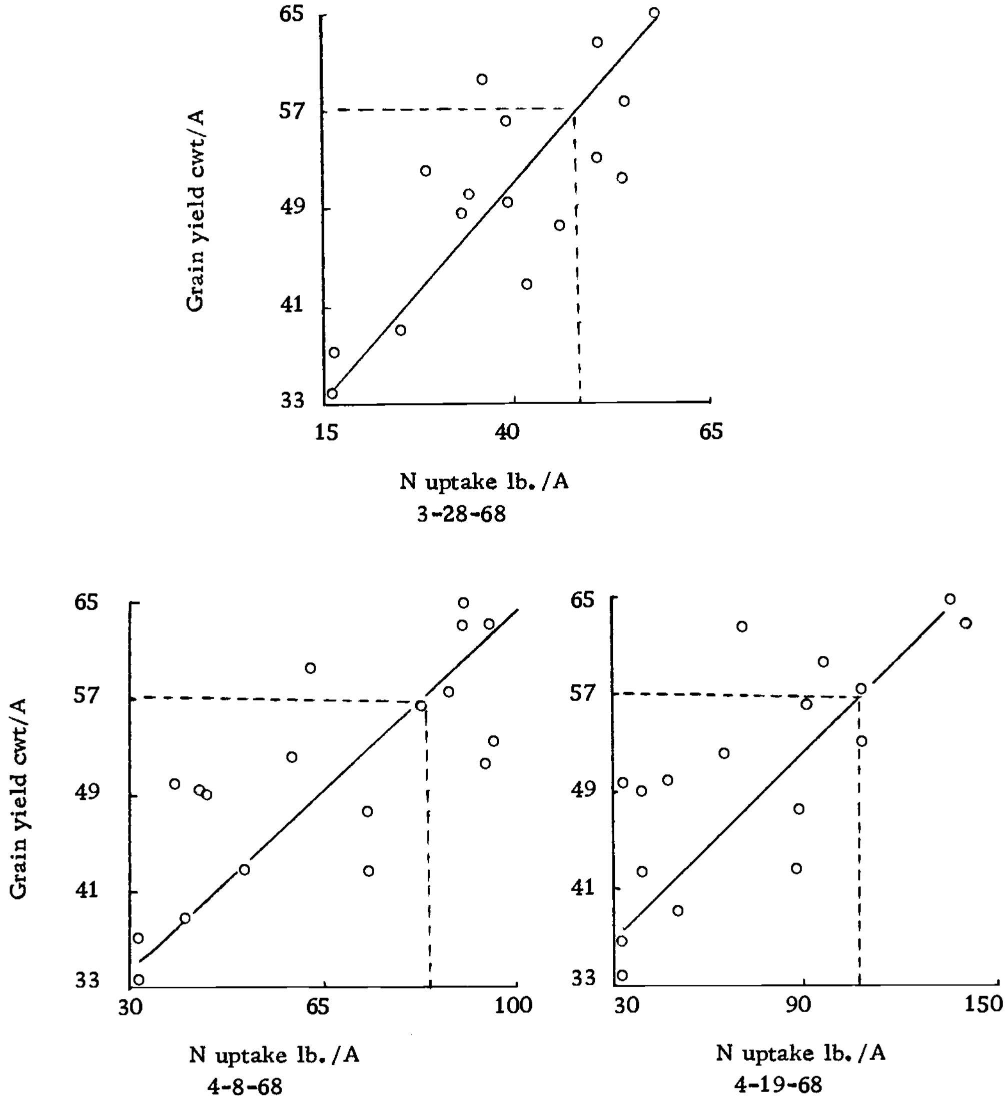


Figure 20. The relationship between total N uptake and grain yield at the indicated dates.

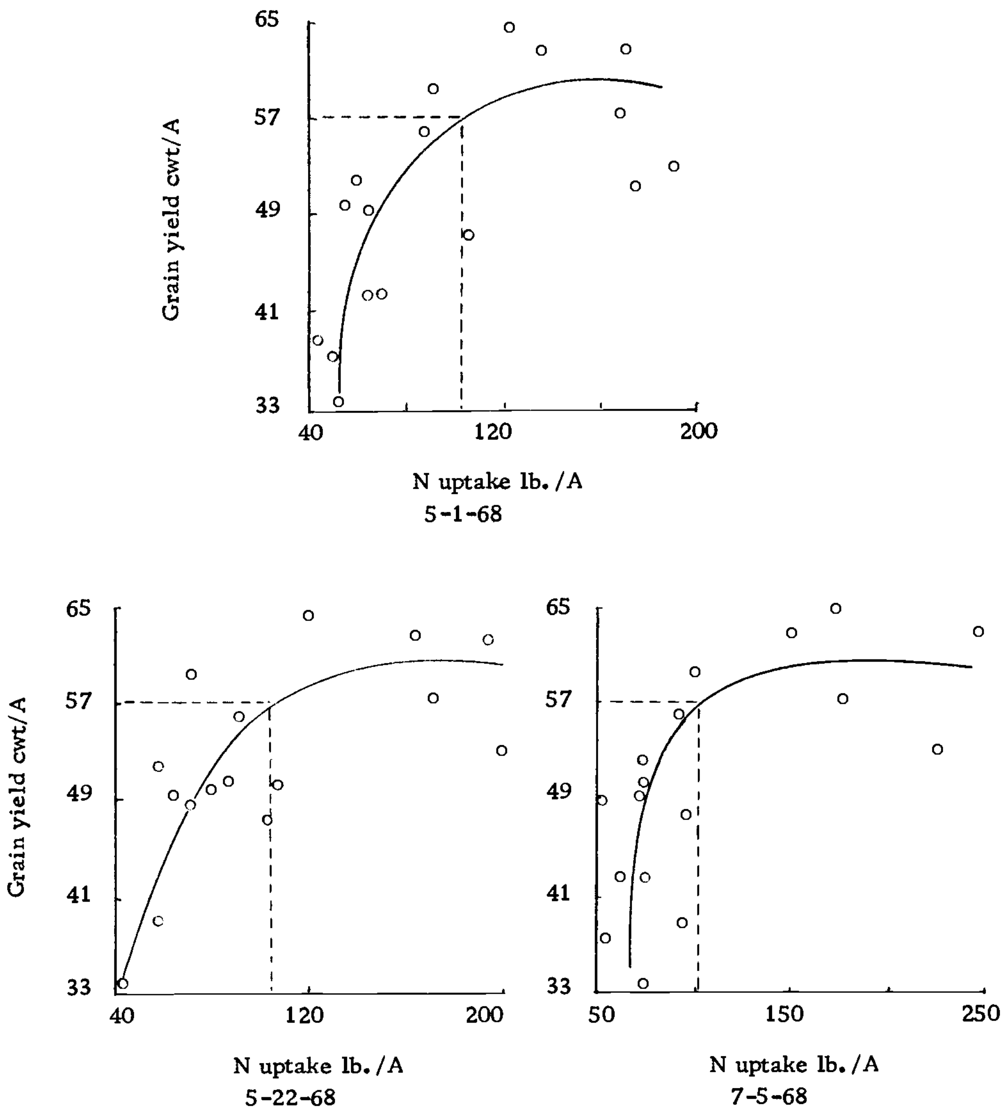


Figure 21. The relationship between total N uptake and grain yield at the indicated dates.

made on six different samplings, indicated considerably greater precision was attained in the total N measurements than for nitrate-N. The critical level of plant N was estimated at 4.4% on 3-28-68 but this decreased to less than 2% on 5-1-68. The first approximation of 2.8% N as the critical level at the jointing stage (Figure 18, 4-19-68) compares favorably with the value reported by Archarya and Jadav (1957). The first approximations for critical levels of N on other sampling dates are shown in Table 14.

The total uptake of N was evaluated as an approach to the assessment of the N status of the wheat plant. As indicated in Table 14 the maximum uptake of N as result of N fertilization was at each sampling consistently three to four fold greater than when there was no application of N. The coefficient of variation indicated a lower degree of precision was obtained in measuring the total uptake of N than in measuring the concentration of N in the plant top (Table 14).

