Phosphorus Time, rate, and placement methods as influencing dryland small grain production
by Roger Lavern Wilson

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crop and Soil Science
Montana State University


Abstract:
Spring and winter wheat were grown under dryland conditions at three Montana locations in 1967 1968, and 1969.

The influence of time, rate, and placement of P fertilizer was evaluated by using grain yield, dry matter yield, P yield, and culm count measurements.

Placement of fertilizer P with-the-seed at rates of 20 and 30 lb, per acre increased grain yields more than did broadcast rates of 30 to 60 lb. P/A, Thirty pounds P with-the-seed and 90 lb, P broadcast gave comparable yields. Starter fertilizer (51b, N plus 2,5 lb. P/A") with-the-seed significantly increased grain yields with broadcast P-rates of 0, 10, 20, and 30 lb. P/A consistently, and only occasionally at 60 and 90 lb. P/A.

P yield increased at a constant rate throughout the growing season, as a function of P treatment. Continued P uptake after heading was noted only with treatments which contained low broadcast P-rates of 0, 10, and 20 lb/A whereas little or none occurred with 60 and 90 lb. P/A.

P percentage values showed good correlation with final grain yields only at the very early stages of plant development and at low rates of added P.

Culm count was directly related to P treatment, and with increasing P-rates significant increases occurred with both culm count and grain yield.

There was no significant loss in 1969 grain yields due to reduced P availability with 10, 20, and 60 lb. P/A applied for the 1967 crop.

# PHOSPHORUS--TIME, RATE, AND PLACEMENT METHODS AS INFLUENCING DRYLAND SMALL GRAIN PRODUCTION

by

Roger Lavern Wilson

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Crop and Soil Science

Approved:

Erhardt R. Stelzer
Head, Major Department

Charles M Smith
Chairman, Examining Committee

H Goering
Dean, Graduate Division

MONTANA STATE UNIVERSITY
Bozeman, Montana

March, 1970

ACKNOWLEDGEMENT

The author would like to express a sincere thanks to Dr. C. M. Smith for patience, consideration, and assistance during the course of this work.

Also, the author would like to acknowledge the help and instruction received from the other committee members: Drs. J. R. Sims, J. H. Brown, E. R. Hehn, I. K. Mills, and V. H. Schmidt.

A special thanks to Glennis Boatwright and Dr. Paul Brown, A.R.S., for helpful comments and suggestions and to Dr. Ervin P. Smith and Roger Stewart for assistance with computer programming.

Thanks also to the Central Exchange Foundation for the Grant-in-Aid which partially financed the work and to the Montana Cooperative Extension Service.

To those involved with the fieldwork; County Extension Agents, Central Exchange fieldmen, and personnel of the Montana Agricultural Experiment Stations, Soil Conservation Service and Agricultural Research Service; thank you.

Lastly, the author wishes to express thanks to his patient family and a very understanding wife who helped at all times, typed the thesis, and provided constant encouragement.

TABLE OF CONTENTS

Table of Contents

(Continued)

# LIST OF TABLES

## Context Tables

## List of Tables

### Context Tables
(Continued)

## List of Tables

### Context Tables
(Continued)



### Appendix Tables

List of Tables

Appendix Tables
(Continued)

## List of Tables

### Appendix Tables
(Continued)

LIST OF FIGURES

## List of Figures

(Continued)

## ABSTRACT

Spring and winter wheat were grown under dryland conditions at three Montana locations in 1967, 1968, and 1969.

The influence of time, rate, and placement of P fertilizer was evaluated by using grain yield, dry matter yield, P yield, and culm count measurements.

Placement of fertilizer P with-the-seed at rates of 20 and 30 lb. per acre increased grain yields more than did broadcast rates of 30 to 60 lb. P/A. Thirty pounds P with-the-seed and 90 lb. P broadcast gave comparable yields. Starter fertilizer (5 lb. N plus 2.5 lb. P/A) with-the-seed significantly increased grain yields with broadcast P-rates of 0, 10, 20, and 30 lb. P/A consistently, and only occasionally at 60 and 90 lb. P/A.

P yield increased at a constant rate throughout the growing season, as a function of P treatment. Continued P uptake after heading was noted only with treatments which contained low broadcast P-rates of 0, 10, and 20 lb/A whereas little or none occurred with 60 and 90 lb. P/A.

P percentage values showed good correlation with final grain yields only at the very early stages of plant development and at low rates of added P.

Culm count was directly related to P treatment, and with increasing P-rates significant increases occurred with both culm count and grain yield.

There was no significant loss in 1969 grain yields due to reduced P availability with 10, 20, and 60 lb. P/A applied for the 1967 crop.

# INTRODUCTION

Agriculture is the main source of income for Montana, and small grain production furnishes the largest segment of this economy. With a needed increase in the economy of the state, more and more fertilizer is used to boost small grain yields. This creates a need to better understand how fertilizers can be used more efficiently.

There has been a great deal of concern about fertilizer application methods and residual influence. To date very little has been done on P fertilized small grain production especially where methods of application and residual influence have been studied in a crop-summer fallow system. Therefore, this experiment was designed to study the effectiveness of methods of applications: P placed with-the-seed, broadcast on the fallow, or just before seeding. The residual carryover from various application rates in previous years will also be studied. In order to study the outlined problems, two sites were selected in predominantly winter wheat producing areas and one in the spring wheat area of Montana for the five-year study.

The present research data include soil and plant analysis for phosphorus, phosphorus uptake by plants at different stages of growth, culm counts, kernel counts, grain protein percentage, grain yield, dry matter yield, and P yield. Although several years will be needed to completely evaluate the residual fertilizer-P influence, this thesis will include three years' results; 1967, 1968, and 1969.

From this research, it is hoped that some specific recommendations can be made on methods, time, and rates of phosphorus applications for small grain production.

## LITERATURE REVIEW

### PLACEMENT OF FERTILIZER

The first recorded use of fertilizer placement in the United States was in 1621 in Plymouth, Massachussets when the white man harvested his first corn crop. According to Lang (38) the main reason he was able to produce corn on that poor land was because Squanto, an Indian, had taught him to place a fish in each hill of corn when it was planted.

Considerable work has been done with fertilizer placement in the corn belt where several placement methods are used. The bulk of the fertilizer is broadcast in the fall or before plowing, and then a small amount is added with or near the seed at seeding time in the spring. When the small amount is placed with-the-seed it is commonly referred to as "pop-up", "split-boot", 2" x 2" placement, or starter fertilizer (12). Advantages of starter fertilizer are better stands, hastened emergence, earlier maturity, crops which are more competitive with weeds, and increased yields shown by Jacob (33). Disadvantages of starter are reduced germination at higher rates of fertilizer and the extra expense of additional time and equipment needed for application (81).

Guttay (29) in working on germination of wheat and oats with banded fertilizer found 100 pounds of nutrients in contact with-the-seed delayed germination and emergence and that phosphorus was as detrimental as nitrogen and potassium. Low quality seed and dry conditions led to a more pronounced detrimental effect. Oats were less affected than wheat, probably because the lemma and palea are attached to the caryopsis while wheat is detached.

Cummins and Parks (20) did not agree with Guttay that phosphorus caused as much damage to germination of wheat and corn and listed the following fertilizers in decreasing order of damage to germination: anhydrous ammonia, urea, muriate of potash, nitrate of soda, ammonium nitrate, ammonium sulfate, sulfate of potash, 6-12-12, 48 percent superphosphate, and 20 percent superphosphate.

Hood and Ensminger (31) recorded at lowered germination due to diammonium phosphate on wheat and cotton was not osmotic effects alone and that the ions per se were not causing the effects. They thought the high acid condition was causing the reduction as damage cound be reduced by adjusting the pH. The corrective effect of $MgSO_4$ and $MgCl_2$ suggested that $(NH_4)_2HPO_4$ may have adversely affected Mg utilization by lowering enzyme activity.

Nelson (52) and Ohlrogge (53) stated there was a greater chance of "fertilizer burn" with banded fertilizer than with broadcast fertilizer. Fertilizer salts may draw water from the germinating plant causing a burned or injured seedling. Other workers have recorded some detrimental effects on seedlings at critical moisture levels when the fertilizer was either placed with-the-seed or banded (58)(63).

Alessi and Power (1) working with barley indicated percent P and P uptake in the plants were higher when P was placed with-the-seed as compared with a two-inch depth in the soil. Fertilizer placed with-the-seed gave the greatest fertilizer P uptake early but as the season progressed more soil P was absorbed. They concluded that P was as beneficial to the plant placed at a two-inch depth beside the seed if water was present and soil P was in the medium to moderate low range. The placement method was less critical when water was adequate. Sherrell et al. (72) found results similar to Alessi and Power when working with oats in Canada.

Smith and Stanford (76) reported P fertilizers at low rates of application are more efficiently used by grain crops when the fertilizer is banded with or near the seed. In their work at Iowa using radioactive phosphorus for oats, disking the P was about 40 to 48 percent as efficient as drilling when the rate was 40 lb. $P_2O_5$ per acre. However, that efficiency increased to 55 to 65 percent for 80 lb. $P_2O_5$ per acre. Also, on calcareous soil topdressing the P fertilizer at 40 lb. per acre soon after seeding was 64 percent as efficient as drilling. Most research in Canada and the United States has shown band-placed P fertilizers were used by grain plants with about double the efficiency of broadcast and disked fertilizer applied prior to seeding.

Barber (2) showed response advantage due to banded or seed applications of fertilizer decreased as the soil level of nutrients increased. Simpson (73) showed similarly that the level of soil P and the rates of application influenced which placement method was best for oat crops.

Considerably less fertilizer was needed banded or with-the-seed as compared with broadcast for good wheat yields as shown by Smith (77). Lutz et al. (44) working with small grains in the South, found that by applying 40 lb. $P_2O_5$ per acre it was only 42 percent as effective broadcast and disked and 33 percent as effective topdressed as compared with placement with-the-seed. Olson et al. (60) and Gingrich (26) reported maximum efficiency of fertilizer P by placing it with-the-seed on small grains and clover. In England, Cooke (19) reported one-half as much grain was produced by broadcasting P and K as was produced by placement with-the-seed. He believed the increased grain yield from placement with-the-seed was due to stimulated root growth.

Prummel (66) in the Netherlands reported P was 2.45 times as effective on cereals placed with-the-seed as broadcast and 1.9 for potatoes, 1.2 for beets, and 2.9 for maize. Placement with-the-seed gave early growth and prevented fixation of P fertilizer.

Banding of phosphate gave the most economical results at lower application rates of fertilizer on corn; but at higher rates, a combination of broadcast and with-the-seed was more economical (Welch et al. (84). Bates et al. (4) found fertilizer with-the-seed markedly increased the early uptake of nutrients and growth of corn. Less K was needed banded than broadcast to obtain the most economical yields of corn according to Welch et al. (83) and Mortensen (50); however, Mortensen found a detrimental effect when N was placed with-the-seed.

Only one-half as much banded phosphorus was needed to produce similar yields on safflower as was needed broadcast reported Werkhoven and Massanitini (85).

Generally, higher rates of fertilizer are broadcast and lower rates applied with-the-seed or banded. Nebraska research of Olson and Dreier (58) showed the upper limit for nitrogen with-the-seed to be 15 lb. per acre on oats and wheat.

Nelson (51) reporting on work done in Wisconsin with small grains under high moisture conditions, stated that up to 75 lb. per acre of N or $K_2O$ could be placed with-the-seed before damage occurred. At higher rates, banding one and one-half inches to the side and one inch below the seed gave better results.

Fertilizer such as 5-20-20 caused considerable damage to seedlings at a rate of 500 lb. per acre placed with wheat seed; but under the same set of conditions, 5-20-0 did not cause detrimental effects reported Lawton and Davis (40).

Of the three major fertilizer nutrients, N, P, and K, P seems to be the least detrimental to seedling development when placed in contact with the seed. Nitrogen and K are more water soluble and most likely to cause fertilizer burn than P (Nelson (52)).

Much of the work in the past has shown that fertilizer placement with-the-seed especially N and K at rates above 25 lb. per acre, can be detrimental to small grain germination and seedling development. Therefore, the higher rates of fertilizer must be applied broadcast. Most of the data reported was based on a one-year, one-crop experiment (18)(44)(58). In order to consider the total effect of higher rates of with-the-seed and broadcast placement of fertilizer, the two will need to be evaluated together and for more than one crop.

Several workers (66)(85)(75)(76)(87) have shown the high efficiency of low rates of fertilizer with-the-seed. More work is needed to show what combination of rates broadcast and/or banded is best suited for each situation.

EFFECT OF ASSOCIATED SALTS ON PHOSPHATE ABSORPTION

The associated salts of other fertilizer materials may have an effect on P uptake by plants. Terman (80) reported ammonium salts increased P uptake by plants. He attributed the increase to stimulated root activity or increased acidity on alkaline soils from the nitrification of the ammonium nitrogen.

Leonce and Miller (42) found the interaction of N with P to be physiological with corn. When $(NH_4)_2SO_4$ or $NH_4Cl$ was added to phosphorus fertilizer labeled $P_{32}$ and placed 1/2 inch to the side of corn roots, the P content in the plant tops was greatly imcreased. Additions of $KNO_3$ reduced P in the tops compared with superphosphate only. When P alone or P plus $KNO_3$ was added, the labeled P accumulated in the roots. Accumulation did not occur in the presence of $NH_4^+$ ions. Addition of $NH_4NO_3$ to nutrient solution increased transfer of P through a one-inch segment of corn root. They concluded that $NH_4^+$ has a specific influence on transfer of phosphorus across the root symplast to the xylem.

Olson and Dreier (59) stated that increased absorption of P was a result of N stimulating root activity. Nitrogen increased N, P, and K concentration in oats. The number of small roots was also increased according to Grunes and Krantz (27).

Duncan and Ohlrogge (22) stated that with N and P together, corn growth was greater and considerably more branching of smaller roots occurred. They believed uptake of P was closely related to root development and volume of fertilized soil if N was present.

Rennie and Soper (67) also found for N to increase P uptake, the N must be in the ammonium form and that N and P be mixed and applied to the soil by restricted placement.

Blanchar and Caldwell (8) found in work with sandy loam soils to which P plus $NH_4Cl$ and P plus KCL were added, that the uptake of P was nearly three fold with P plus $NH_4Cl$ than with P plus KCl or P alone.