Estimated critical levels based on the uptake of total N, unlike those based on concentration of N in the tissue, increased with time and then remained constant after 4-19-68 (Table 14). There is considerable difficulty in estimating the critical level for uptake of N particularly for the first three sampling dates. Figure 20 suggests a linear relationship between grain yield and total N uptake for the first three dates of sampling although there is considerable deviation from the regression line.

For samples collected on 5-1-68 and thereafter a strong inflection was evident in the yield curve (Figure 21) which was indicative of increased N uptake in the absence of an increase in yield. Indeed, concentration of plant nitrogen data reported in Table 6 supports this conclusion. It appears that ultimately the uptake of a minimum of 100 pounds per acre of N may be necessary to meet the requirement for wheat yields comparable to those obtained in this experiment.

Of course, it is not possible to obtain a reliable value for a critical level of nutrient from a single experiment. Further experiments are needed in order to examine whether the observed optimum levels of nitrate-N, total N or total N uptake for particular dates of sampling could be adopted as a reliable guide for applying nitrogenous fertilizers. Supplemental applications of N fertilizer must also be considered from the standpoint of cost and crop response before the present observations could be developed into a useful guide for fertilization.

Plant Morphology

In the preceeding section of this report a tentative calibration curve is presented for predicting the yield of wheat from the concentration of N in a specific part of the wheat plant. It is believed that once a reliable calibration curve is obtained, then plant tissue analysis for N may serve as a direct approach for assessing the N status of the wheat plant. For commercial wheat production, a supplemental application of N may be advisable when on the basis of tissue analysis the predicted yield falls below the desired optimum level.

Other investigators (McNeal and Davis, 1954; Wahhab and Hussain, 1957; and Rhode, 1964) indicated changes in the morphology or growth pattern of the wheat plant were associated with variations in the rate of N fertilization. A part of this research deals with an investigation of the potential use of plant morphological characteristics as an indication of the N status of the wheat plant.

Presented in Table 15 is a summary of the effects of N availability on selected parameters which are designated as morphological in nature. The numerical range between the value recorded for the control and the highest value found for any of the experimental treatments is shown for each parameter. The precision of measurement attainable in the experiment is indicated in terms of the coefficient of variation (C. V.) for each of the morphological changes (yield of dry matter, culm count and leaf percentage) which are significantly affected by the level of N fertilization. Considerably greater precision is attainable for measuring leaf percentage than for the other parameters. The first significant increase in leaf percentage as a result of N treatment is reported for the sampling date of 4-19-68

Table 15. Sensitivity of the measurements of the morphological characteristics of the wheat plant to different levels of available nitrogen.

Parameter	Date of Measurement	Range of Parameter	Fold Increase of Treated over Control	Probability for Treatment Effects	C. V. %	Estimated Critical Level
Dry matter lb./A	3-28-68	820-1320	1.6	N.S.	23.2	-
	4- 8-68	1480-2410	1.6	0.01	12.8	1,900
	9-19-68	2210-3900	1.8	N.S.	29.2	-
	5- 1-68	3650-6340	1.7	0.01	16.5	5,000
	5-22-68	6180-11720	1.9	0.01	7.4	8,500
	7- 5-68	8140-16730	2.1	0.01	20.3	11,000
Number of culms/foot of row	3-28-68	41-67	1.6	N.S.	21.6	-
	4- 8-68	47-73	1.5	N.S.	18.4	-
	4-19-68	50-76	1.5	N.S.	27.0	-
	5- 1-68	39-67	1.7	0.01	14.1	56
	5-22-68	33-62	1.9	0.01	15.1	65
Leaf Percentage	3-28-68	58.2-64.6	1.1	N.S.	6.9	-
	4- 8-68	51.8-57.8	1.1	N.S.	4.4	-
	4-19-68	46.0-56.0	1.2	0.05	7.4	-
	5- 1-68	34.0-42.1	1.2	0.05	6.0	36
	5-22-68	18.3-25.7	1.4	0.01	5.4	17

when the plants were at the jointing stage. From a practical standpoint this early diagnosis of plant N status is important so that ample time remains for additional N fertilization.

A graphical technique similar to that outlined by Ulrich (1967) was used for estimating the critical levels (Table 15) the same as in the previous section for plant N. The data for yield of grain was plotted against the yield of dry matter, culms per foot of drill-row and leaf percentage (Figures 22, 23 and 24). Consideration of the critical levels for the plant morphological changes were undertaken since these characteristics along with grain yield were all significantly affected by N fertilization.

No close relationship was apparent between grain yield and such plant morphological characteristics as dry matter yield, number of culms per foot of drill-row and leaf percentage (Figures 22, 23 and 24). However, scatter diagrams show a trend between increase in yield being associated with increase in these plant measurements (positive correlation). In contrast, extremely high values for plant measurements were associated with a decrease in grain yield which was indicative of a negative correlation. Therefore the technique of linear regression analysis was of limited value for handling the data from the experiment. But as shown in Figure 23 there was a highly significant correlation between the grain yield and the number of culms per foot of drill-row which was recorded on 5-1-68 ($r = 0.61$)

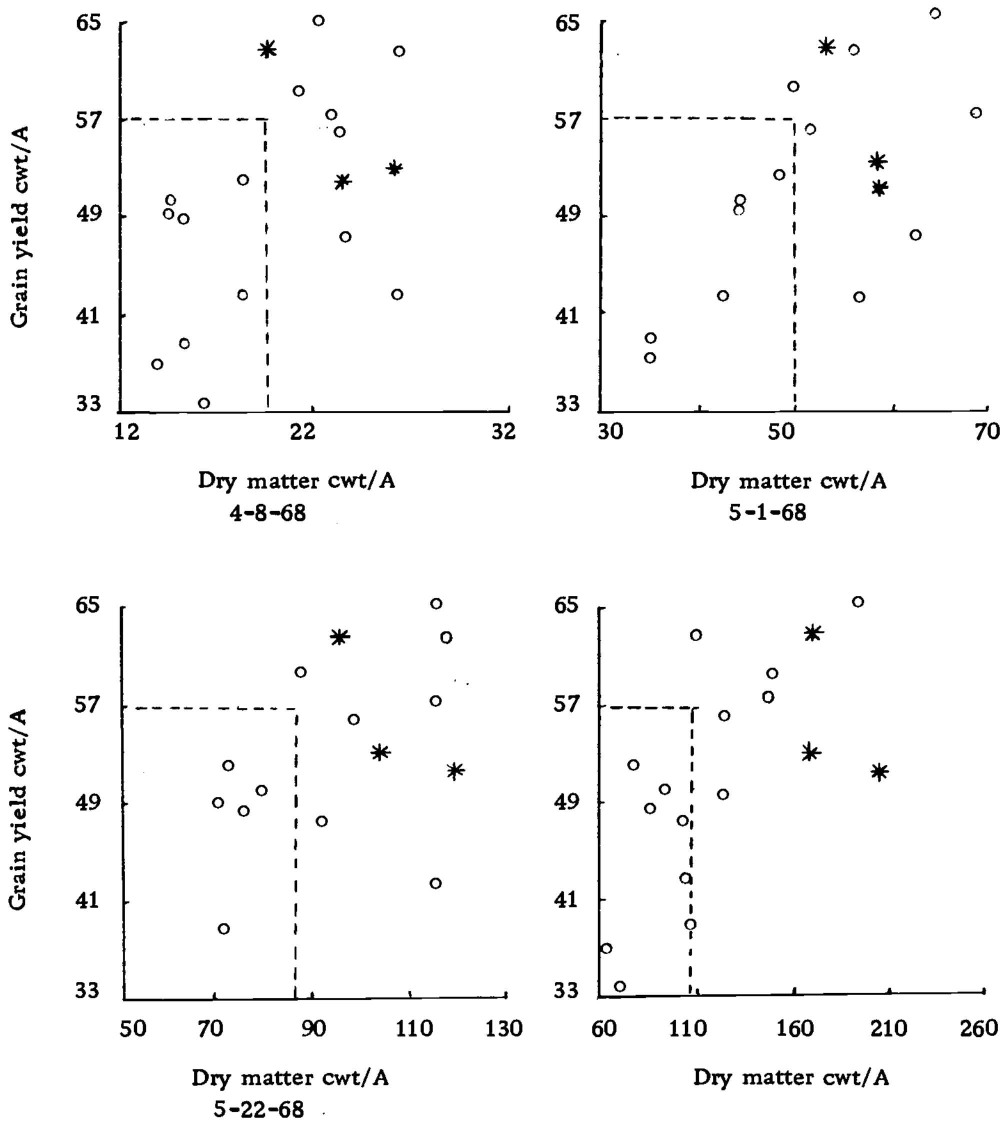


Figure 22. The relationship between dry matter and grain yield at the indicated dates. (The optimum yield or 95% of the yield for the maximum treatment mean and the estimated critical level for the measurement are denoted by the horizontal dashed line and by the vertical dashed line, respectively. The asterisks denote data points for which a definite yield depression resulted from excess N fertilizer.)

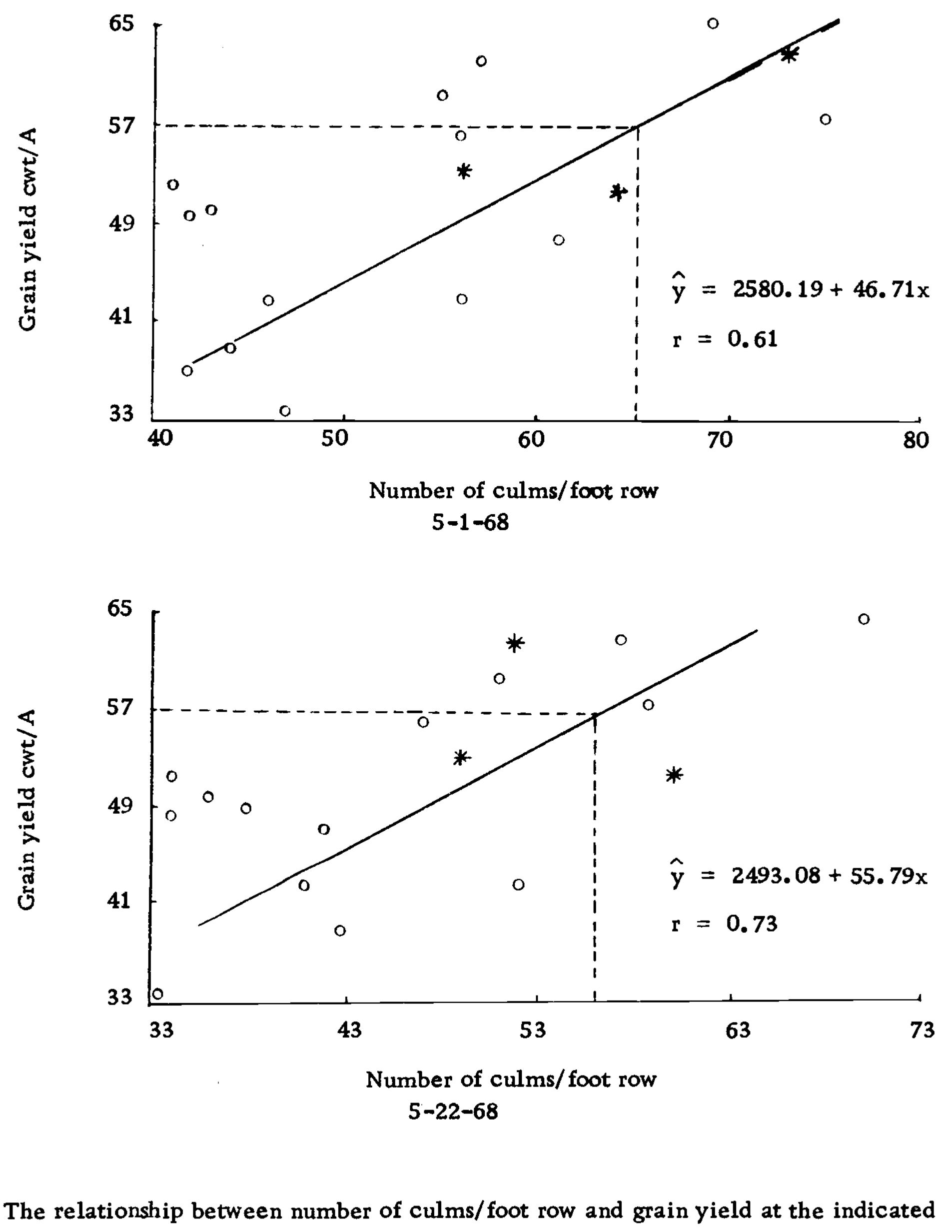


Figure 23. The relationship between number of culms/foot row and grain yield at the indicated dates. (The optimum yield or 95% of the yield for the maximum treatment mean for the experiment and the critical range for the plant measurement are indicated by the horizontal dashed line and pair of vertical dashed lines respectively. The asterisks denote data points of known yield depression resulting from excess N fertilizer.)

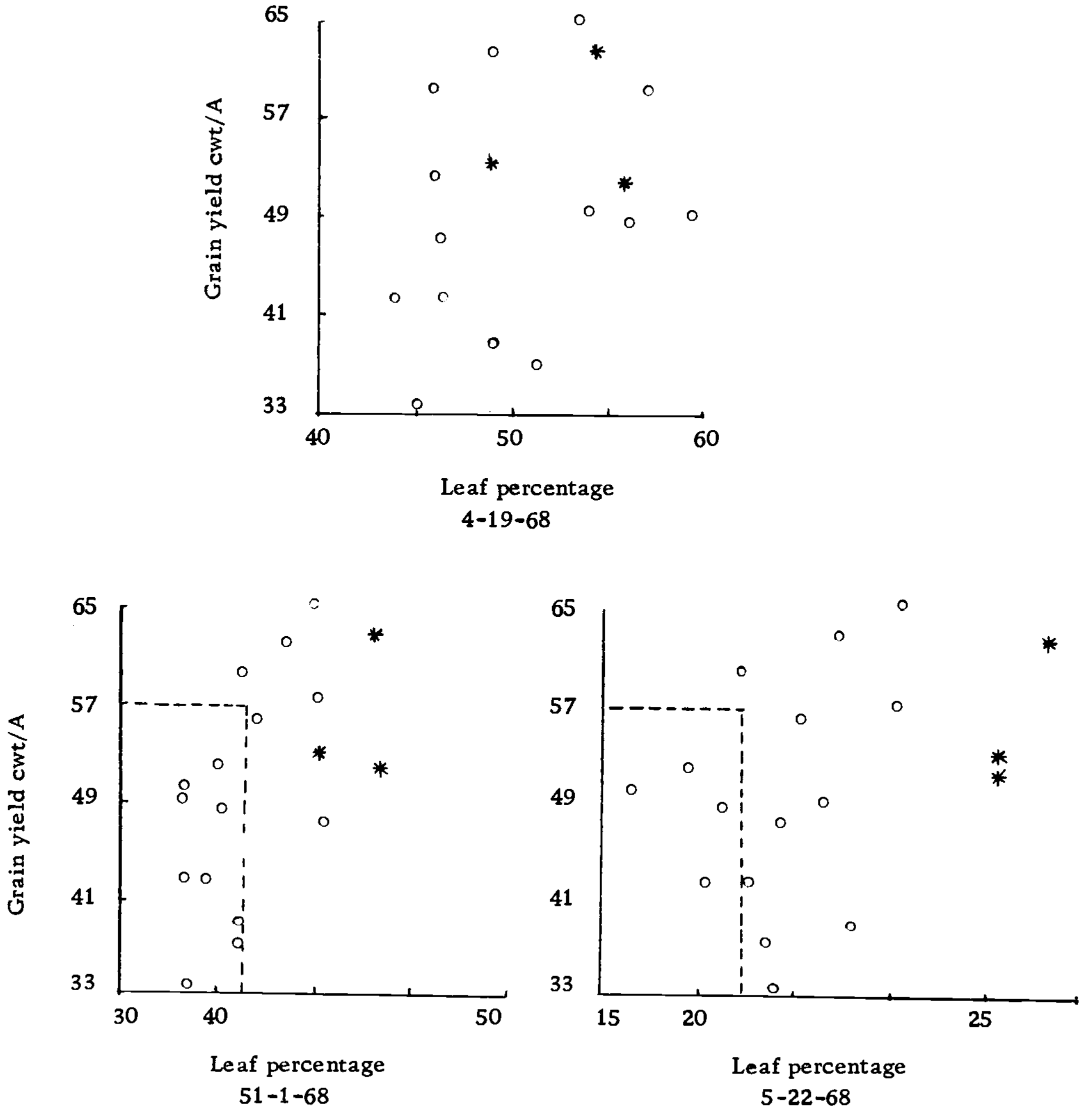


Figure 24. The relationship between leaf percentage and grain yield at the indicated dates. (Horizontal dash line represents the optimum yield or 95% of the mean maximum yield for the maximum treatment mean for the experiment and the vertical dashed line represents the estimated critical level. Data points denoted by asterisks are known cases of yield depression resulting from excessive N fertilization.)

and on 5-22-68 ($r = 0.73$).