Other workers (13)(49)(28) have determined the beneficial effect on P uptake by N on the basis of double banding experiments.

Cole et al. (17) found P uptake to be greatly increased by adding supplemental N treatments. P uptake per unit dry weight of roots was increased more by higher N levels in the roots than by a ten fold increase in the P concentration of the external solution.

Boatwright and Haas (10) working with wheat showed that N increased P uptake mostly in the early plant development stages, Robertson et al. (69) noted that placement of N with a N and P mixture significantly increased the percent P in the plant as well as yields. However, the best utilization of P was obtained by mixing N, K, and P together before placement.

Application of N and P banded together gave much better yields than when the two were banded separately as stated by Nelson (52). Absorption of P was enhanced by the application of N, especially when the two were mixed before application as shown by Miller and Ashton (48), Nelson (51), and Miller and Ohlrogge (49).

Werkhoven and Miller (86) found N increased P uptake with sugar beets and N was more effective where P was banded than mixed with soil.

SOIL pH

It has been known for several years that the pH of the soil influences P uptake by plants. Several facts have been summarized by Pierre and Norman (62). For example the results of various investigations agree generally that P solubility in calcareous soils is at a minimum in the range of pH 7.0 to 7.5. Solubility increases with either an increase or decrease of pH.

It is also known that with changing pH values, the predominant form of P ions in the soil changes and as reported by Pierre and Norman (62), the predominant P ion was $H_2PO_4^-$ at pH values of 3 to 8 and predominantly $HPO_4^{=}$ at pH 9.

Hendrix (30) stated that the most important factors affecting P uptake are the forms of the P ions and the effects of pH per se on anion uptake. He also stated $OH^-$ concentrations associated with increasing pH competitively inhibited anion uptake.

Arnon et al as reported in the book by Pierre and Norman (62) noted pH influence on P uptake and suggested that, since anions appear to be absorbed by plant roots in exchange of $OH^-$ and $HCO_3^-$, an increasing $OH^-$ concentration might decrease the rate of exchange of $H_2PO_4^-$ on the root membrane.

Smith (74) noted that in general as the soil pH increases, the proportion of calcium phosphates increases and the iron and aluminum phosphates decrease. He also noted when P fertilizer was added, the adjoining soil pH was much lower than the surrounding soil.

Research work in Oklahoma on wheat reported by Robertson (68) showed broadcast rates greater than 20 lb. $P_2O_5$ per acre were as good for increasing grain yields as banded fertilizer on neutral to calcareous soils. Higher rates of fertilizer were needed under similar conditions to obtain the same response with acid soils. This agrees in principle with work in Iowa by Smith and Pesek (75) and Smith and Stanford (76) as the efficiency of topdressed or disked-in P fertilizer was closer to that of drilling with-the-seed on calcareous soils than acid soils.

TEXTURE, TEMPERATURE, AND MOISTURE INFLUENCE ON P

Several studies have shown soil texture, temperature, and moisture to significantly influence P response.

This research was conducted at three locations in Montana. Widely varying climatic and soil conditions at these locations prompted the consideration of soil temperature, precipitation, and soil characteristics. A brief literature review of the influence of texture, moisture, and temperature was included to allow comparisons of previous studies with this study.

Olsen and Watanabe (57) stated that plant uptake of P was greater from clay textured soils than from sandy soils. There were three factors involved: concentration gradient between soil and root surface, diffusion coefficient, and the capacity of the soil to replenish

P removed by the plant. With more soil particles as in a clay soil, the concentration of P was greater closer to the plant root due to reactions of soil particles with phosphate. At any given moisture tension, a clay soil had more available water for diffusion than a sandy soil and the solution renewal was greater for clay soil as more particles were closer to the root. Their equation, relating uptake of P by plant roots to the diffusion coefficient and the phosphate capacity, predicted the rate of uptake to be approximately 1/3 as much for a sandy soil as clay soil at equal concentrations of P in the soil solution. Actual P uptake was very close to the predicted results for P concentrations less than 0.2 ppm.

Levesque (43) studied P uptake as influenced by soil texture and temperature. He concluded temperature had more influence on P fixation in fine textured soils and therefore coarse textured soils would make better use of native P supply than fine textured soils at low soil temperatures.

Nelson (51) found that clay soils require more fertilizer for a particular situation than sandy soils. This was partially a result of nutrient "tie-up" (chemical fixation by the soil) by the finer clay soil particles.

The absorption of P was influenced by soil temperatures according to Simpson (73). A $5^{o}$ C. increase in temperature increased P uptake especially in soils low in P. A rise in temperature also increased fertilizer P uptake from soils high in P. Power et al. (65) noted that growth response of barley to P fertilizer was more dependent on the temperature for soils low in P than for soils medium in P.

Mack and Barber (45) incubated two soils for 74 days at three temperatures (23°, 2.7°, and -20° C). They found the higher the temperature prior to cropping, the greater was the yield of dry matter and P uptake by plants.

Dadykin (21) and Ketcheson (34) showed that the effectiveness of P fertilizer was greater at 20° C than at 5° C which indicated a lower P availability in colder soils. Similar results were found by Ellis (23) and Beaton et al. (6).

Robinson et al. (70) related slow P uptake and slow growth to low soil temperature and rapid uptake of P and increased yields to higher soil temperature. Gingrich (26) noted similar response in winter wheat when yield of P and top growth were significantly higher in soils maintained at 15.5° and 21° C than at 10° C.

The research data indicate that P availability was increased by increased temperatures but there is also some evidence that a cold period may be beneficial in increasing P availability. Phung (61) in studying the effect of soil freezing and thawing found P uptake by winter wheat to be higher on soils incubated under frozen conditions as compared with soils incubated at room temperature. Dry matter yields were lower on soils incubated under the frozen conditions but this was believed to be due mainly to the impaired physical properties of the frozen soils.

In a study by Beaton and Read (5) P was added to soils stored at 5°, 16°, and 27° C for one and seven weeks. Phosphorus uptake by oats was increased at 5° C than at 16° and 27° C.

Simpson (73) working with soil moisture found P uptake by oats increased when soil moisture tension was lowered to field capacity. High moisture tension decreased the rate of fixation of phosphorus and helped to confirm the statement that temperature and moisture effects were responsible for low recovery of fertilizer phosphorus in warm, dry seasons as compared with cool, moist seasons. Barber (2) agreed with Simpson that during dry, warm seasons less P was fixed and less was absorbed by corn plants.

Boatwright et al. (9) reported that spring wheat did not absorb fertilizer P from a dry soil and a lag in absorption followed watering, depending on the age of the plant. If the fertilizer zone was not wet for at least three or four days, it contributed little to P uptake.

Choriki (15) noted that only one of several soils low in P showed response to added P fertilizer. He concluded this lack of response must have been due to the low spring moisture conditions at this location. Fawcett and Quirk (24) found that moisture stress did not reduce P uptake in wheat until the roots were damaged by wilting.

Power et al. (64) showed that with spring wheat, P fertilizer had no effect on total water use; but P fertilizer increased plant material produced per unit of water used at the soft dough and harvest stages of growth.

As noted by Brown and Campbell (11) wheat fertilized with P or N and P used water at an accelerated rate during the early season as compared with the nonfertilized check treatment. Reduced moisture use later in the growing season was attributed to a depleted moisture supply.

Yield increases as shown by Power et al. (63) on medium P soils were directly proportional to the amount of moisture available at seeding and to the sum of seeding time moisture plus precipitation received during tillering to heading. On relatively high or low P soils the availability of soil P largely determined how P applications affected yield increases.

Olsen et al. (56) working with sugar beets found that in a dry year, band placed P beside the seed increased uptake of P by plants in the later stages of growth more than P fertilizer placed with-the-seed. During wet years uptake of P was equal.

RESIDUAL PHOSPHORUS

The effectiveness of residual P from P fertilizer applications in providing crop yield response is a major consideration in evaluating broadcast P for dryland grain.

Mannering et al. (46) working with a six-year rotation of barley, alfalfa, field beans, and sugar beets on calcareous soils in Idaho, concluded that with applications of 120 lb. per acre of $P_2O_5$ that even after six years sufficient P was available to furnish a large part of the crop requirements.

Research by Campbell and Brown (14) with residual P on a six-year irrigated rotation of barley, alfalfa, corn, and sugar beets in Montana obtained results similar to Mannering et al.. Phosphorus rates of 26, 52, 105, and 210 lb. per acre gave yield increases for 4, 6, 9, and 9 years respectively. The experiment was terminated at the end of nine years. Crop yields declined to check plot levels when 42 percent and 49 percent of the 26 and 52 lb. P/A application rates had been taken up by the crops grown.

Leamer (41) also found yield increases after up to six years with 26, 52, 105, and 210 lb. of P/A in the Southwest with irrigated rotations.

McAuliffe et al (47) indicated a response from 400 lb. of $P_2O_5$ per acre after eight years but did get an added response from 11 lb. $P_2O_5$ per acre.

In comparing sources of P fertilizer on calcareous soils, Webb and Pesek (82) found the residual effect of superphosphate, concentrated superphosphate, and calcium metaphosphate on oats to be equal; but on acid soils fused tri-calcium phosphate was more available.

Smith and Pesek (75) found in working with three Iowa soils that residual fertilizer P applied one to two years previously averaged 56 to 72 percent as effective as currently applied P.

Koehler (36) showed very little phosphorus fixation in eastern Washington soils as rates of 0, 20, 40, and 80 lb. of P/A resulted in respective yields of 12, 27, 29, and 20 bu. of wheat the second crop year. Several soils showed a second year crop response from the residual P.

Regardless of differences in rate of fertilizer addition, soil pH, $CaCO_3$ content, level of available soil P, soil organic matter, and soil texture; Koswara and Hanway (37) found little difference in fertilizer P uptake on ten principal soil associations in Iowa. In greenhouse experiments approximately 50 percent of added P was taken up in one year by rye plants.

Olsen and Watanabe (57) reported that applied P recovery on calcareous soils was only two percent on first year alfalfa and 12 percent on sugar beets. Values were less on acid soils.

## MATERIALS AND METHODS

This research project was initiated in the spring of 1967 to study the effects of rate, time, and method of placement of phosphorus on dryland spring and winter wheat in Montana.

Three representative sites were selected with the aid of soil survey maps, field checking with the assistance of soil scientists with the USDA Soil Conservation Service, soil sampling, and visual observation. Soil series descriptions are given in Appendix tables 29, 30, and 31. Two locations were in winter wheat producing areas and one in the major spring wheat area of the state. Adjacent strips were selected so that crops could be alternated with fallow in each area for the five-year study. After the sites were selected wooden posts were buried at plot corners and steel posts driven at the strip edge to aid in later staking and location.

The first year, spring barley (Hordeum distichum L., var. Hypana) was grown on the two winter wheat locations at Power and Stanford, Montana. The Power experimental area is located approximately 20 miles NW of Great Falls on the Carl Neuman farm in the SE¼ of the SW¼ of section 13, T22N, R1E. Stanford is approximately 60 Miles SE of Great Falls, Montana. Spring wheat (Triticum vulgare L., var. Fortuna) was grown at the Froid location on the Vernon Danielson farm in the SW¼ of section 32, T31N, R56E. Figure 0 shows the locations of each site in the state.

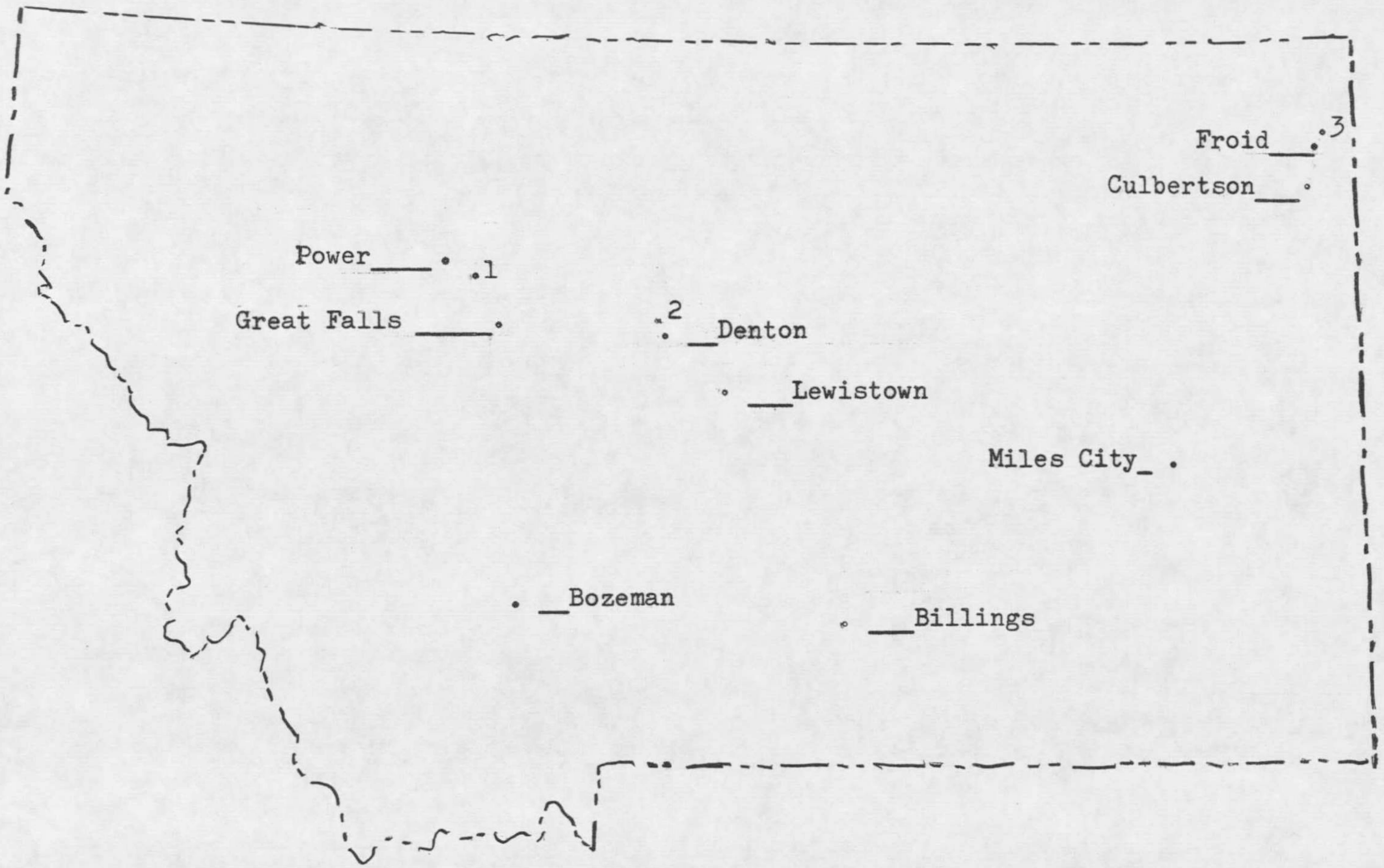


Figure 0. Location of experimental areas in Montana; 1--Power area, 2--Denton area, and 3--Froid area.