The estimated critical level for yield of dry matter needed to produce the optimum grain yield was about 1,900 pounds per acre on 4-8-68. The estimated critical levels increased with time as more dry matter was produced, and beginning on 5-22-68 and ending on 7-5-68, the critical values increased from 8,500 to 11,000 pounds of dry matter per acre (Table 15).

The data suggest that 56 to 65 culms per foot of drill-row is sufficient to produce the optimum yield of wheat (Figure 23). But on the basis of r values (Figure 23) the number of culms per foot of drill-row account for only about half of the variation in yield. The approximation of the critical level for leaf percentage fluctuates markedly with time. The value of the critical level for leaf percentage decreased nearly 50% in the interval 5-1-68 to 5-22-68 (Table 15). Certainly any attempt to use leaf percentage and dry matter for diagnosing the N status of the wheat plant must take into consideration the time of sampling.

It is evident from this experiment that "wheat morphology" (dry weight, culms per foot of drill-row and leaf percentage) probably has limited utility as a tool for evaluating N status of the wheat plant since they are obviously influenced by many other factors besides N. These measurements also lack specificity, in that a deficiency of other nutrients or a shortage of another growth factor may also produce similar effects on plant morphology. For this reason, chemical analysis is probably much more useful a tool in identifying pending N deficiency.

SUMMARY AND CONCLUSION

An experimental field trial was conducted during the 1968 growing season to study the response of Nugaines wheat to different rates of N fertilization. The soil at the experimental site in Lane County was classified as the Malabon series which normally produce some of the highest wheat yields recorded in the Willamette Valley. The experimental site was selected to provide cropping conditions which were representative of the wheat producing areas of western Oregon.

The general objective of the study was to obtain research information with definite implication on the development of a diagnostic test for assessing the N status of the wheat plant under different N regimes. To achieve this objective the results obtained were first analyzed statistically to determine the effects of various N treatments on the wheat plant. Next comparisons of the data were undertaken to evaluate the sensitivity of certain measured parameters to changes in the level of N fertilization. The final step in data processing was to estimate periodically through the growing season by graphical means the critical levels of the measured parameters for the wheat plants.

A randomized block design with three replications was used for the experiment. The six experimental treatments which were applied to paired plots within each replication, consisted of five different rates of N plus an untreated control. One plot of each pair served as the source of plant tissue samples which were collected at six different times during the growing season for analytical purposes. The second plot was harvested at maturity for determining the yield of grain. Measurements were recorded to study the effect of N on grain yield, grain quality, plant morphology, dry matter yield, nutrient concentration of plant tissue, and total uptake of selected nutrients.

The experimental results obtained from this study supported the following conclusions:

1. Significantly greater yields of grain and dry matter were produced by the plots which received N fertilizer at rates ranging from 50 to 200 pounds per acre than by the control plots which were unfertilized.

2. The application of 125 pounds of N per acre in the spring produced the highest yield of grain (6100 pounds per acre), and 200 pounds of N per acre produced the highest yield of dry matter. On 7-5-68 which was the latest sampling date, the highest yield of dry matter (18,250 lbs./A) was recorded.

3. An application of N at a rate equivalent to 200 pounds per acre caused a depression in grain yield compared with the 125-pound N rate. The yield depression may have resulted from a shortage of

available moisture at this high rate of N.

4. The 200 pounds of N per acre treatment produced the largest number of culms per foot of drill-row and the highest percentage of leaf material on the wheat plants. Responses to N fertilizer in terms of both culms and leaf percentage was significantly greater than the control.

5. There was an increase in the production of dry matter with time, but as the wheat plants matured there was a decrease in both leaf percentage and in the production of normal sized culms per foot of drill-row.

6. The statistical significance of the effect of N fertilization on the wheat plant was first demonstrated for dry matter production on 4-8-68, for culm counts on 5-22-68 and for leaf percentage on 5-1-68 (Table 15).

7. The application of N up to 75 pounds of N per acre resulted in small decreases in protein content of the grain, but had no noticeable effect on test weight. Compared with the treatments consisting of the untreated control or the low rates of N, the protein content of the grain increased significantly and the test weight decreased significantly as a result of applying either 125 or 200 pounds of N per acre in the spring.

8. The concentration of N, P, K, Ca and Mg in the plant tissue decreased with time as the plants matured. The total uptake of these

nutrients except K increased with time and reached peak values at the soft dough stage on 7-5-68. The uptake of K by the wheat plant reached a peak prior to the soft dough stage and then dropped off slightly which seemed to indicate a loss of K from the plant tops.

9. The N treatments significantly increased the concentration of N, P, K, and Ca but not Mg in the wheat plant top at one or more of the dates when samples were collected. The statistically significant increase in the concentration of N was demonstrated in the plant tops soon after N fertilization, increases in the concentration of nitrate-N were demonstrated in the leaves, stems and plant tops.

10. For each of several successive sampling dates the concentration of nitrate-N in the stems was higher than the concentration of nitrate-N in the leaves irrespective of the N treatment. The concentration of nitrate-N in the lower leaves was less than the concentration of nitrate-N in the two uppermost leaves particularly at the boot stage on 5-22-68.

11. The N applications significantly increased both the concentration of N in the plant and the uptake of N in plant tops over the entire period when samples were collected. The quantity of N taken up the treatment consisting of 200 pounds of N per acre resulted in the uptake of three times as much N by wheat plants at the soft dough stage as did the treatment consisting of 75 pounds N per acre or less.

12. Only the plants from plots with the high rate of N

fertilization showed an increased K concentration over untreated control at the "boot" stage. The concentration of P at the boot stage was unaffected by N fertilization.

13. There was a significant correlation between the K concentration in the plant at the jointing stage and the final yield of grain ($r = 0.68$).

14. The 1968 growing season had only minor deviations from the normal weather pattern for the Willamette Valley. One should anticipate obtaining similar results for crop response to N if the experiment were repeated at other locations in the Willamette Valley in succeeding years.

15. The critical levels for the concentration of nutrients in the wheat tissue were estimated at 5700 pounds of grain yield per acre which was 95% of the yield of the maximum treatment mean for the experiment.

16. The observed critical levels of these parameters changed markedly with time. For example the estimated critical level for nitrate-N concentration in wheat leaves approached 900 parts per million on 3-28-68, but was estimated at about 300 parts per million on 4-19-68 or 5-1-68. In the stem the critical levels for nitrate-N was estimated at 4200 parts per million on 3-28-68 and dropped back to 600 and 200 parts per million on 4-19-68 and 5-1-68, respectively.

17. The greater precision of measurement was attained for

total N than for nitrate-N. The critical level of plant N was estimated at 4.4% on 3-28-68, but this decreased to less than 2% on 5-1-68. The critical level for N uptake was very constant and was estimated at a minimum of 100 pounds per acre in the plant tops from 4-19-68 to 7-5-68.

18. The feasibility of tissue testing was demonstrated as a guide for use in determining the N fertilizer requirement of wheat in western Oregon.