EXPERIMENTAL DESIGN

A randomized block experiment was established with 46 treatments and four replications. Plot size was 14 by 40 feet. Treatments for phosphorus applications include: broadcasting, spring and fall, with and without starter fertilizer (5 N and 2.5 P); and various phosphorus rates applied with-the-seed. N and K were applied uniformly at the rate of 40 pounds of N and 25 pounds of K per acre to reduce the chances for deficiency of these nutrients. See Table 1 for listing of treatments. Where more than one treatment is listed together, these treatments are alike and only the average values were listed.

Broadcasting of fertilizer was done by hand in the fall and the soil worked with a disk just prior to seeding. In the spring, fertilizer was applied by hand as soon as fields were workable and incorporated during the first summer fallow operation. The growing winter wheat crop was topdressed with N and K.

Rates of phosphorus applied broadcast were 10, 20, 30, 60, and 90 pounds of P per acre. After incorporating the fertilizer with about the upper two inches of soil, the plots were seeded using a tractor-pulled seven-row furrow drill with special fertilizer attachments for metering the fertilizer uniformly in each row. Row spacing was set at one foot. Barley was seeded at 50 lb. per acre and wheat at 60-65 lb. per acre. Higher seeding rates than are commonly recommended for producers have been used to insure a good stand. Fertilizer

Table 1. Listing of fertilizer treatments for experiments at three locations.

| Treatment No. | Fall Broadcast After Fallow Crop 1 P lb/A | Fall Broadcast After Fallow Crop 2,3 P lb/A | N-Spring Topdressing Crop 1,2,3 N lb/A | Spr. or Fall With-the-Seed Crop 1,2,3 N lb/A | Spr. or Fall With-the-Seed Crop 1,2,3 P lb/A |
|---|---|---|---|---|---|
| 1, 39 1/ | 0 | 0 | 0 | | |
| 2, 40 | 0 | 0 | 0 | | |
| 3 | | | 40 | | |
| 4 | | | 40 | 5 | |
| 5 | | | 40 | | 2.5 |
| 6 | | | 40 | 5 | 2.5 |
| 7 | | | 40 | 5 | 5 |
| 8 | | | 40 | 5 | 10 |
| 9 | | | 40 | 5 | 20 |
| 10 | | | 40 | 5 | 30 |
| 11 | | | 40 | | 10 2/ |
| 12 | | | 40 | | 20 2/ |
| 13 | 10 | | 40 | | |
| 14 | 10 | | 40 | 5 | 2.5 |
| 15 | 10 | 10 | 40 | | |
| 16 | 10 | 10 | 40 | 5 | 2.5 |
| 17 | 20 | | 40 | | |
| 18 | 20 | | 40 | 5 | 2.5 |
| 19 | 20 | 20 | 40 | | |
| 20 | 20 | 20 | 40 | 5 | 2.5 |
| 21 | 20 | 20 | 0 | 5 | 2.5 |
| 22 | 20 | 20 | 20 | 5 | 2.5 |
| 23 | 30 | | 40 | | |
| 24 | 30 | | 40 | 5 | 2.5 |
| 25 | 30 | 30 | 40 | | |
| 26 | 30 | 30 | 40 | 5 | 2.5 |
| 27 | 60 | | 40 | | |
| 28 | 60 | | 40 | 5 | 2.5 |
| 29 | 90 | | 40 | | |
| 30 | 90 | | 40 | 5 | 2.5 |
| 41 | 20 | 20 | 40 | 5 | 5 |
| 42 | 30 | 30 | 40 | 5 | 5 |
| 43 | 20 | 20 | 60 | 5 | 2.5 |
| 44 | 20 | 20 | 80 | 5 | 2.5 |
| 45 | 10 | 10 | 40 | | 2.5 |
| 46 | 20 | 20 | 40 | | 2.5 |

Table continued. . .

Table 1 Continued.....

| Treatment No. | Spring Broadcast Before Fallow Crop 1 N lb/A | Crop 1 P lb/A | Crop 2,3 N lb/A | Crop 2,3 P lb/A | N-Spring Topdressing Crop 1,2,3 N lb/A | Spring or Fall With-the-Seed Crop 1,2,3 N lb/A | Crop 1,2,3 P lb/A |
|---|---|---|---|---|---|---|---|
| 31 | | 10 | | | 40 | | |
| 32 | | 10 | | | 40 | 5 | 2.5 |
| 33 | | 20 | | | 40 | | |
| 34 | | 20 | | | 40 | 5 | 2.5 |
| 35 | 40 | 10 | 40 | 10 | | | |
| 36 3/ | 40 | 10 | 40 | 10 | | | |
| 37 | 40 | 20 | 40 | 20 | | | |
| 38 3/ | 40 | 20 | 40 | 20 | | | |

1/ 25 lbs. K/A on all treatments except 1 and 39.

2/ Broadcast just prior to seeding.

3/ 15-60-0 TVA (ammonium polyphosphate) and 33.5-0-0.

applied with-the-seed was delivered down the fertilizer tubes and dropped directly with-the-seed. This also included starter fertilizer (5 N and 2.5 P) that was applied in addition to one-half of the broadcast phosphorus treatments giving a split plot design for all broadcast phosphorus applications. Fertilizer was either measured or weighed from ammonium nitrate (33.5-0-0) and concentrated superphosphate (0-45-0). One other fertilizer, ammonium polyphosphate (15-60-0), was used to check the effect of source of phosphorus on residual carryover. Potassium was applied as muriate of potash (0-0-60).

1967 PROCEDURE

To get the project initiated in early 1967, spring grains were seeded on the winter wheat location the first year. Barley was seeded at Power, May 26 and at Stanford, May 25. Spring wheat was seeded at Froid, May 18. A very poor stand of barley at Power necessitated the reseeding of three of the four replications on June 14. Fertilizers of appropriate treatments were applied on the adjacent strips for seeding of winter wheat in the fall of 1967. Before application of fertilizer treatments, soil samples were taken from 16 blocks in a grid pattern (see Table 2) within the experimental areas and analyzed for pH, conductivity, organic matter, phosphorus, and nitrate to help characterize the sites for uniformity. Table 3 lists average values for these five soil properties for all three locations. Individual values for soil pH, conductivity, and organic matter for Power,

Table 2. Grid pattern for soil samples at three locations.

| | A | B | C | D |
|---|---|---|---|---|
| I | I-A | I-B | I-C | I-D |
| II | II-A | II-B | II-C | II-D |
| III | III-A | III-B | III-C | III-D |
| IV | IV-A | IV-B | IV-C | IV-D |

Table : Soil analysis information (average values from samples 0-6") for Power, Denton, and Froid.

| Location | Soil pH 1/ | Soil Conductivity 2/ millimohs/cm | Soil O.M. 3/ % | Bray P 4/ ppm | $NO_3$ 5/ ppm N |
|---|---|---|---|---|---|
| Power | 7.4 | .19 | 2.6 | 18 6/ | 5.5 7/ |
| Denton | 6.3 | .13 | 1.9 | 32 8/ | 1.6 7/ |
| Froid | 6.8 | .08 | 2.3 | 22 6/ | 2.4 7/ |

1/ Soil pH determination procedure in Appendix table 37.

2/ Soil conductivity determination procedure in Appendix table 38.

3/ Organic matter determination procedure in Jackson (32) pp. 219-221.

4/ Bray P determination in Olsen (55) and Smith (77).

5/ Soil $NO_3$ determination procedure in Jackson (32) pp. 197-201.

6/ Bray P range 0-30 ppm - very low.

7/ Soil samples for $NO_3$ determination 0-6'; average value/foot.

8/ Bray P range 30-60 ppm - low.

Denton, and Froid are listed in Appendix table 32. Soil P analyses using the Bray and $NaHCO_3$ methods are shown for all three locations in Appendix tables 33, 34, and 35. Soil nitrate determinations for each location are in Apprendix table 36.

Harvesting of plots was done with a gasoline-powered three-foot mower with mounted catcher on the sickle bar. Three one-foot spaced rows approximately 20 feet in length were cut after the outside rows of the seven-foot drill width were eliminated to avoid tractor tire compaction and approximately ten feet on each end of the plots to avoid nonuniform fertilizer delivery. All plots were measured for length of area harvested to determine grain and dry matter yields.

The moisture percentage of straw plus grain was determined and total dry matter yields calculated. The weight of the oven-dry above ground plant portion was reported as dry matter yield. Bundles from the cut area were weighed, threshed, and grain collected for individual plots. Grain samples were then cleaned with a small blower, weighed, test weight determined, and protein analysis made using the Kjeldahl method (32) pp. 183-190. Grain yields were converted to bushels per acre using 48 lb. per bu. for barley and 60 lb. per bu. for wheat. Culm counts were made in the field by counting all culms in two four-foot sections of row in individual plots.

Due to soil variability, the Stanford location was discontinued after 1967 and another site was selected at Denton, Montana which is approximately 25 miles north of the Central Montana Branch Experiment Station on the Larry Barber farm in the NW¼ of NE¼ of section 18, T19N, R14E. The Denton soils information is given in Table 3 and Appendix tables 32, 34, and 36.

1968 PROCEDURE

The Power location was fertilized on September 19, 1967 and the seeding completed by September 21. The Denton plots were fertilized on September 28, 1967 and seeded by September 30. At Denton the P treatments which should have been applied in early summer, 1967, were applied just prior to seeding, by necessity.

On November 9, 1967, when the plants were in the three-leaf stage (stage 2 designated by Feekes (26) and illustrated by Large (40)); see Table 4 for listing of growth stages and Feekes scale, plant samples were collected from two feet of row with a spade to a depth of approximately six inches. Two replications of treatments 3, 4, 5, 6, 8, 9, 13, 14, 17, 18, 23, 24, 27, 28, 29, and 30 were sampled at Denton and Power, the two winter wheat locations. Soil was partially shaken from the roots and samples were sealed in plastic bags and kept cool. The roots were later washed free of soil and tops and roots separated by clipping just above the point of attachment of roots. Plant samples were then dried at 65° C for 48 hours, weighed, and ground for analysis. The percent phosphorus was determined

Table 4. Stages of plant development when plant samples were collected.

| Plant Stage | Feekes Scale 1/ |
|---|---|
| 3-4 leaf | 2 |
| 5 leaf | 4 |
| 6 leaf | 4-5 |
| Heading | 10.1-10.5 |
| Heading to Soft-Dough | 10.5-10.5.5 |
| Mature | 11.2-11.4 |

1/ As illustrated by Large (39).

colorimetrically with ammonium vanadate, using the method of Barton (3) and Kitson (36).

The following spring, plant samples were collected at the Power location on May 27 and on May 28 at Denton. Plants were mostly in the six-leaf stage (Feekes stage 4-5) of growth. Although fertilizer treatments caused considerable change in plant development, especially later in the season, all treatments were sampled on the same date. The Feekes rating scale was used to identify the most predominant developmental stage. Beginning with the spring samples, all plants were clipped within one inch of the soil. Plants from two four-foot sections were taken from two corresponding rows in each plot of all four replications. Treatments 2, 3, 4, 5, 6, 7, 8, 9, 10, 13, 14, 17, 18, 23, 24, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 41, 42, 45, and 46 were sampled at Power. These same treatments except 31-34 were sampled at Denton. The same treatments sampled at Power plus treatments 11 and 12 were sampled at Froid. Seeding at Froid was completed on May 3. Plant samples were taken on June 20 when they reached the six-leaf (Feekes 4-5) stage.

Due to the distance between Bozeman and the experiment locations, approximately 200 miles to Denton and Power and 500 miles to Froid, it was decided to concentrate on the Power location for the most intensified plant sample collection. Samples were collected June 27, during the boot-to-heading stage (Feekes 10.1) and again July 15 at full heading-dough stage (Feekes 10.5.0-10.5.4) and the final sample made at maturity (Feekes 11.4 stage) on August 1. Beside the first samples, others were taken at Denton, July 10, at heading (Feekes 10.4) and August 6 at maturity (Feekes 11.2) and at Froid, July 30, at maturity (Feekes 11.2).

All samples collected were placed in an oven at Bozeman for 48 hours at 65° C. then weighed and the small subsample, approximately 25 stems collected at random from the larger sample, was ground through a Wiley mill for later phosphorus determination. The entire above ground plant portion was ground for analysis which included the grain on the mature plants.

Culm counts were made by counting the number of culms in two four-foot sections of row at harvest. Harvesting and measurements for 1968 were the same as for 1967 except the Denton grain samples contained buckwheat seed which was practically removed by running all samples through a dockage machine.

Soil temperature at the two-inch depth was recorded at both winter wheat locations, Power and Denton, by the use of a thermograph. Rain gauges were used at all locations. Temperature and precipitation data are recorded in Appendix tables 39, 41, 44, 45, and 46.

1969 PROCEDURE

The Power plots were fertilized and seeded October 1, 1968 and the Denton plots were fertilized and seeded September 27. There was a miscalculation on the setting of the fertilizer attachment for the two locations seeded in the fall of 1968 which resulted in a 15 percent increase over the original fertilizer rates applied with-the-seed. Rates for 1967 and 1968 with-the-seed were 5 N plus 0, 2.5, 5, 10, 20, 30 P. In 1969 all rates with-the- seed were 5.75 N plus 0, 2.875, 5.75, 11.5, 23.0, and 34.5, respectively.