A suitable approach for assessing the N status of the wheat plant appeared to be that of measuring either the level of total N in plant tops or the level of nitrate-N in the plant leaves the latter part of April. In order to produce an optimum yield, a desirable level of total N in the plant top was about 2.8% while a desirable level of nitrate-N in the leaves was about 300 parts per million.

BIBLIOGRAPHY

Acharya, C. N. and K. J. Jadav. 1957. The chemical composition of the wheat plant as a guide to its manurial requirements. I. The relation between the chemical composition of the leaves, stem, and the whole aboveground plant to the final crop yields. Indian Journal of the Society of Soil Science 5: 173-180.

Allison, F. E. and L. D. Sterling. 1949. Nitrate formation from soil organic matter in relation to total nitrogen and cropping practices. Soil Science 67: 239-252.

Ames, J. W. 1910. The composition of wheat; influence of various factors on the phosphorus potassium and nitrogen content of the wheat plant. Columbus. 37p. (Ohio. Agricultural Experiment Station. Bulletin 221)

Arnon, D. L. 1939. Effect of ammonium and nitrate nitrogen on the composition and sap characteristic barley. Soil Science 48: 295-307.

Baker, G. O. 1950. Effect of nitrogen fertilizer on wheat in the Palous area. Northwest Science 24: 137-139.

Baldwin, C. S. and J. W. Ketcheson. 1958. Influence of soil texture, reaction and temperature on the uptake of nitrogen from three nitrogen fertilizers. Canadian Journal of Soil Science 38: 134-142.

Bayfield, E. G. 1936. The influence of climate, soil and fertilizers upon quality of winter wheat. Columbus. 77p. (Ohio. Agricultural Experiment Station. Bulletin 563)

Blackett, G. A. 1957. Effect of rate and time of application of nitrogen on the yield of winter wheat. Empire Journal of Experimental Agriculture 25: 19-23.

Bremner, J. M. 1965. Total nitrogen. In: Methods of soil analysis. Part 2. Chemical and microbiological properties, ed. by C. A. Black et al. Madison, Wisconsin. p. 1149-1178. (American Society of Agronomy. Agronomy; a Series of Monographs. No. 9)

Bremner, J. M. and A. P. Edwards. 1965. Determination and isotope-ratio analysis of different forms of nitrogen in soils. 1. Apparatus and procedure for distillation and determination of ammonium. Proceedings of the Soil Science Society of America 29: 504-507.

Bremner, J. M. and D. R. Keeney. 1966. Determination and isotope-ratio analysis of different forms of nitrogen in soils. 3. Exchangeable ammonium, nitrate, and nitrate by extraction-distillation methods. Proceedings of the Soil Science Society of America 30: 577-582.

Breon, W. S. et al. 1944. Influence of phosphorus supply and the form of available nitrogen on the absorption and distribution of phosphorus by tomato plant. Plant Physiology 19: 495-506.

Brown, J. G., O. Littleland and R. K. Jackson. 1948. The determination of calcium and magnesium in leaves using flame methods and quartz spectrophotometer. Proceedings of the American Society for Horticultural Science 52: 1-6.

Carpenter, R. W., H. J. Haas and E. F. Miles. 1952. Nitrogen uptake by wheat in relation to nitrogen content of soil. Agronomy Journal 44: 420-423.

Cook, G. W. and R. K. Cunningham. 1958. Mineralizable nitrogen determined by an incubation technique. Journal of the Science of Food and Agriculture 9: 324-330.

Crawford, R. F., W. K. Kennedy and W. C. Johnson. 1961. Some factors that affect nitrate accumulation in forages. Agronomy Journal 53: 159-162.

Davidson, J. and J. A. LeClure. 1917. The effect of sodium nitrate applied at different stages of growth on the yield, composition, and quality of wheat. Journal of the American Society of Agronomy 9: 145-154.

Davidson, J. and J. A. LeClure. 1918. The effect of sodium nitrate applied at different stages of growth on the yield, composition and quality of wheat. Journal of the American Society of Agronomy 10: 193-198.

Dijksnoorn, W. 1958. Nitrogen and potassium in perrenial ryegrass and their relation to the mineral balance. Netherlands Journal of Agricultural Science 6: 131-138, 211-221.

Doneen, L. D. 1934. Nitrogen in relation to composition, growth and yield of wheat. Pullman. 70p. (Washington. Agricultural Experiment Station. Bulletin 296)

Doormaar, F. J. and J. W. Ketcheson. 1960. The effect of nitrogen form and soil temperature on the growth and phosphorus uptake of corn plants grown in the greenhouse. Canadian Journal of Soil Science 40: 177-181.

Dubetz, S. 1961. Effect of soil type, soil moisture and N fertilization on the growth of spring wheat. Canadian Journal of Soil Science 41: 44-51.

Fernandez, R. G. and R. J. Laird. 1959. Yield and protein content of wheat in central Mexico as affected by available soil moisture and nitrogen fertilization. Agronomy Journal 51: 33-36.

Gardner, W. H. 1965. Water content. In: Method of soil analysis. Part 1. Physical and mineralogical properties, including statistics of measurement and sampling, ed. by C. A. Black et al. Madison, Wisconsin. p. 82-127. (American Society of Agronomy. Agronomy; a Series of Monographs. No. 9)

Gilbert, G. S. et al. 1946. Nitrate accumulation in cultivated plants and weeds. Laramie. 39p. (Wyoming. Agricultural Experiment Station. Bulletin 277)

Gonke, R. G. and D. R. Keeney. 1967. Effect of fertilizer N, variety and maturity on the dry matter yield and nitrogen fractions of corn grown for silage. Agronomy Journal 61: 72-76.

Grunes, D. L. et al. 1958. Proportionate uptake of soil and fertilizer phosphorus by plants as affected by nitrogen fertilization. 1. Growth chamber experiment. Proceedings of the Soil Science Society of America 22: 43-48.

Grunes, D. L. 1959. Effect of nitrogen on the availability of soil and fertilizer phosphorus to plants. Advances in Agronomy 11: 369-393.

Hanway, J. J. and A. J. Englehorn. 1958. Nitrate accumulation in some Iowa crop plants. Agronomy Journal 50: 331-334.

Hobbs, J. A. 1953. The effect of spring nitrogen fertilization on plant characteristics of winter wheat. Proceedings of the Soil Science Society of America 17: 39-42.

Hopkins, J. W. 1935. Influence of weather conditions on nitrogen content of wheat. Canadian Journal of Research 12:228-237.

Hunter, A. S. et al. 1958. The effect of nitrogen fertilizers on the relationship between increases in yields and protein content of pastry type wheats. Agronomy Journal 51:311-314.

Hunter, A. S. et al. 1961. Investigations of fertilizer needs of wheat in the Columbia Basin Dryland area of Oregon. Corvallis. 45p. (Oregon. Agricultural Experiment Station. Technical Bulletin 57)

Hutcheon, W. L. and E. A. Paul. 1966. Control of the protein content of Thatcher wheat by N fertilization and moisture stress. Canadian Journal of Soil Science 46:101-108.

Jackson, M. L. 1958. Soil chemical analysis. Englewood Cliffs, New Jersey, Prentice Hall. 500p.

Jacob, K. D. and W. L. Hill. 1953. Laboratory evaluation of phosphorus fertilizers. In: Soil and fertilizer phosphorus in crop nutrition, ed. by W. H. Pierre and A. G. Norman. New York, Academic. p. 299-345. (American Society of Agronomy. Agronomy; a Series of Monographs. Vol. 4)

Johnson, C. M. and A. Ulrich. 1959. Analytical methods for use in plant analysis. Part II. Davis. p. 25-78. (California. Agricultural Experiment Station. Bulletin 766)

Knowles, F. and J. E. Watkins. 1931. The assimilation and translocation of plant nutrients in wheat during growth. Journal of Agriculture Science 21:612-637.

Koehler, F.E. 1961. Fertilizer and wheat quality. Proceedings of Pacific Northwest Fertilizer Conference 12:73-78.

Lathane, J. J. and W. J. Staple. 1959. Effects of soil moisture tensions on growth of wheat. Canadian Journal of Soil Science 42:180-188.

Laude, H. H. 1938. Relation of some plant characters to yield in winter wheat. Journal of the American Society of Agronomy 30:610-615.

LeClere, J. A. and P. A. Yoder. 1914. Environmental influences on the physical and chemical characteristics of wheat. Journal of Agricultural Research 1:275-291.

Lehr, J. J. and J. Van Wesemael. 1956. Variation in the uptake by plants of soil phosphate as influenced by sodium nitrate and calcium nitrate. Journal of Soil Science 7: 148-155.

Long, O. H. and J. A. Ewing. 1949. Fertilizer studies on small grains with special emphasis on time and rate of nitrogen application. Knoxville. (Tennessee. Agricultural Experiment Station. Bulletin 209)

Long, O. H. and C. D. Sherbakoff. 1951. Effect of nitrogen on yield and quality of wheat. Agronomy Journal 43: 320-321.

McCalla, A. G. and E. K. Woodford. 1938. Effects of limiting element on the absorption of individual elements and on anion-cation balance in wheat. Plant Physiology 13: 695-712.

McLean, E. O. 1957. Plant growth and uptake of nutrients as influenced by levels of nitrogen. Proceedings of the Soil Science Society of America 21:219-222.

McNeal, F. H. and D. J. Davis. 1954. Effect of nitrogen fertilization on yield, culm and protein content of certain spring wheat varieties. Agronomy Journal 46: 375-378.

Miller, M. H. and A. J. Ohlrogge. 1958. Principle at nutrient uptake from fertilizer bands. I. Effect of placement of N fertilizer on uptake of band placed P at different soil P levels. Agronomy Journal 50: 95-97.

Moeller, W. J. and R. L. Thurman. 1966. Nitrate content of fall-sown rye, wheat and oat forages. Agronomy Journal 58: 627-628.

Noggle, J. C. 1966. Ionic balance and growth of sixteen plant species. Proceedings of the Soil Science Society of America 30: 763-766.

Olson, G. A. 1923. A study of factors affecting the nitrogen content of wheat and of the changes that occur during the development of wheat. Journal of Agricultural Research 24: 939-953.

Olson, S. R. et al. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Washington, D. C. 19p. (U. S. Department of Agriculture. Circular 939)

Peterson, H. B. 1952. Effect of N fertilizer on yields and protein content of wheat in Utah. Logan. 29p. (Utah. Agricultural Experiment Station. Bulletin 353)

Rankin, W. H. 1947. Effect of N supplied at various stages of growth on the development of the wheat plant. Proceedings of the Soil Science Society of America 11: 384-387.

Rannie, D. A. and R. J. Soper. 1958. The effect of nitrogen additions on fertilizer phosphorus availability. Journal of Soil Science 9: 155-167.

Reitz, L. P. 1967. World distribution and importance of wheat. In: Wheat and wheat improvement, ed. by K. S. Quisenberry and L. P. Reitz. Madison, Wisconsin. p. 1-18. (American Society of Agronomy. Agronomy; a Series of Monographs. No. 13)

Rhode, C. R. 1963. Effect of N fertilization on yield, components of yield and other agronomic characteristics of winter wheat. Agronomy Journal 55: 455-458.

Rossner, J. T. 1968. The response of winter wheat to irrigation in the Willamette Valley. Master's thesis. Corvallis, Oregon State University. 50 numb. leaves.

Russel, G. C., A. D. Smith and U. J. Pittman. 1958. The effect of nitrogen on the yield and protein content of spring wheat grown on stubble fields in southern Alberta. Canadian Journal of Soil Science 38: 139-144.

Sayre, J. D. 1948. Mineral accumulation in corn. Plant Physiology 23: 267-281.

Schollengberger, C. J. and R. H. Simon. 1945. Determination of exchange capacity and exchangeable bases in soils-ammonium acetate method. Soil Science 59: 13-24.

Shaw, G. W. and E. C. Walters. 1911. A progress report upon soil and climatic factors influencing the composition of wheat. Berkeley. p. 549-574. (California. Agricultural Experiment Station. Bulletin 216)

Shenk, M. D. 1968. Some components of test weight of soft white wheat. Master's thesis. Corvallis, Oregon State University. 67 numb. leaves.

Smith, J. C., L. C. Kapp and R. C. Potts. 1950. The effects of fertilizer treatments upon yield and composition of wheat forage. Proceedings of the Soil Science Society of America (1949) 14:241-245.

Snyder, H. 1907. Fertilizer tests with wheat and corn. St. Paul. 38p. (Minnesota. Agricultural Experiment Station. Bulletin 102)

Staple, W. J. and J. J. Lathane. 1954. Weather conditions influencing wheat yields in tanks and field plots. Canadian Journal of Agricultural Science 34: 553-564.

Tromp, J. 1962. Interaction in the absorption of ammonium, potassium and sodium ions by wheat roots. Aeta Botanica Neerlandica 11: 147-192.

Udy, D. C. 1956. Estimation of protein in wheat and flour by ion binding. Cereal Chemistry 33: 190-197.

Ulrich, A. 1950. Critical nitrate levels of sugar beets estimated from analysis of petioler and blades with special reference to yield and sucrose concentrations. Soil Science 69:291-309.

Ulrich, A. and F. J. Hills. 1967. Principle and practices of plant analysis. In: Soil testing and plant analysis. Part II. Plant analysis. Madison, Wisconsin. p. 11-24. (Soil Science Society of America. Special Publication no. 2)

Wahhab, A. and I. Hussain. 1957. Effect of N on growth quality and yield of irrigated wheat in West Pakistan. Agronomy Journal 49: 116-119.

Warder, F. G. et al. 1963. The effect of fertilizer on growth nutrient uptake moisture use of wheat on two soils in southwestern Saskachewan. Canadian Journal of Soil Science 43: 107-116.

Whitson, A. R., F. J. Wells and A. Vivian. 1903. Influence of the soil on the protein content of crops. In: Annual report of the Agricultural Experiment Station, 1901-1902. Madison, Wisconsin. p. 192-209.

Wiersum, L. K. 1962. Uptake of nitrogen and phosphorus in relation to soil structure and nutrient mobility. Plant and Soil 16: 62-70.

Williams, B. C. and F. W. Smith. 1954. The effect of different rate, times and methods of application of various fertilizer combinations on the yield and quality of hard red winter wheat. Proceedings of the Soil Science Society of America 18: 56-60.

Willis, W. O. et al. 1957. Corn growth as affected by soil temperature and mulch. Agronomy Journal 49: 323-328.

Wit, C. T. de, W. Dijksnoorn and J. C. Noggle. 1963. Ionic balance and growth of plants. Verslagen Van Landouwkundige Onderzoekingen 15: 1-68.

Yuen, S. H. and A. G. Pollard. 1957. The availability of soil phosphate. IV. The effect of nitrogen on the utilization of phosphate by Italian ryegrass. Journal of the Science of Food and Agriculture 8: 475-482.

APPENDICES

APPENDIX A

DESCRIPTION OF SOIL AT EXPERIMENTAL SITE[a]

Soil Series: Malabon 67 Oreg 20-13
Location: SE NE Sec. 19, T15S, R4W
Slope: 1%

Physiography: Winkle terrace
Relief: Slightly convex
Date Sampled: July 14, 1967

Horizon	Depth, cm	Morphology
Ap	0-15	Dark brown (7.5YR3/2)[b] silty clay loam, dark grayish brown (10YR4/2) dry; moderate fine granular and subangular blocky structure; hard, friable, sticky, plastic; many fine tubular pores and many interstitial pores; abrupt smooth boundary.
A3	15-30	Dark brown (7.5YR3/2) silty clay loam, dark grayish brown (10YR4/2) dry; weak medium subangular blocky structure and massive; hard, friable, sticky, plastic; many very fine tubular pores; few 1-2 inch pebbles; clear wavy boundary.
Blt	30-46	Dark brown (7.5YR3/3) light silty clay; moderate medium subangular blocky structure; firm, sticky, plastic; many fine and few medium tubular pores; few thin dark brown (7.5YR3/2) clay films; clear wavy boundary.
B21t	46-86	Dark brown (7.5YR3/3) light silty clay; moderate medium subangular blocky and strong fine granular structure; firm, sticky, plastic; many and common medium pores; common thin dark brown (7.5YR3/2) clay films; gradual wavy boundary.
B22t	86-119	Dark yellowish brown (10YR3/4) heavy silty clay loam; moderate medium and fine subangular blocky structure with pockets of strong fine granular structure; friable, sticky, plastic; many fine and common medium tubular pores; common moderately thick dark brown (7.5YR 3/2) clay films; gradual wavy boundary.
B3t	119-147	Dark yellowish brown (10YR3/4) silty clay loam; weak coarse subangular blocky structure; friable, sticky, slightly plastic; many fine and few medium tubular pores; few thick dark brown (7.5YR3/2) clay films on peds and few moderately thick clay films in pores; gradual wavy boundary.
IIC1	147-160	Brown (10YR4/3) sandy loam; massive; very friable, slightly sticky, slightly plastic; many fine tubular pores; few thin clay films; abrupt wavy boundary.
IIIC2	160-165	Sandy gravel

[a]By Parsons, R. B. and R. C. Herriman.