Because moisture was lacking and seedlings were extremely small in late November, no plant samples were taken in the fall of 1968 for plant analysis. Plants were collected after growth occurred in the spring at the five-leaf (Feekes 4) stage at all locations. A second set of samples was collected at heading to dough stage (Feekes stage 10.4) and a final set at maturity (Feekes stage 11.2) from all three locations. Sampling and analysis were the same as the previous years.

Grain and dry matter yields were measured on four rows about 20 feet in length instead of three rows as in the previous years to give a more uniform harvest area.

The culm counts for 1969 included only culms which contained heads with three or more kernels and the two four-foot sections of row counted were threshed and kept separate to determine the number of kernels per head. Kernels were counted for a ten-gram sample and the number of kernels calculated for the eight-foot sample. With very few barren culms, the number of heads and culms were practically the same.

Soil temperatures were recorded at the Power and Denton locations and are listed in Appendix tables 40 and 42. Rain gauges were used at all locations and precipitation data are included in Appendix tables 47, 48, and 49. Complete data are available at Froid at the ARS research farm south of Froid. Soil moisture data are listed in Appendix table 50 for all locations.

STATISTICAL PLAN

All data for 1967, 1968, and 1969 harvests were coded, recorded, and punched on computer cards for analysis. The Sigma 7 computer at Montana State University Computer Center was used to process the data.

Two statistical methods were used to analyze the data for 1967; standard analysis of variance and least squares analysis. There was some question which analysis would be most valid with the duplication of treatments that occurred the first year. The duplication of treatments was necessary the first season permitting additional fertilizer on some treatments so that residual P response could be studied in the following years.

Duplicate analyses were made on the data from the locations, Power and Froid, and evidently with several treatments, 46 in this instance, the difference between methods of analyses was insignificant. F values for grain yields were 1.69 for standard analysis of variance and 1.75 on least squares analysis for the Froid grain yields. The values at the Stanford location were 1.39 and 1.44 respectively.

The small differnece in values did not change their significance at either location. Since the duplication of treatments decreased each year and the least squares program would not be applicable after 1968, it was decided to use the standard analysis of variance program throughout the experiment.

In addition to analysis of variance on grain and dry matter yields for 1967, 1968, and 1969; analyses have been made on culm count per eight feet of row in 1967, 1968, and 1969; kernels per eight feet of row in 1969; phosphorus yield (P% x dry weight) in 1968 for four dates on the Power data, two dates on the Denton data, and two on the Froid data. In 1969 three dates for P yield for each location were analyzed.

Analyses of variance were made for percentage P and dry matter yield for each plant sample date for 1968 and 1969. The correlation of the first plant samples in the spring with grain yields for 1968 was determined.

Significant differences were listed at the five percent level unless stated otherwise. Many comparisons have been made by using the LSD and single degree of freedom tests. Standard statistical methods were followed (82).

## RESULTS AND DISCUSSION

### 1967 Results On Barley And Spring Wheat

The results and discussion are mostly centered around grain yields as influenced by phosphorus fertilizer treatments. Dry matter yields are included in the data tables but are not discussed separately. In general, dry matter yield changes were reflected by grain yields.

Due to the limited moisture and the late seeding of spring grains, fertilizer response was low in 1967. The dry season did help in emphasizing soil variability at the Stanford location, which resulted in the selection of another site to continue the experiment. Precipitation data are listed in Appendix table 43.

Significant yield responses were limited to four treatments at the Froid location. There were some interesting trends noted in the data at Power and Stanford.

The Power data are listed in Table 5 for barley grain yield, dry matter yield, and culm count. Treatment response comparisons for P fertilizer broadcast should be make with treatment 3 which had a grain yield of 25 bu/A. Comparisons for treatment response for P with-the-seed should be made with treatment 4. Least significant difference (LSD) values are listed with analysis of variance figures near the bottom of each table. Yields or culm counts are not starred unless significantly different from treatment 3.

Table 5. Grain yield, dry matter yield, and culm count - Power, 1967; barley.

| Treatment No. | Fertilizer Broadcast N | Broadcast P | With-Seed N | With-Seed P | Total Dry Matter lbs/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 1, 39 2/ | 0 | 0 | 0 | 0 | 1971 | 20.3 | 161 |
| 2, 40 | 0 | 0 | 0 | 0 | 2054 | 21.7 | 167 |
| 3 | 40 | 0 | 0 | 0 | 2301 | 25.1 | 175 |
| 4 | 40 | 0 | 5 | 0 | 2602 | 24.3 | 202 |
| 5 | 40 | 0 | 0 | 2.5 | 2296 | 24.4 | 186 |
| 6, 43 | 40 | 0 | 5 | 2.5 | 2231 | 25.1 | 165 |
| 7, 44 | 40 | 0 | 5 | 5 | 2629 | 25.8 | 184 |
| 8 | 40 | 0 | 5 | 10 | 2324 | 27.6 | 171 |
| 9 | 40 | 0 | 5 | 20 | 2473 | 28.0 | 198 |
| 10 | 40 | 0 | 5 | 30 | 2735 | 28.7 | 188 |
| 11, 13, 15, 31, 35 | 40 | 10 | 0 | 0 | 2464 | 25.2 | 180 |
| 14, 16, 32 | 40 | 10 | 5 | 2.5 | 2608 | 26.9 | 177 |
| 12, 17, 19, 33, 37 | 40 | 20 | 0 | 0 | 2179 | 24.1 | 177 |
| 18, 20, 34 | 40 | 20 | 5 | 2.5 | 2289 | 23.5 | 173 |
| 21 | 0 | 20 | 0 | 0 | 2051 | 21.3 | 180 |
| 22 | 20 | 20 | 0 | 0 | 2157 | 21.8 | 176 |
| 23, 25 | 40 | 30 | 0 | 0 | 2258 | 23.8 | 182 |
| 24, 26 | 40 | 30 | 5 | 2.5 | 2223 | 24.7 | 181 |
| 27 | 40 | 60 | 0 | 0 | 2601 | 27.5 | 206 |
| 28 | 40 | 60 | 5 | 2.5 | 2934 | 26.4 | 194 |
| 29 | 40 | 90 | 0 | 0 | 2305 | 24.3 | 179 |
| 30 | 40 | 90 | 5 | 2.5 | 2341 | 25.1 | 217 |
| 36 | 40 | 10 | 0 | 0 | 2123 | 24.0 | 172 |
| 38 | 40 | 20 | 0 | 0 | 2278 | 25.6 | 171 |
| 41 | 40 | 20 | 5 | 5 | 2628 | 28.1 | 172 |
| 42 | 40 | 30 | 5 | 5 | 2699 | 28.2 | 175 |
| 45 | 40 | 10 | 0 | 2.5 | 2229 | 26.0 | 194 |
| 46 | 40 | 20 | 0 | 2.5 | 2143 | 24.3 | 155 |

Analysis of Variance

| Source of Variation | df | MS | df | MS | df | MS |
|---|---|---|---|---|---|---|
| Treatments | 45 | 248940 | 45 | 12.8 | 45 | 920 |
| Experimental Error | 135 | 275021 | 135 | 10.4 | 135 | 714 |
| LSD (.05) | | 727 | | 5.6 | | 37 |

1/ All culms counted (heads not considered).
2/ 25 lb. K on all treatments except 1 and 39.

The trends in grain yield response to P are shown by observing the yields of 5 lb/A N plus 5 to 30 lb/A P placed with-the-seed, treatments 4, 6, 7, 8, 9, and 10. The greatest yield response was noted with treatment 10 with a 4.4 bu/A increase over treatment 4. Two other treatments that note observation are treatments 41 and 42. The only difference between treatments 18, 20, and 34 and 41 was the starter fertilizer (5 N plus 5 P) for 41 compared with 5 N plus 2.5 P for 18, 20, and 34. The same difference exists between treatments 24 and 26 with 42. Grain yield for treatments 18, 20, and 30 was 23.5 compared with 28.1 for treatment 41. Grain yield for treatments 24 and 26 was 24.7 compared with 28.2 for treatment 42. This was an appreciable increase for only 2.5 lb. P per acre difference in treatments and may indicate that 2.5 lb. P per acre in the starter was low.

The Stanford data for barley shown in Table 6 indicated that very similar trends were evident as at Power. Treatments 6, 7, 8, 9, and 10 and 41 and 42 increased yields compared with treatment 4. It was unusual that the exact treatments showed this same trend. There was some inconsistency with treatments 8 and 9, though, as they were lower in yields than treatment 7. Dry matter yields were also lower for the same treatments.

Harvest data for spring wheat grown at Froid shown in Table 7 did not follow the same trends as noted at the Power and Stanford locations with respect to with-the-seed treatments as very little difference in

Table 6. Grain yield, dry matter yield, and culm count - Stanford, 1967, barley.

| Treatment No. | Fertilizer Broadcast N | Fertilizer Broadcast P | Fertilizer With-Seed N | Fertilizer With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 1, 39 2/ | 0 | 0 | 0 | 0 | 1152 | 14.3 | 214 |
| 2, 40 | 0 | 0 | 0 | 0 | 1301 | 16.4 | 205 |
| 3 | 40 | 0 | 0 | 0 | 1810 | 21.3 | 271 |
| 4 | 40 | 0 | 5 | 0 | 1736 | 20.0 | 250 |
| 5 | 40 | 0 | 0 | 2.5 | 1975 | 22.7 | 284 |
| 6, 43 | 40 | 0 | 5 | 2.5 | 1991 | 21.9 | 272 |
| 7, 44 | 40 | 0 | 5 | 5 | 2238 | 25.0 | 307 |
| 8 | 40 | 0 | 5 | 10 | 2070 | 24.0 | 292 |
| 9 | 40 | 0 | 5 | 20 | 2146 | 24.5 | 311 |
| 10 | 40 | 0 | 5 | 30 | 2310 | 27.1 | 341 |
| 11, 13, 15, 31, 35 | 40 | 10 | 0 | 0 | 1797 | 21.1 | 243 |
| 14, 16, 32 | 40 | 10 | 5 | 2.5 | 1683 | 19.4 | 243 |
| 12, 17, 19, 33, 37 | 40 | 20 | 0 | 0 | 1832 | 20.9 | 293 |
| 18, 20, 34 | 40 | 20 | 5 | 2.5 | 1794 | 21.0 | 257 |
| 21 | 0 | 20 | 0 | 0 | 1332 | 16.6 | 207 |
| 22 | 20 | 20 | 0 | 0 | 1738 | 20.4 | 238 |
| 23, 25 | 40 | 30 | 0 | 0 | 1976 | 22.3 | 278 |
| 24, 26 | 40 | 30 | 5 | 2.5 | 1928 | 23.4 | 246 |
| 27 | 40 | 60 | 0 | 0 | 2149 | 25.0 | 296 |
| 28 | 40 | 60 | 5 | 2.5 | 2211 | 25.6 | 264 |
| 29 | 40 | 90 | 0 | 0 | 2273 | 24.8 | 301 |
| 30 | 40 | 90 | 5 | 2.5 | 2258 | 25.5 | 294 |
| 36 | 40 | 10 | 0 | 0 | 2015 | 24.6 | |
| 38 | 40 | 20 | 0 | 0 | 1905 | 22.3 | |
| 41 | 40 | 20 | 5 | 5 | 1993 | 25.0 | |
| 42 | 40 | 30 | 5 | 5 | 1992 | 25.6 | |

Analysis of Variance

| Source of Variation | df | MS | df | MS | df | MS |
|---|---|---|---|---|---|---|
| Treatments | 43 | 383059* | 43 | 30.5 | 23 | 5870** |
| Experimental Error | 129 | 235190 | 129 | 21.9 | 69 | 3225 |
| LSD (.05) | | 672 | | 8.1 | | 80 |

1/ All culms counted (heads not considered).
2/ 25 lb. K on all treatments except 1 and 39.
** Significant at the .01 level.
* Significant at the .05 level.

Table 7. Grain yield, dry matter yield, and culm count - Froid, 1967; spring wheat.

| Treatment No. | Fertilizer Broadcast N | Fertilizer Broadcast P | Fertilizer With-Seed N | Fertilizer With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 1, 39 2/ | 0 | 0 | 0 | 0 | 2682 | 23.2 | 225 |
| 2, 40 | 0 | 0 | 0 | 0 | 2635 | 23.7 | 229 |
| 3 | 40 | 0 | 0 | 0 | 2885 | 23.3 | 217 |
| 4 | 40 | 0 | 5 | 0 | 2849 | 24.6 | 240 |
| 5 | 40 | 0 | 0 | 2.5 | 2798 | 23.6 | 226 |
| 6 | 40 | 0 | 5 | 2.5 | 2796 | 24.1 | 227 |
| 7 | 40 | 0 | 5 | 5 | 2763 | 25.5 | 236 |
| 8 | 40 | 0 | 5 | 10 | 3059 | 24.8 | 232 |
| 9 | 40 | 0 | 5 | 20 | 2909 | 24.3 | 242 |
| 10 | 40 | 0 | 5 | 30 | 2881 | 23.2 | 247 |
| 11, 13, 15, 31, 35 | 40 | 10 | 0 | 0 | 2767 | 23.4 | 228 |
| 14, 16, 32 | 40 | 10 | 5 | 2.5 | 2947 | 24.4 | 243 |
| 12, 17, 19, 33, 37 | 40 | 20 | 0 | 0 | 2826 | 23.8 | 247 |
| 18, 20, 34 | 40 | 20 | 5 | 2.5 | 2975 | 25.2 | 242 |
| 21 | 0 | 20 | 0 | 0 | 2763 | 24.0 | 229 |
| 22 | 20 | 20 | 0 | 0 | 2943 | 24.2 | 234 |
| 23, 25 | 40 | 30 | 0 | 0 | 3033 | 24.8 | 213 |
| 24, 26 | 40 | 30 | 5 | 2.5 | 3034 | 24.5 | 237 |
| 27 | 40 | 60 | 0 | 0 | 2766 | 23.1 | 226 |
| 28 | 40 | 60 | 5 | 2.5 | 2842 | 22.3 | 219 |
| 29 | 40 | 90 | 0 | 0 | 2920 | 25.6 | 248 |
| 30 | 40 | 90 | 5 | 2.5 | 3036 | 26.3* | 230 |
| 36 | 40 | 10 | 0 | 0 | 2793 | 22.7 | |
| 38 | 40 | 20 | 0 | 0 | 2921 | 24.3 | |
| 41 | 40 | 20 | 5 | 5 | 3082 | 26.5* | |
| 42 | 40 | 30 | 5 | 5 | 3155 | 26.2* | |
| 43 | 60 | 20 | 5 | 2.5 | 2961 | 24.8 | |
| 44 | 80 | 20 | 5 | 2.5 | 3172 | 27.1* | |
| 45 | 40 | 10 | 0 | 2.5 | 2813 | 23.3 | |
| 46 | 40 | 20 | 0 | 2.5 | 2915 | 25.7 | |

Analysis of Variance

| Source of Variation | df | MS | df | MS | df | MS |
|---|---|---|---|---|---|---|
| Treatments | 45 | 89947* | 45 | 5.8* | 23 | 380 |
| Experimental Error | 135 | 54249 | 135 | 3.4 | 69 | 397 |
| LSD (.05) | | 323 | | 2.6 | | 28 |

1/ All culms counted (heads not considered).
2/ 25 lb. K on all treatments except 1 and 39.
* Significant at the .05 level.

yields was noted. This location did show some response, although not significant at the level tested, to starter fertilizer, 5 N plus 2.5 P placed with-the-seed in combination with broadcast P. Grain yields due to starter fertilizer plus 10, 20, and 90 P broadcast compared with those same rates broadcast and no starter fertilizer were 24.4 to 23.4, 25.2 to 23.8, and 26.3 to 25.6, respectively. The only significant yield increases for 1967 were for yields of treatments 30, 41, 42, and 44 at Froid. Grain yields of treatments 41 and 42 were increased at Power and Stanford but were non-significant.