[b]All Munsell notations for moist soil unless otherwise indicated.

APPENDIX B

Appendix Table 1. The moisture and nitrate-N content of soil to a depth of four feet on the dates indicated for the wheat experiment at the Drake Farm.

Spring Applied N lbs./A	Sampling Depth Feet	Soil Moisture Percentage and NO_3-N on Indicated Dates											
		3-28-68		4-8-68		4-19-68		5-1-68		5-22-68		7-5-68	
		Moisture %	NO_3N ppm	Moisture %	NO_3N ppm	Moisture %	NO_3N ppm	Moisture %	NO_3N ppm	Moisture %	NO_3N ppm	Moisture %	NO_3N ppm
0	0-1	31.32	3	28.63	2	b	9	21.20	10	19.08	3	10.26	10
	1-2	29.11	2	28.49	1	b	7	27.84	7	25.95	2	14.22	5
	2-3	33.46	1	39.64	2	b	10	31.06	12	32.83	0	24.55	7
	3-4	42.34	3	43.95	2	b	8	44.18	9	40.04	2	32.46	8
50	0-1	28.79	3	27.78	3	b	9	22.31	4	24.69	1	8.59	13
	1-2	30.62	2	27.66	3	b	9	24.24	3	22.93	0	11.78	8
	2-3	32.54	3	31.75	3	b	9	28.85	4	28.56	2	14.00	9
	3-4	41.91	5	43.01	2	b	10	42.81	4	32.05	3	17.53	7
50[a]	0-1	29.80	2	27.43	12	b	1	20.49	10	21.67	7	6.08	2
	1-2	28.48	3	28.38	15	b	7	25.93	9	21.09	8	9.64	-
	2-3	33.58	2	32.82	9	b	10	33.77	10	29.13	7	15.57	10
	3-4	34.30	4	32.06	10	b	10	22.04	11	22.18	13	18.57	10
75	0-1	29.37	3	27.72	11	b	11	21.39	2	20.66	2	8.45	9
	1-2	28.26	3	26.88	7	b	9	25.98	10	25.94	0	14.22	7
	2-3	33.30	4	34.80	7	b	10	34.34	10	27.33	0	17.62	8
	3-4	32.73	6	37.11	11	b	11	23.76	11	30.11	3	17.62	1
125	0-1	28.08	4	25.18	11	b	1	19.85	9	20.06	2	7.50	3
	1-2	28.71	5	30.56	11	b	2	25.00	9	21.83	8	13.39	2
	2-3	31.09	2	32.48	10	b	1	31.02	10	26.43	8	15.75	4
	3-4	33.95	3	33.26	10	b	3	35.46	10	33.43	8	12.28	1

Continued on next page

Appendix Table 1 Continued.

Spring Applied N lbs./A	Sampling Depth Feet	Soil Moisture Percentage and NO_3-N on Indicated Dates											
		3-28-68		4-8-68		4-19-68		5-1-68		5-22-68		7-5-68	
		Moisture %	NO_3N ppm	Moisture %	NO_3N ppm	Moisture %	NO_3N ppm	Moisture %	NO_3N ppm	Moisture %	NO_3N ppm	Moisture %	NO_3N ppm
200	0-1	30.11	7	24.66	25	b	11	19.04	11	28.70	9	14.16	13
	1-2	28.74	4	29.94	10	b	11	23.05	1	21.82	9	14.07	9
	2-3	33.67	4	29.53	10	b	11	29.23	1	25.36	1	16.52	13
	3-4	30.24	5	32.26	15	b	14	25.04	4	23.12	20	15.08	13

[a]This treatment received 45 lb N/A in the fall at seeding time; the control treatment received no fall applied N and all other treatments received 20 lb N/A at seeding time.

[b]Not determined.

Appendix Table 2. Ammonium-N content of soil to a depth of four feet for the wheat experiment at the Drake Farm on the dates indicated.

Spring Applied N lbs./A	Sampling Depth Feet	NH_4-N Content (ppm) of Soil on Indicated Dates					
		3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	7-5-68
0	0-1	13	15	8	14	13	6
	1-2	13	10	6	7	7	7
	2-3	10	12	7	11	8	7
	3-4	11	11	5	9	3	7
50	0-1	22	13	10	13	11	7
	1-2	10	9	9	21	12	5
	2-3	14	9	11	8	10	4
	3-4	10	14	8	12	10	3
50[a]	0-1	14	14	8	10	13	10
	1-2	8	9	11	7	4	9
	2-3	7	10	10	10	5	7
	3-4	8	7	7	10	5	9
75	0-1	21	14	8	12	10	1
	1-2	10	8	8	11	13	--
	2-3	11	6	9	6	11	7
	3-4	17	6	10	7	9	10
125	0-1	19	19	11	20	10	11
	1-2	12	11	8	7	7	7
	2-3	13	11	8	8	8	8
	3-4	14	8	9	11	7	19
200	0-1	14	22	16	23	11	12
	1-2	14	7	11	7	7	9
	2-3	9	9	11	7	9	8
	3-4	10	6	6	10	8	12

[a]This treatment received 45 lb N/A in the fall at seeding time; the control treatment received no fall applied N and all other treatments received 20 lb N/A at seeding time.

Appendix Table 3. The effect of N fertilization on the yield of total tops of the wheat plant on the sampling dates indicated.

Spring Applied N lbs./A	Average Dry Matter (lbs./A) on Different Dates of Sampling					
	3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	7-5-68
0	820	1520	2310	3650	6180	8140
50	1320	2260	3310	5130	10740	11050
50[a]	1100	1480	2210	3980	7620	10170
75	930	2120	3130	5170	8470	11230
125	1260	2410	3621	6360	11720	15270
200	1230	2320	3900	5660	10700	18250
LSD .05	-	470	-	1500	1250	860

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

Appendix Table 4. The effect of N fertilization on grain protein and test weight of wheat.

Spring Applied N lbs./A	Average Grain Protein (%)	Average Test Weight (lbs./bu)
0	7.17	62.20
50	6.71	61.83
50[a]	6.77	61.87
75	7.20	62.07
125	8.77	60.57
200	10.03	59.77
LSD 0.05	1.05	1.33

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

Appendix Table 5. The effect of N fertilization on nitrate-N content in leaf, steam and total top at different stages of wheat growth.

Rates of N Application in Spring (lbs./A)		Average NO_3-N (ppm) in Leaf, Stem and Total Top at Several Dates					
		3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	
						Upper	Lower
0	Leaf	200	120	130	190	110	220
	Stem	190	170	150	60	140	
	Total top	200	140	140	110	140	
50	Leaf	290	200	160	160	150	190
	Stem	1700	480	200	120	180	
	Total top	820	330	160	140	180	
50[a]	Leaf	410	150	190	270	160	140
	Stem	2020	340	210	90	140	
	Total top	940	240	200	150	140	
75	Leaf	1080	420	230	170	210	140
	Stem	4210	1630	350	170	100	
	Total top	2640	960	290	170	120	
125	Leaf	2200	1060	320	450	220	270
	Stem	6000	3940	1630	580	240	
	Total top	3680	2370	700	530	240	
200	Leaf	2410	2580	1540	1500	2140	350
	Stem	6920	7800	3560	1420	760	
	Total top	4150	4760	2480	1450	890	
LSD 0.05	Leaf	390	320	130	310	170	80
	Stem	1600	1060	480	90	140	
	Total top	830	580	190	130	80	

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

Appendix Table 6. The effect of N fertilization on the percentage of N in plant top at different times of sampling.