It was noted that in most cases dry matter yield corresponds fairly close to grain yields expecially with those treatments showing significant grain yield increases.

Culm count was quite variable at all locations for 1967 but there were some increases over the check noted at higher rates of P with-the-seed and higher broadcast rates.

Even though test weight and protein percentage measurements were made, differences due to P fertilizer were insignificant and are not included in this thesis write-up. Yield information was helpful in estimating P use and for determining residual phosphorus effectiveness in later years.

1968 Results On Winter And Spring Wheat

The experimental results for 1968 could be better handled in sections, especially with three locations to compare. For this reason the data, including treatments for dry matter yields, grain yields, and culm count are listed in the following tables: Power, Table 8; Denton, Table 9; and Froid, Table 10. P yield data are discussed in a later section.

A few general points are listed that may help in understanding the data. Grain and dry matter yields were significantly increased with P fertilizer at all locations in 1968. Grain yields were in the range of 35 to 45 bu/A at Power, the highest yields recorded for 1968. Grain yields at Denton were lower due to hail damage, estimated at 12 to 18 percent. There may have been some variation in hail damage due to treatment effect. Check treatments 1, 39 and 2, 40 and 21 seemed to show more damage with fewer culm/A than other treatments with thicker stands. Grain yields at Froid were not exceptional, but fair for spring wheat in that area being in the 23 to 28 bu/A range. Test weight values were in the 61-64 lb/bu range at both Denton and Power and 58-60 at Froid. Normally, test weight of spring wheat will be approximately 2 lb/bu less than winter wheat.

It was noticeable that the number of treatments with significant differences was greater with dry matter yield than with grain yield. This could and probably does mean that P has more influence on dry

Table 8. Grain yield, dry matter yield, and culm count-Power, 1968; winter wheat.

| Treatment No. | Fertilizer Broadcast N | Broadcast P | With-Seed N | With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 1, 39 2/ | 0 | 0 | 0 | 0 | 4240 | 32.8 | 225 |
| 2, 40 | 0 | 0 | 0 | 0 | 4295 | 32.0 | 223 |
| 3 | 40 | 0 | 0 | 0 | 4426 | 38.4 | 250 |
| 4 | 40 | 0 | 5 | 0 | 4487 | 34.7 | 243 |
| 5 | 40 | 0 | 0 | 2.5 | 5132 | 40.3 | 266 |
| 6 | 40 | 0 | 5 | 2.5 | 5093 | 40.0 | 290 |
| 7 | 40 | 0 | 5 | 5 | 5077 | 41.9 | 277 |
| 8 | 40 | 0 | 5 | 10 | 5495* | 41.6 | 340* |
| 9 | 40 | 0 | 5 | 20 | 6128* | 41.5 | 337* |
| 10 | 40 | 0 | 5 | 30 | 6316* | 43.1 | 353* |
| 11, 13, 15 | 40 | 10 | 0 | 0 | 4940 | 38.5 | 270 |
| 14, 16 | 40 | 10 | 5 | 2.5 | 5009 | 38.8 | 281 |
| 12, 17, 19 | 40 | 20 | 0 | 0 | 5015 | 38.3 | 254 |
| 18, 20 | 40 | 20 | 5 | 2.5 | 5486* | 44.3 | 284 |
| 21 | 0 | 20 | 0 | 0 | 4215 | 34.8 | 235 |
| 22 | 20 | 20 | 0 | 0 | 4780 | 38.8 | 245 |
| 23, 25 | 40 | 30 | 0 | 0 | 5408* | 40.1 | 256 |
| 24, 26 | 40 | 30 | 5 | 2.5 | 5530* | 43.2 | 326 |
| 27 | 40 | 60 | 0 | 0 | 5855* | 43.9 | 279 |
| 28 | 40 | 60 | 5 | 2.5 | 5957* | 44.3 | 313 |
| 29 | 40 | 90 | 0 | 0 | 6127* | 45.6* | 326 |
| 30 | 40 | 90 | 5 | 2.5 | 6719* | 45.8* | 340* |
| 31 3/ | 40 | 10 | 0 | 0 | 5069* | 40.2 | 268 |
| 32 | 40 | 10 | 5 | 2.5 | 5639* | 43.8 | 299 |
| 33 | 40 | 20 | 0 | 0 | 5692* | 44.0 | 282 |
| 34 | 40 | 20 | 5 | 2.5 | 6016* | 41.7 | 311 |
| 35 | 40 | 10 | 0 | 0 | 4882 | 38.9 | 261 |
| 36 4/ | 40 | 10 | 0 | 0 | 4959 | 39.3 | 231 |
| 37 | 40 | 20 | 0 | 0 | 5671* | 42.9 | 296 |
| 38 4/ | 40 | 20 | 0 | 0 | 5838* | 45.0* | 321 |
| 41 | 40 | 20 | 5 | 5 | 5652* | 42.8 | 332* |
| 42 | 40 | 30 | 5 | 5 | 5216* | 44.4 | 307 |
| 43 | 60 | 20 | 5 | 2.5 | 5801* | 44.3 | 298 |
| 44 | 80 | 20 | 5 | 2.5 | 5668* | 45.1* | 272 |
| 45 | 40 | 10 | 0 | 2.5 | 5151* | 41.1 | 264 |
| 46 | 40 | 20 | 0 | 2.5 | 5385* | 40.4 | 290 |

Table continued. . .

Table 8. Continued. . .

| | Total Dry Matter lb/A | | Grain Yield Bu/A | | Culm Count 1/ 8' of Row | |
|---|---|---|---|---|---|---|
| | Analysis of Variance | | | | | |
| Source of Variation | df | MS | df | MS | df | MS |
| Treatments | 45 | 1390546** | 45 | 55.4** | 45 | 8154** |
| Experimental Error | 135 | 258776 | 135 | 22.3 | 135 | 3196 |
| LDS (.05) | 712 | | 6.6 | | 79 | |

1/ All culms counted (heads not considered).

2/ 25 lb. K on all treatments except 1 and 39.

3/ Treatments 31-38 were applied in the spring before fallow.

4/ 15-60-0 TVA (ammonium polyphosphate) and 33.5-0-0.

** Significant at the .01 level.

* Significant at the .05 level.

Table 9. Grain yield, dry matter yield, and culm count - Denton, 1968; winter wheat.

| Treatment No. | Fertilizer Broadcast N | Fertilizer Broadcast P | Fertilizer With-Seed N | Fertilizer With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 1, 39 2/ | 0 | 0 | 0 | 0 | 2640 | 16.3 | 274 |
| 2, 40 | 0 | 0 | 0 | 0 | 3003 | 17.5 | 230 |
| 3 | 40 | 0 | 0 | 0 | 4281 | 25.2 | 260 |
| 4 | 40 | 0 | 5 | 0 | 4571 | 25.0 | 290 |
| 5 | 40 | 0 | 0 | 2.5 | 4354 | 26.8 | 306 |
| 6 | 40 | 0 | 5 | 2.5 | 4879* | 30.0 | 328 |
| 7 | 40 | 0 | 5 | 5 | 4741 | 27.8 | 311 |
| 8 | 40 | 0 | 5 | 10 | 4712 | 26.9 | 330 |
| 9 | 40 | 0 | 5 | 20 | 4828 | 27.9 | 348* |
| 10 | 40 | 0 | 5 | 30 | 5011* | 28.4 | 305 |
| 11, 13, 15, 31, 35 | 40 | 10 | 0 | 0 | 4566 | 25.5 | 287 |
| 14, 16, 32 | 40 | 10 | 5 | 2.5 | 4905* | 29.3 | 317 |
| 12, 17, 19, 33, 37 | 40 | 20 | 0 | 0 | 4680 | 28.1 | 303 |
| 18, 20, 34 | 40 | 20 | 5 | 2.5 | 4994* | 31.0* | 309 |
| 21 | 0 | 20 | 0 | 0 | 2690 | 15.5 | 232 |
| 22 | 20 | 20 | 0 | 0 | 3767 | 21.4 | 281 |
| 23, 25 | 40 | 30 | 0 | 0 | 4844 | 29.9 | 316 |
| 24, 26 | 40 | 30 | 5 | 2.5 | 4908* | 29.9 | 316 |
| 27 | 40 | 60 | 0 | 0 | 4920* | 29.4 | 300 |
| 28 | 40 | 60 | 5 | 2.5 | 5049* | 29.0 | 304 |
| 29 | 40 | 90 | 0 | 0 | 5018* | 29.4 | 319 |
| 30 | 40 | 90 | 5 | 2.5 | 5282* | 29.9 | 321 |
| 36 | 40 | 10 | 0 | 0 | 4719 | 27.7 | 321 |
| 38 | 40 | 20 | 0 | 0 | 4835 | 28.0 | 320 |
| 41 | 40 | 20 | 5 | 5 | 4495 | 26.9 | 340* |
| 42 | 40 | 30 | 5 | 5 | 5358* | 30.5* | 325 |
| 43 | 60 | 20 | 5 | 2.5 | 5726* | 35.2* | 323 |
| 44 | 80 | 20 | 5 | 2.5 | 5305* | 32.7* | 353* |
| 45 | 40 | 10 | 0 | 2.5 | 3928 | 27.5 | 315 |
| 46 | 40 | 20 | 0 | 2.5 | 4680 | 28.1 | 328 |

Table continued. . .

Table 9. Continued. . .

| | Total Dry Matter lb/A | | Grain Yield Bu/A | | Culm Count 1/ 8' of Row | |
|---|---|---|---|---|---|---|
| | Analysis of Variance | | | | | |
| Source of Variation | df | MS | df | MS | df | MS |
| Treatments | 45 | 2042356** | 45 | 76.8** | 45 | 4091 |
| Experimental Error | 135 | 182757 | 135 | 12.4 | 135 | 2952 |
| LSD (.05) | 595 | | 4.9 | | 76 | |

1/ All culms counted (heads not considered).

2/ 25 lb. K on all treatments except 1 and 39.

** Significant at the .01 level.

* Significant at the .05 level.

Table 10. Grain yield, dry matter yield, and culm count - Froid, 1968; spring wheat.

| Treatment No. | Fertilizer | | | | Total Dry Matter | Grain Yield | Culm Count 1/ |
|---|---|---|---|---|---|---|---|
| | Broadcast | | With-Seed | | | | |
| | N | P | N | P | lb/A | Bu/A | 8' of Row |
| 1, 39 2/ | 0 | 0 | 0 | 0 | 2868 | 22.7 | 213 |
| 2, 40 | 0 | 0 | 0 | 0 | 2940 | 23.6 | 209 |
| 3 | 40 | 0 | 0 | 0 | 2893 | 23.1 | 195 |
| 4 | 40 | 0 | 5 | 0 | 2855 | 23.4 | 209 |
| 5 | 40 | 0 | 0 | 2.5 | 2870 | 22.7 | 211 |
| 6 | 40 | 0 | 5 | 2.5 | 3134 | 24.4 | 217 |
| 7 | 40 | 0 | 5 | 5 | 3241 | 25.1 | 253* |
| 8 | 40 | 0 | 5 | 10 | 3677* | 27.0* | 257* |
| 9 | 40 | 0 | 5 | 20 | 3542* | 26.0 | 269* |
| 10 | 40 | 0 | 5 | 30 | 3466* | 26.5* | 307* |
| 11 | 40 | 10 3/ | 0 | 0 | 3066 | 23.7 | 227 |
| 12 | 40 | 20 3/ | 0 | 0 | 3292* | 24.9 | 239 |
| 13, 15 | 40 | 10 | 0 | 0 | 3120 | 24.5 | 230 |
| 14, 16 | 40 | 10 | 5 | 2.5 | 3474* | 26.5* | 250* |
| 17, 19 | 40 | 20 | 0 | 0 | 3127 | 23.8 | 232 |
| 18, 20 | 40 | 20 | 5 | 2.5 | 3369* | 26.2* | 252* |
| 21 | 0 | 20 | 0 | 0 | 3424* | 27.9* | 236 |
| 22 | 20 | 20 | 0 | 0 | 3521* | 26.4* | 236 |
| 23, 25 | 40 | 30 | 0 | 0 | 3248 | 24.5 | 248* |
| 24, 26 | 40 | 30 | 5 | 2.5 | 3367* | 25.0 | 250* |
| 27 | 40 | 60 | 0 | 0 | 3153 | 22.8 | 254* |
| 28 | 40 | 60 | 5 | 2.5 | 3523* | 25.3 | 259* |
| 29 | 40 | 90 | 0 | 0 | 3527* | 25.2 | 276* |
| 30 | 40 | 90 | 5 | 2.5 | 3513* | 26.8* | 257* |
| 31 4/ | 40 | 10 | 0 | 0 | 3058 | 24.3 | 238 |
| 32 | 40 | 10 | 5 | 2.5 | 3329* | 26.8* | 251* |
| 33 | 40 | 20 | 0 | 0 | 2733 | 21.4 | 228 |
| 34 | 40 | 20 | 5 | 2.5 | 3026 | 23.4 | 196 |
| 35 | 40 | 10 | 0 | 0 | 3015 | 24.6 | 218 |
| 36 5/ | 40 | 10 | 0 | 0 | 2944 | 24.0 | 212 |
| 37 | 40 | 20 | 0 | 0 | 2833 | 24.5 | 202 |
| 38 5/ | 40 | 20 | 0 | 0 | 2915 | 24.1 | 228 |
| 41 | 40 | 20 | 5 | 5 | 3362* | 25.9 | 267* |
| 42 | 40 | 30 | 5 | 5 | 3461* | 25.8 | 258* |
| 43 | 60 | 20 | 5 | 2.5 | 3303* | 25.0 | 279* |
| 44 | 80 | 20 | 5 | 2.5 | 3340* | 24.3 | 291* |
| 45 | 40 | 10 | 0 | 2.5 | 3459* | 26.7* | 237 |
| 46 | 40 | 20 | 0 | 2.5 | 3876* | 29.2* | 226 |

Table continued. . .

Table 10. Continued. . .

| | Total Dry Matter lb/A | | Grain Yield Bu/A | | Culm Count 1/ 8' of Row | |
|---|---|---|---|---|---|---|
| | **Analysis of Variance** | | | | | |
| Source of Variation | df | MS | df | MS | df | MS |
| Treatments | 45 | 285707** | 45 | 10.4** | 45 | 2584** |
| Experimental Error | 135 | 70332 | 135 | 4.9 | 135 | 1016 |
| LSD (.05) | 371 | | 3.1 | | 45 | |

1/ All culms counted (heads not considered).

2/ 25 lb. K on all treatments except 1 and 39.

3/ Broadcast in spring just prior to seeding

4/ Treatments 31-38 were applied in the spring before fallow.

5/ 15-60-0 TVA (ammonium polyphosphate) and 33.5-0-0.

** Significant at the .01 level.

* Significant at the .05 level.

matter production than grain yield. It could also mean that less variation existed within treatments among replications, and the relative error was smaller, probably because seed production is more subject to small differences in available water and nutrients in the soil than is production of vegetative growth.

Placement Of Fertilizer With-The-Seed

At this point meaningful comparisons can be made between the locations. Table 11 shows grain yields for all three locations with respect to rates of fertilizer with-the-seed.

The true check for rates of P with-the-seed is treatment 4 which received 5 lb. N per acre and no P, with all these treatments receiving 40 lb. N/A, topdressed. At Power, grain yield of treatment 4 was very low--less than the check (treatments 2, 40). It is not surprising that this occurred considering the responses from P evident in early growth, through heading. N alone apparently compounded P deficiencies.

Significant grain yield increases were recorded at the Froid location with spring wheat. Treatments 8, 9, and 10 showed increases of up to 3.6, 3.2, and 3.1 bu/A, respectively, compared with treatment 4. Treatment means were also significant at Power and Denton with yield increases of up to 8.4 bu/A at Power.

Treatment 6 at Denton seemed out of line compared with 7, 8, 9, and 10 which did not show the yield increase with higher rates of P. This variation was not noted at the other locations.

Table 11. Grain yield for rates of fertilizer placed with-the-seed for 1968; winter wheat at Power and Denton, spring wheat at Froid.

| Treatment No. | With-the-Seed 1/ N | With-the-Seed 1/ P | Power bu/A | Denton bu/A 2/ | Froid bu/A |
|---|---|---|---|---|---|
| 3 | 0 | 0 | 38.4 | 25.2 | 23.1 |
| 4 | 5 | 0 | 34.7 | 25.0 | 23.4 |
| 5 | 0 | 2.5 | 40.3 | 26.8 | 22.7 |
| 6 | 5 | 2.5 | 40.0 | 30.0* | 24.4 |
| 7 | 5 | 5 | 41.9* | 25.6 | 25.1 |
| 8 | 5 | 10 | 41.6* | 26.8 | 27.0* |
| 9 | 5 | 20 | 41.5* | 27.9 | 26.6* |
| 10 | 5 | 30 | 43.1* | 28.4 | 26.5* |
| LSD (.05) level | | | 6.6 | 4.9 | 3.1 |

1/ All treatments have 40 lb. N and 25 lb. K/A, topdressed in the spring.

2/ Hail damage of 12-18% reduced yields.

* Significant at the .05 level compared with treatment 4.

Spring grain as at the Froid location seemed to benefit from the higher rates of fertilizer application with-the-seed. This may be due partially to the length of time roots are in contact with the soil and fertilizer compared with winter wheat. With the higher concentration of fertilizer near the seed, spring wheat yields may show a greater increase.

Broadcast P Fertilizer And Its Relationship With Starter

For this thesis, starter fertilizer is defined as 5 lb. N and 2.5 lb. P per acre applied with-the-seed and will be termed "starter". Figure 1 shows the starter influence on grain yields at 0 to 90 lb. P per acre broadcast at Power.

Starter had the greatest influence on yields at 20 lb. P broadcast and somewhat less at 30 lb. P per acre. This response was significant at the 10% probability level using single degrees of freedom comparisons. At the higher rates, 60 and 90 lb. P/A, the expected occurred with little added response due to starter fertilizer. To explain why little or no response was obtained from starter at zero P and 10 P, broadcast is not easy; however, it may be that available P was enough to produce some plant response but not enough to carry through to increased grain yield.

The Denton grain yields were plotted in Figure 2 with reference to broadcast P with and without starter. There were noticeable increases from starter through the rate of 20 lb. P per acre. Using a single

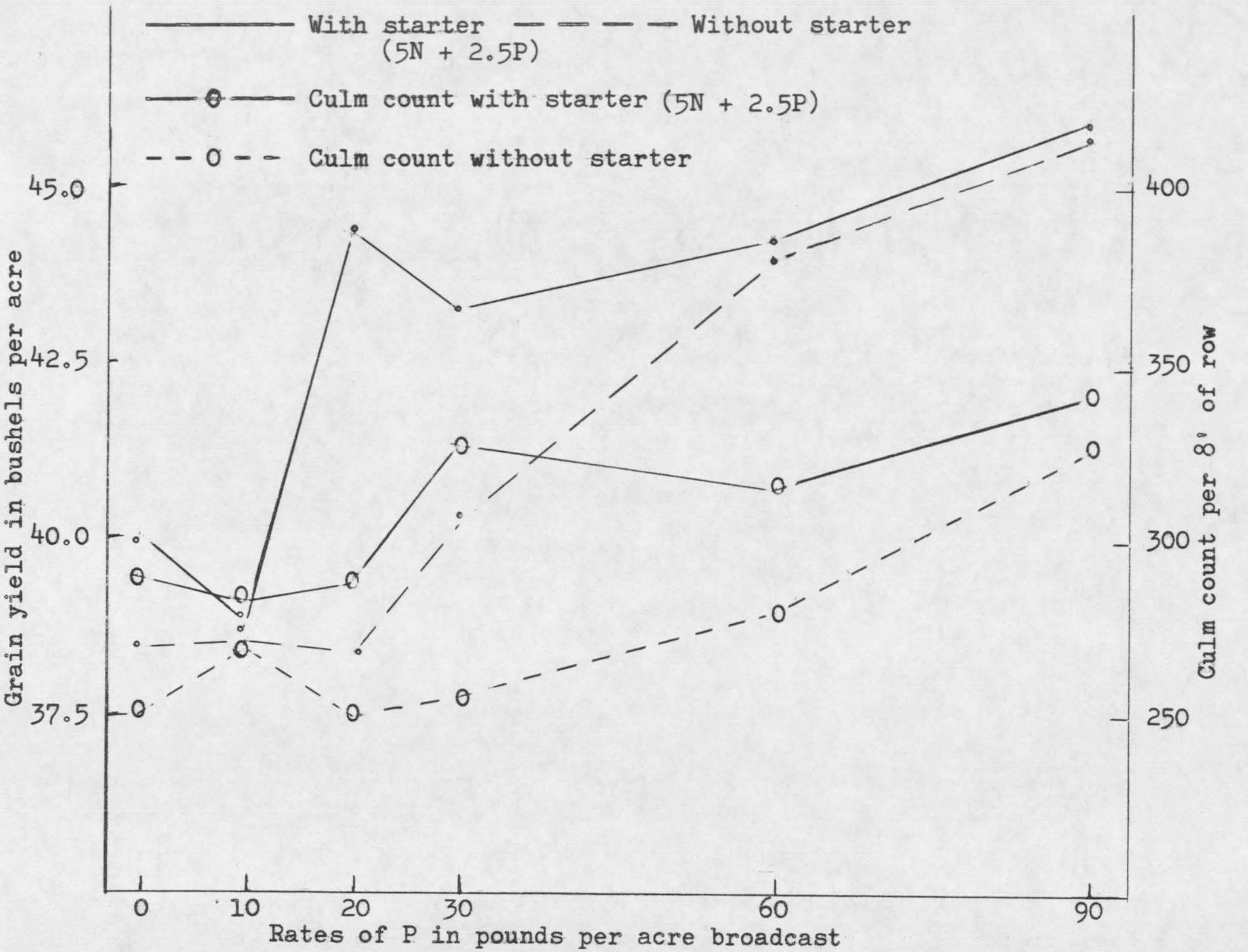


Figure 1. Grain yield and culm count for broadcast P with and without starter fertilizer - Power, 1968; winter wheat (all treatments had 40 lb. N/A and 25 lb. K/A, topdressed in the spring).

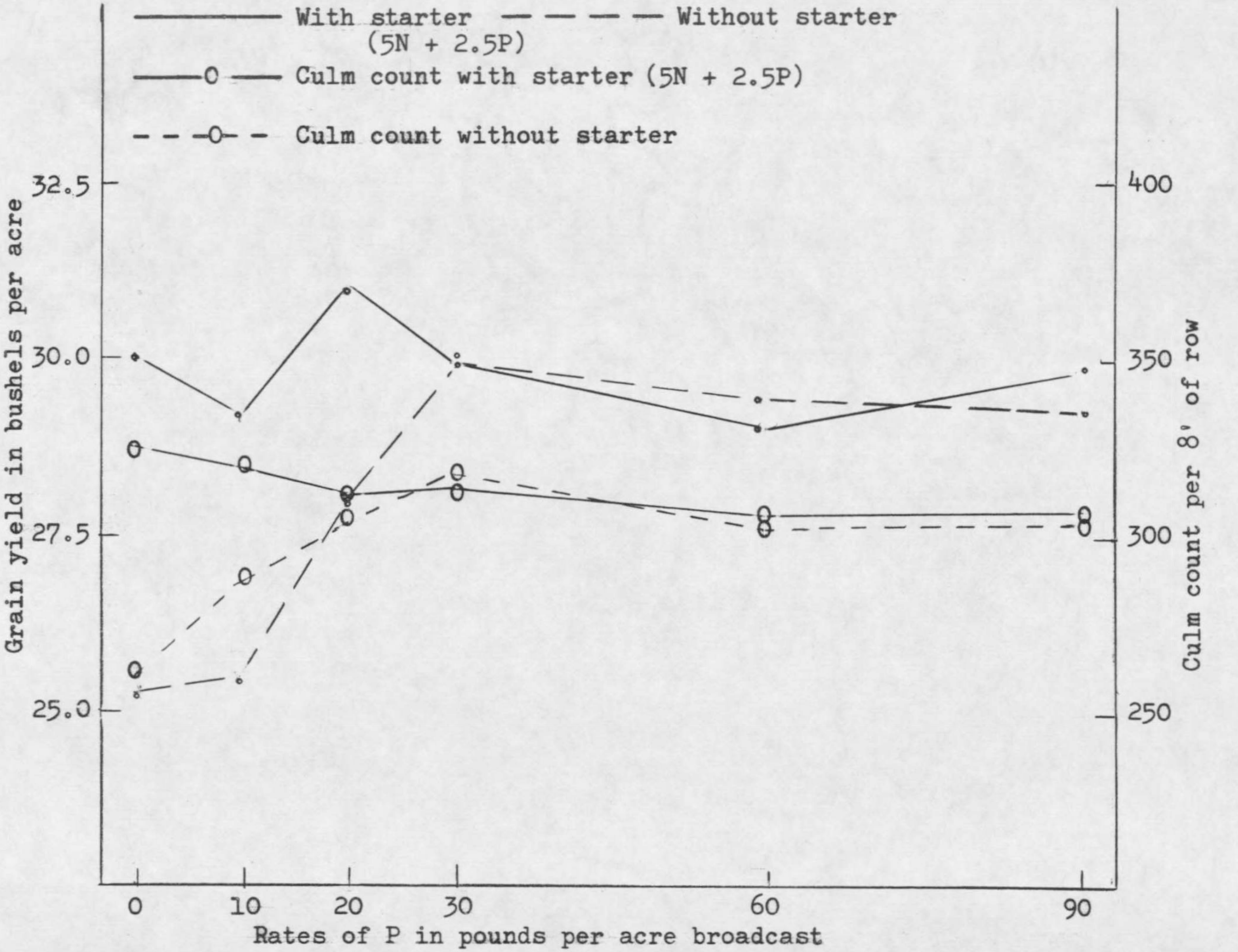


Figure 2. Grain yield and culm count for broadcast P with and without starter fertilizer - Denton, 1968; winter wheat (all treatments had 40 lb. N/A and 25 lb. K/A, topdressed in the spring).

degree of freedom test, yields were significantly increased with starter fertilizer at broadcast P-rates of 0, 10, and 20 lb. P per acre. Yield differences were significant at the 1% probability level, while at higher broadcast rates of 30 lb. P/A and above there was little or no influence. The differences in the level of broadcast P for starter effect at Denton compared with Power may be related to the soil P level. Soil P level at Power was "very low", 18 ppm, while at Denton the P level was "low", 32ppm. Starter influenced yields up to 60 lb. P per acre broadcast at Power and only up to 30 lb. P/A at Denton. This may have practical significance for making fertilizer recommendations if grain yield responses are closely related to the results obtained by soil tests on available P.