Spring Applied N lbs./A	% N in Plant Top at a Different Time of Sampling					
	3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	7-5-68
0	2.36	2.23	1.60	1.37	0.78	0.94
50	3.79	3.03	2.22	1.52	0.87	0.71
50[a]	3.29	2.84	1.84	1.36	0.96	0.68
75	4.00	3.09	2.73	1.67	0.95	0.83
125	4.35	3.79	2.93	2.26	1.37	1.15
200	4.76	4.12	3.68	3.20	1.79	1.40
LSD 0.05	0.49	0.54	0.38	0.41	0.09	0.20

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

Appendix Table 7. The effect of N fertilization on N uptake at different times of sampling.

Rates of N Application in Spring lbs./A	N Uptake lbs./A at Different Times of Sampling					
	3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	7-5-68
0	20	39	37	50	49	76
50	49	69	91	77	92	90
50[a]	36	42	41	54	73	68
75	37	65	84	87	81	90
125	55	91	106	144	161	168
200	59	95	145	181	191	235
LSD 0.05	18	24	36	33	34	35

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

Appendix Table 8. The effect of N fertilization on P and K uptake at different times of sampling.

Spring Applied N lbs./A	Average P and K Uptake lbs./A at Different Periods of Plant Growth											
	P Uptake						K Uptake					
	3-28	4-8	4-19	5-1	5-22	7-5	3-28	4-8	4-19	5-1	5-22	7-5
0	3.25	4.47	5.94	8.81	9.22	12.00	26.43	33.52	39.24	55.43	91.04	73.65
50	5.62	8.97	10.54	12.95	14.32	16.38	61.67	91.38	113.72	104.19	154.04	55.76
50[a]	4.36	5.97	6.95	9.46	10.78	14.47	45.35	57.44	61.84	78.37	101.95	52.39
75	3.82	8.14	13.07	13.10	15.49	15.54	42.74	89.08	123.03	141.07	116.97	100.81
125	7.16	10.64	16.75	19.25	20.66	20.75	59.52	115.75	136.57	117.29	230.54	143.47
200	5.22	11.37	16.27	22.03	20.51	27.93	57.51	124.45	172.96	218.67	223.98	236.07
LSD .05	-	-	-	-	-	3.72	-	-	-	-	-	51.76

[a]This treatment includes 45 lb of N/A in the fall at seeding; all other treatments except the control received 20 lb of N/A at seeding.

- Not analyzed statistically.

Appendix Table 9. Analysis of variance table for wheat yield and quality.

Source of Variation	d. f.	Mean Square for Variable Tested		
		Yield of Grain	Test Weight	% Protein
Rep	2	925,539*	1.995	0.7294
Treat	5	2,238,969**	2.9103*	5.3480**
Error	10	135,366	0.5363	0.3336

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 10. Analysis of variance table for dry matter at variable dates of sampling.

Source of Variation	d.f.	Mean Square for Variable Dates					
		3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	7-5-68
Rep	2	15,694	78,438	423,360	13,653	2,110,168	631,516
Treat	5	117,078	509,929**	1,425,029	3,120,062*	13,858,347**	1,474,530**
Error	10	65,950	66,892	808,167	682,448	468,820	224,929

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 11. Analysis of variance table for number of culms per foot of drill-row.

Source of Variation	d. f.	Mean Square for Variable Dates				
		3-28-68	4-8-68	4-19-68	5-1-68	5-22-68
Rep	2	30.39	247.72	192.22	57.72	12.00
Treat	5	261.79	287.92	220.19	357.38**	386.37**
Error	10	136.33	152.59	269.42	56.12	48.47

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 12. Analysis of variance table for leaf percentage.

		Mean Square for Variable Dates				
Source of Variation	d.f.	3-28-68	4-8-68	4-19-68	5-1-68	5-22-68
Rep	2	15.18	37.14**	56.68*	7.59**	6.08*
Treat	5	14.29	11.51	60.48*	28.25*	24.51**
Error	10	18.24	5.85	13.66	5.06	1.25

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 13. Analysis of variance for nitrate-N concentration in leaves of wheat.

		Mean Square for Variable Dates					
		3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	
Source of Variation	d.f.					Upper Leaves	Lower Leaves
Rep	2	148,272	29,090	5,435	37,711	1,660	15,713
Treat	5	2,897,021**	2,772,543**	901,418**	818,803**	1,952,307**	18,621**
Error	10	45,686	30,523	5,078	28,603	9,187	2,294

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 14. Analysis of variance for nitrate-N concentration in stems of wheat.

		Mean Square for Variable Dates				
Source of Variation	d.f.	3-28-68	4-8-68	4-19-68	5-1-68	5-22-68
Rep	2	1,990,362	502,290	16,341	2,245	1,282
Treat	5	20,917,972**	27,033,022**	5,600,267**	847,589**	189,195**
Error	10	774,340	339,072	70,328	2,597	6,348

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 15. Analysis of variance for nitrate-N concentration in plant tops.

Source of Variation	d.f.	Mean Square for Variable Tested 3-28-68	4-8-68	4-19-68	5-1-68	5-22-68
Rep	2	133,995	144,152	5,168	7,132	127.17
Treat	5	8,124,416**	9,912,319**	2,512,652**	836,788**	269,253**
Error	10	207,043	101,084	10,258	5,463	2,072

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 16. Analysis of variance for concentration of total N in plant tops.

Source of Variation	d.f.	Mean Square for Variable Dates 3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	7-5-68
Rep	2	0.3335*	0.019	0.006	0.018	0.043	0.0385
Treat	5	2.158**	1.383**	1.774**	1.543**	0.447**	0.235**
Error	10	0.0733	0.088	0.0431	0.0497	0.024	0.0135

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 17. Analysis of variance for total N uptake in plant tops.

Source of Variation	d.f.	Mean Square for Variable Dates 3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	7-5-68
Rep	2	6.03	2.92	950.89	64.26	1,104.15	426.31
Treat	5	627.72**	1845.43**	4961.55**	8,215.93**	9,234.72**	16,918.34**
Error	10	94.176	174.10	393.50	327.64	343.98	365.47

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 18. Analysis of variance table for nutrient percentage in the wheat plant tops.

Source of Variation	d.f.	Mean Square for Variable Dates: % Nutrient on 4-8-68 P	K	Ca	Mg	% Nutrient on 5-22-68 P	K	Ca	Mg
Rep	2	0.0029*	0.086	0.0001	0.0006	0.0002	0.064	0.0001	0.00005
Treat	5	0.0131**	1.970**	0.0019	0.0002	0.0016	0.324**	0.001**	0.0001
Error	10	0.0006	0.237	0.0371	0.00009	0.0097	0.043	0.0002	0.00008

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 19. The analysis of variance table for nutrient uptake by wheat plant tops.

Source of Variation	d.f.	Mean Square for Variable Tested on 7-5-68: P	K	Ca	Mg
Rep	2	35.54*	2,068.38	12.465	8.10
Treat	5	100.39**	14,808.46**	66.16**	53.05**
Error	10	6.72	809.74	11.198	3.237

**F value significant at 1% level
*F value significant at 5% level

Appendix Table 20. Simple correlation between the concentrations of P, K and N.

Nutrients	Correlation Coefficient (r) at Various Sampling Dates: 3-28-68	4-8-68	4-19-68	5-1-68	5-22-68	7-5-68
P	N.S.	0.92	0.699	0.95	0.55[a]	N.S.
K	0.817	0.817	0.814	0.746	0.748	N.S.

[a]Value is significant at the 0.05 level of probability and all other values are significant at the 0.01 level. Non-significant relationships are indicated by N.S.