Figure 3 is included for the Power data to show the influence of starter on grain yield as related to broadcast P at 0 and 20 lb/A. It can be observed with 40 lb. N/A without starter, there was little difference in yields with 0 and 20 lb. P proadcast. At 40 lb. N plus starter, grain yield increased from 40 bu/A to 44 bu/A with the 20 lb. P per acre addition. Similar results were obtained at Denton and Froid with a 1.8 bu/A increase due to starter at Froid and 1 bu/A increase at Denton. At Denton there was also a 2.9 bu/A yield increase with 20 lb. P/A over 0 P without starter.

Different results were obtained at the Froid location with starter fertilizer. Figure 4 indicates that there was a starter influence with

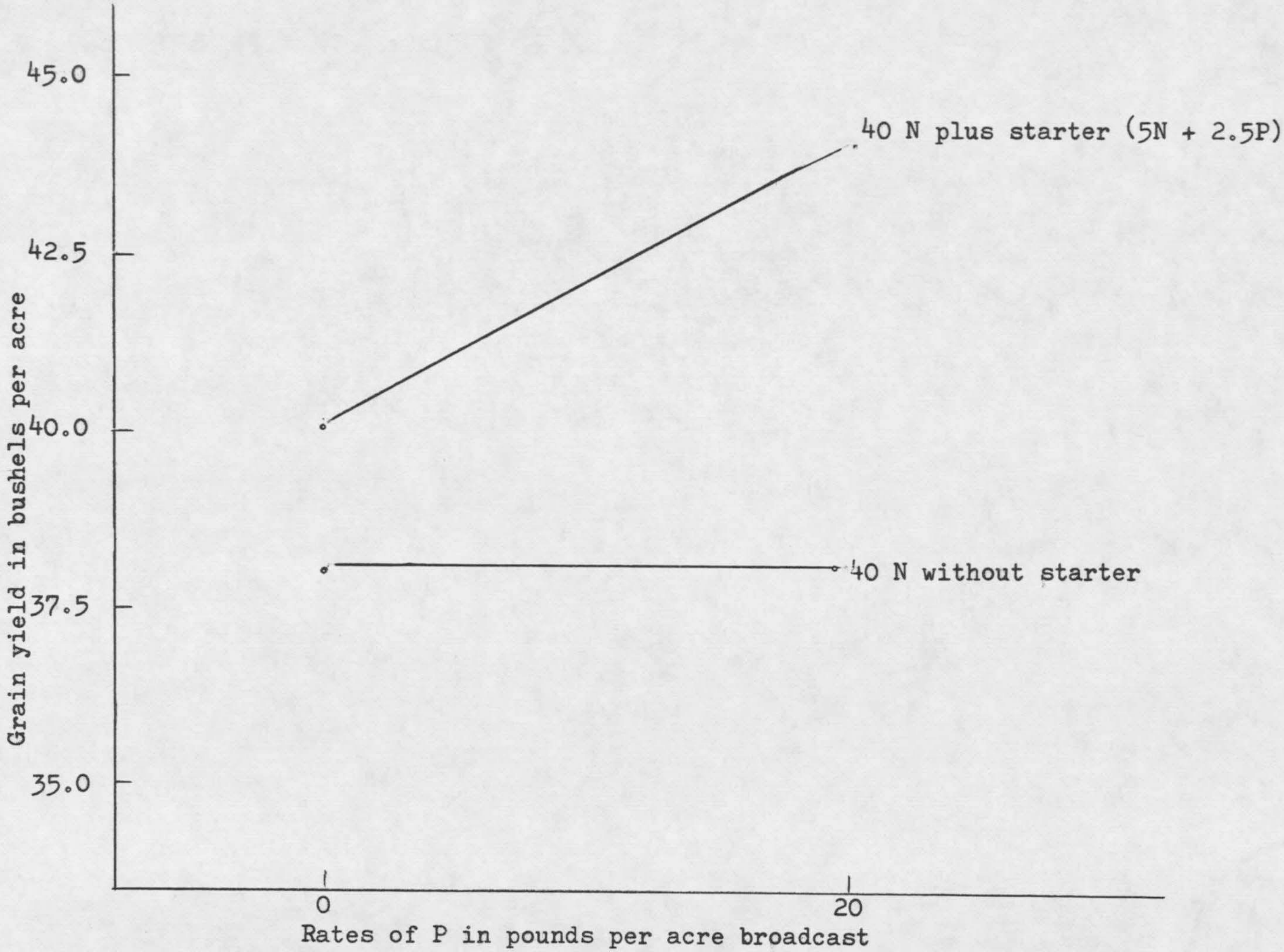


Figure 3. Grain yield as influenced by 0 and 20 lb P/A broadcast - Power, 1968; winter wheat (all treatments had 25 lb.K/A).

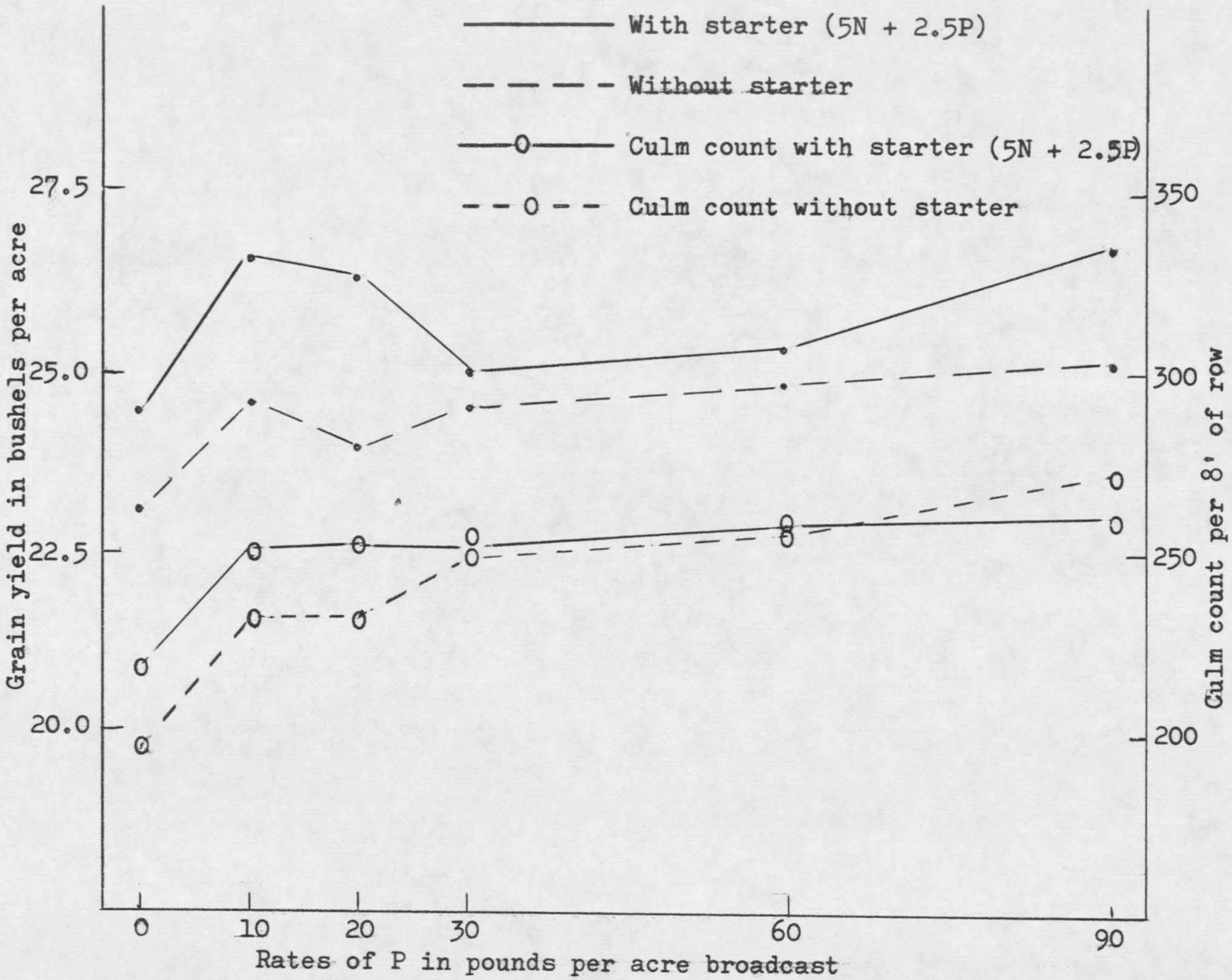


Figure 4. Grain yield and culm count for broadcast P with and without starter fertilizer - Froid, 1968; spring wheat (all treatments had 40 lb. N/A and 25 lb. K/A, topdressed in the spring).

up to 90 lb. P per acre broadcast. The average yield response to starter was significant at the 1% level. This yield response pattern may be only characteristic of spring wheat. Spring wheat does not have the length of time for root development that winter wheat does and starter fertilizer near the rooting area may be more beneficial for spring wheat than winter wheat. The broadcast P was worked into the soil in the fall before spring seeding and if reduced availability were not a problem, it should have been positionally more available to the plants. Also, there were two treatments, 11 and 12, broadcast in the spring to check on possible loss of availability overwinter because of soil and P reaction. There appeared to be no advantage or disadvantage of this spring application.

## 1969 Results On Winter And Spring Wheat

With the discussion which follows being so interrelated between 1968 and 1969, the first sections will be those in 1969 results which can be separated, then the sections will combine 1968 and 1969.

The dry matter yields, grain yields, and culm counts for the 1969 crops are listed in Tables 12 for Power, 13 for Denton, and 14 for Froid. Yields were influenced by a cold, late spring and frost damage during the heading stage of growth. Although frost damage on these experiments was not considered major, the low temperatures probably reduced yields. The soil temperatures recorded in Appendix tables 41 and 42 for 1968 and 1969 at Denton showed the lower temperatures in

Table 12. Grain yield, dry matter yield, and culm count - Power, 1969; winter wheat.

| Treatment No. | Fertilizer Broadcast N | Fertilizer Broadcast P | Fertilizer With-Seed N | Fertilizer With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 1, 39 2/ | 0 | 0 | 0 | 0 | 3407 | 24.6 | 157 |
| 2, 40 | 0 | 0 | 0 | 0 | 3229 | 23.9 | 225 |
| 3 | 40 | 0 | 0 | 0 | 3166 | 23.6 | 197 |
| 4 | 40 | 0 | 5 | 0 | 3258 | 23.7 | 169 |
| 5 | 40 | 0 | 0 | 2.5 | 3254 | 23.4 | 185 |
| 6 | 40 | 0 | 5 | 2.5 | 3395 | 24.2 | 180 |
| 7 | 40 | 0 | 5 | 5 | 3841* | 25.6 | 217 |
| 8 | 40 | 0 | 5 | 10 | 4100* | 28.1* | 232 |
| 9 | 40 | 0 | 5 | 20 | 4009* | 25.6 | 264* |
| 10 | 40 | 0 | 5 | 30 | 4465* | 29.4 | 250* |
| 11 | 40 | 10 3/ | 0 | 0 | 3867* | 27.7* | 196 |
| 12 | 40 | 20 3/ | 0 | 0 | 4167* | 29.7* | 194 |
| 13 | 40 | 0 4/ | 0 | 0 | 3524 | 26.2 | 184 |
| 14 | 40 | 0 4/ | 5 | 2.5 | 3498 | 26.8 | 196 |
| 15 | 40 | 10 | 0 | 0 | 3906* | 28.3* | 182 |
| 16 | 40 | 10 | 5 | 2.5 | 4071* | 29.4* | 220 |
| 17 | 40 | 0 5/ | 0 | 0 | 4273* | 30.2* | 212 |
| 18 | 40 | 0 5/ | 5 | 2.5 | 4398* | 29.8* | 221 |
| 19 | 40 | 20 | 0 | 0 | 3868* | 26.5 | 214 |
| 20 | 40 | 20 | 5 | 2.5 | 3853* | 27.7* | 212 |
| 21 | 0 | 20 | 0 | 0 | 3489 | 26.8 | 194 |
| 22 | 20 | 20 | 0 | 0 | 3523 | 25.9 | 195 |
| 23 | 40 | 0 6/ | 0 | 0 | 3763* | 26.1 | 236 |
| 24 | 40 | 0 6/ | 5 | 2.5 | 3942* | 26.5 | 214 |
| 25 | 40 | 30 | 0 | 0 | 4332* | 29.9* | 229 |
| 26 | 40 | 30 | 5 | 2.5 | 4189* | 28.7* | 258* |
| 27 | 40 | 60 | 0 | 0 | 4191* | 28.9* | 222 |
| 28 | 40 | 60 | 5 | 2.5 | 4179* | 28.5* | 220 |
| 29 | 40 | 90 | 0 | 0 | 4829* | 32.4* | 246* |
| 30 | 40 | 90 | 5 | 2.5 | 4766* | 31.0* | 245* |
| 31 7/ | 40 | 10 | 0 | 0 | 3713* | 27.3 | 195 |
| 32 | 40 | 10 | 5 | 2.5 | 3874* | 28.5* | 181 |
| 33 | 40 | 20 | 0 | 0 | 3627 | 25.5 | 210 |
| 34 | 40 | 20 | 5 | 2.5 | 3824* | 26.7 | 210 |
| 35 | 40 | 10 | 0 | 0 | 4305* | 30.1* | 174 |
| 36 8/ | 40 | 10 | 0 | 0 | 4028* | 28.2* | 207 |

Table continued. . .

Table 12. Continued. . .

| Treatment No. | Fertilizer Broadcast N | Fertilizer Broadcast P | Fertilizer With-Seed N | Fertilizer With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 37 | 40 | 20 | 0 | 0 | 3976* | 28.8* | 214 |
| 38 8/ | 40 | 20 | 0 | 0 | 4172* | 30.1* | 270* |
| 41 | 40 | 20 | 5 | 5 | 3932* | 26.8 | 227 |
| 42 | 40 | 30 | 5 | 5 | 4224* | 28.1* | 249* |
| 43 | 60 | 20 | 5 | 2.5 | 3610 | 25.6 | 196 |
| 44 | 80 | 20 | 5 | 2.5 | 3967* | 28.2* | 186 |
| 45 | 40 | 10 | 0 | 2.5 | 3558 | 26.3 | 214 |
| 46 | 40 | 20 | 0 | 2.5 | 3686 | 25.9 | 232 |

Analysis of Variance

| Source of Variation | df | MS | df | MS | df | MS |
|---|---|---|---|---|---|---|
| Treatments | 45 | 658995** | 45 | 20.1** | 45 | 3240** |
| Experimental Error | 135 | 141969 | 135 | 7.6 | 135 | 1015 |
| LSD (.05) | | 526 | | 3.9 | | 45 |

1/ Includes culms with heads containing three or more kernels.

2/ 25 lb. K on all treatments except 1 and 39.

3/ P broadcast in spring just prior to seeding.

4/ 10 lb. P/A applied broadcast in 1967.

5/ 20 lb. P/A applied broadcast in 1967.

6/ 30 lb. P/A applied broadcast in 1967.

7/ Treatments 31-38 applied in spring before fallow.

8/ 15-60-0 TVA (ammonium polyphosphate) and 33.5-0-0.

** Significant at the .01 level.

* Significant at the .05 level.

Table 13. Grain yield, dry matter yield, and culm count - Denton, 1969; winter wheat.

| Treatment No. | Fertilizer Broadcast N | Fertilizer Broadcast P | Fertilizer With-Seed N | Fertilizer With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' or Row |
|---|---|---|---|---|---|---|---|
| 1, 39 2/ | 0 | 0 | 0 | 0 | 1448 | 9.5 | 129 |
| 2, 40 | 0 | 0 | 0 | 0 | 1316 | 9.1 | 115 |
| 3 | 40 | 0 | 0 | 0 | 2281 | 14.1 | 144 |
| 4 | 40 | 0 | 5 | 0 | 2252 | 14.9 | 173 |
| 5 | 40 | 0 | 0 | 2.5 | 2389 | 17.1* | 177 |
| 6 | 40 | 0 | 5 | 2.5 | 2553 | 18.2* | 224* |
| 7 | 40 | 0 | 5 | 5 | 2409 | 16.9 | 198 |
| 8 | 40 | 0 | 5 | 10 | 2354 | 17.6* | 222* |
| 9 | 40 | 0 | 5 | 20 | 2653 | 18.2* | 216* |
| 10 | 40 | 0 | 5 | 30 | 2762* | 18.6* | 207* |
| 11, 13, 15 | 40 | 10 | 0 | 0 | 2268 | 15.3 | 167 |
| 14, 16 | 40 | 10 | 5 | 2.5 | 2462 | 16.8 | 193 |
| 12, 17, 19 | 40 | 20 | 0 | 0 | 2156 | 14.7 | 149 |
| 18, 20 | 40 | 20 | 5 | 2.5 | 2501 | 17.0 | 158 |
| 21 | 0 | 20 | 0 | 0 | 1470 | 9.8 | 132 |
| 22 | 20 | 20 | 0 | 0 | 1979 | 12.7 | 149 |
| 23, 25 | 40 | 30 | 0 | 0 | 2331 | 17.7* | 182 |
| 24, 26 | 40 | 30 | 5 | 2.5 | 2437 | 17.6* | 219* |
| 27 | 40 | 60 | 0 | 0 | 2586 | 17.0 | 222* |
| 28 | 40 | 60 | 5 | 2.5 | 2597 | 17.3* | 197 |
| 29 | 40 | 90 | 0 | 0 | 2390 | 16.3 | 155 |
| 30 | 40 | 90 | 5 | 2.5 | 2610 | 17.5* | 220* |
| 31 3/ | 40 | 10 | 0 | 0 | 2462 | 15.3 | 169 |
| 32 | 40 | 10 | 5 | 2.5 | 2407 | 16.9 | 208* |
| 33 | 40 | 20 | 0 | 0 | 2281 | 14.7 | 167 |
| 34 | 40 | 20 | 5 | 2.5 | 2325 | 15.2 | 166 |
| 35 | 40 | 10 | 0 | 0 | 1048 | 6.8 | 112 |
| 36 4/ | 40 | 10 | 0 | 0 | 1128 | 7.6 | 133 |
| 37 | 40 | 20 | 0 | 0 | 1194 | 8.2 | 109 |
| 38 4/ | 40 | 20 | 0 | 0 | 1201 | 8.3 | 106 |
| 41 | 40 | 20 | 5 | 5 | 2675* | 17.0 | 237* |
| 42 | 40 | 30 | 5 | 5 | 2784* | 19.5* | 207* |
| 43 | 60 | 20 | 5 | 2.5 | 2863* | 19.6* | 236* |
| 44 | 80 | 20 | 5 | 2.5 | 2953* | 20.3* | 225* |
| 45 | 40 | 10 | 0 | 2.5 | 2372 | 16.0 | 196 |
| 46 | 40 | 20 | 0 | 2.5 | 2219 | 14.6 | 163 |

Table continued. . .

Table 13. Continued. . .

| | Total Dry Matter lb/A | | Grain Yield Bu/A | | Culm Count 1/ 8' of Row | |
|---|---|---|---|---|---|---|
| | Analysis of Variance | | | | | |
| Source of Variation | df | MS | df | MS | df | MS |
| Treatments | 45 | 1018863** | 45 | 46.9** | 45 | 5816** |
| Experimental Error | 135 | 78681 | 135 | 4.7 | 135 | 1754 |
| LSD (.05) | 393 | | 3.0 | | 59 | |

1/ Includes culms with heads containing three or more kernels.

2/ 25 lb. K on all treatments except 1 and 39.

3/ Treatments 31-38 applied in spring before fallow.

4/ 15-60-0 TVA (ammonium polyphosphate) and 33.5-0-0.

** Significant at the .01 level.

* Significant at the .05 level.

Table 14. Grain yield, dry matter yield, and culm count - Froid, 1969; spring wheat.

| Treatment No. | Fertilizer Broadcast N | Fertilizer Broadcast P | Fertilizer With-Seed N | Fertilizer With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 1, 39 2/ | 0 | 0 | 0 | 0 | 3409 | 17.6 | 241 |
| 2, 40 | 0 | 0 | 0 | 0 | 3236 | 20.6 | 206 |
| 3 | 40 | 0 | 0 | 0 | 3139 | 20.9 | 188 |
| 4 | 40 | 0 | 5 | 0 | 3629 | 21.3 | 186 |
| 5 | 40 | 0 | 0 | 2.5 | 3377 | 22.0 | 211 |
| 6 | 40 | 0 | 5 | 2.5 | 3638 | 21.1 | 214 |
| 7 | 40 | 0 | 5 | 5 | 3806* | 25.3 | 242* |
| 8 | 40 | 0 | 5 | 10 | 3501 | 23.9 | 241* |
| 9 | 40 | 0 | 5 | 20 | 3867* | 26.2* | 257* |
| 10 | 40 | 0 | 5 | 30 | 3564 | 24.2 | 250* |
| 11 | 40 | 10 3/ | 0 | 0 | 3649 | 21.6 | 195 |
| 12 | 40 | 20 3/ | 0 | 0 | 3608 | 22.8 | 218 |
| 13 | 40 | 0 4/ | 0 | 0 | 3511 | 22.5 | 198 |
| 14 | 40 | 0 4/ | 5 | 2.5 | 3809* | 25.6* | 218 |
| 15 | 40 | 10 | 0 | 0 | 3360 | 21.4 | 215 |
| 16 | 40 | 10 | 5 | 2.5 | 3500 | 22.1 | 206 |
| 17 | 40 | 0 5/ | 0 | 0 | 3045 | 19.1 | 227 |
| 18 | 40 | 0 5/ | 5 | 2.5 | 3197 | 20.0 | 225 |
| 19 | 40 | 20 | 0 | 0 | 2610 | 22.3 | 227 |
| 20 | 40 | 20 | 5 | 2.5 | 3808* | 24.9 | 233 |
| 21 | 0 | 20 | 0 | 0 | 3432 | 22.3 | 213 |
| 22 | 20 | 20 | 0 | 0 | 3736 | 24.1 | 250* |
| 23 | 40 | 0 6/ | 0 | 0 | 3386 | 21.6 | 254* |
| 24 | 40 | 0 6/ | 5 | 2.5 | 3664 | 24.3 | 255* |
| 25 | 40 | 30 | 0 | 0 | 3706 | 24.2 | 215 |
| 26 | 40 | 30 | 5 | 2.5 | 3694 | 24.1 | 249* |
| 27 | 40 | 60 | 0 | 0 | 3408 | 21.9 | 215 |
| 28 | 40 | 60 | 5 | 2.5 | 3565 | 23.9 | 224 |
| 29 | 40 | 90 | 0 | 0 | 3805* | 25.7* | 233 |
| 30 | 40 | 90 | 5 | 2.5 | 3960* | 26.1* | 252* |
| 31 7/ | 40 | 10 | 0 | 0 | 3099 | 19.1 | 240* |
| 32 | 40 | 10 | 5 | 2.5 | 3428 | 21.5 | 210 |
| 33 | 40 | 20 | 0 | 0 | 3433 | 22.2 | 224 |
| 34 | 40 | 20 | 5 | 2.5 | 3593 | 23.0 | 188 |

Table continued. . .

Table 14. Continued. . .

| Treatment No. | Fertilizer Broadcast N | Broadcast P | With-Seed N | With-Seed P | Total Dry Matter lb/A | Grain Yield Bu/A | Culm Count 1/ 8' of Row |
|---|---|---|---|---|---|---|---|
| 35 | 40 | 10 | 0 | 0 | 3712 | 24.5 | 231 |
| 36 8/ | 40 | 10 | 0 | 0 | 3692 | 25.7* | 235 |
| 37 | 40 | 20 | 0 | 0 | 3473 | 24.6 | 172 |
| 38 8/ | 40 | 20 | 0 | 0 | 4013* | 27.0* | 240* |
| 41 | 40 | 20 | 5 | 5 | 3792* | 25.6* | 242* |
| 42 | 40 | 30 | 5 | 5 | 3906* | 24.9 | 231 |
| 43 | 60 | 20 | 5 | 2.5 | 3675 | 23.0 | 189 |
| 44 | 80 | 20 | 5 | 2.5 | 3664 | 23.8 | 234 |
| 45 | 40 | 10 | 0 | 2.5 | 3410 | 22.1 | 233 |
| 46 | 40 | 20 | 0 | 2.5 | 3491 | 22.7 | 225 |

Analysis of Variance

| Source of Variation | df | MS | df | MS | df | MS |
|---|---|---|---|---|---|---|
| Treatments | 45 | 319874* | 45 | 21.1** | 45 | 1819 |
| Experimental Error | 135 | 199549 | 135 | 11.3 | 135 | 1256 |
| LSD (.05) | | 625 | | 4.7 | | 50 |

1/ Includes culms with heads containing three or more kernels.

2/ 25 lb. K on all treatments except 1 and 39.

3/ P broadcast in spring just prior to seeding.

4/ 10 lb. P/A applied in 1967.

5/ 20 lb. P/A applied in 1967.

6/ 30 lb. P/A applied in 1967.

7/ Treatments 31-38 applied in spring before fallow.

8/ 15-60-0 TVA (ammonium polyphosphate) and 33.5-0-0.

** Significant at the .01 level.

* Significant at the .05 level.

late May and early June for 1969. However, the differences recorded at the Power location between 1968 and 1969, Appendix tables 39 and 40 do not show the lower temperatures for 1969, as clearly. Evidently, the thermograph sensing element was either placed at a shallower depth in 1969 or the soil was disturbed above the element as temperatures seemed to show a wider range between high and low as compared with 1968. The range was approximately 10°- 12° F in 1968 and 15°- 18° F in 1969. It also appeared that the thermograph might have been calibrated slightly higher in 1969 which would record the temperatures higher than they actually were.

Yields at Denton in 1969 were influenced by cheatgrass and were further affected by low moisture. Effective moisture received at the Denton location for the growing season was approximately one inch in May. See appendix table 47 for precipitation data. The 2.6 inches of precipitation on June 28 was too late to affect the 1969 crop, except to help mature what was already developed. Plant samples were taken June 18 and at this time, plants were in the heading stage of development (Feekes stage 10.2). Test weight was slightly lower in 1969 at Denton than in 1968, probably due to the lower moisture. Average values were approximately 61 lb/bu at Denton, 62.5 lb/bu at Power, and 59.5 lb/bu at Froid.

Fertilizer Applied With-The-Seed

In 1969, the wheat yields were influenced by fertilizer applications with-the-seed for the 1967 crop in addition to 1969 at two locations, Power and Froid. There was an influence of treatments on yield at the two locations as noted in Table 15. Significant yield increases were obtained at Power in 1969 from P fertilizer banded with-the-seed. Yields ranged from 23.7 bu/A for zero P to 29.4 bu/A for 30 lb. P/A (total of 60 lb. P/A for two crop years).

Froid had yields which ranged from 21.3 bu/A for zero P to 26.2 bu/A at 20 lb. P/A with-the-seed (a two-year total of 40 P). However, at both Power and Froid, the response to rates of P did not show the typical increase in yields with increasing fertilizer with-the-seed. A contributing factor may have been the residual effects of P fertilizer applied with-the-seed for the 1967 crop.

At the Denton location, a more normal pattern of yield increases occurred with increasing rates of P especially from 5 to 30 lb. P/A. Significance level is listed in Table 15. The yields listed in the table indicate that the small amount of P, 2.5 lb/A, was adequate to show good yield increases with little added increase at higher P rates. This location did not have the P applications for the 1967 crop.

Starter Influence On Broadcast P - 1969

The fertilizer treatments for Power and Froid differed from Denton for 1969. This was the third year for the experiment at both

Table 15. Grain yield for rates of fertilizer placed with-the-seed for 1969; winter wheat at Power and Denton, spring wheat at Froid.

| Treatment 1/ No. | With-the-Seed 2/ N | P | Power Bu/A | Denton Bu/A | Froid Bu/A |
|---|---|---|---|---|---|
| 3 | 0 | 0 | 23.6 | 14.1 | 20.9 |
| 4 | 5 | 0 | 23.7 | 14.9 | 21.3 |
| 5 | 0 | 2.5 | 23.4 | 17.1 | 22.0 |
| 6 | 5 | 2.5 | 24.2 | 18.2* | 21.1 |
| 7 | 5 | 5 | 25.6 | 16.9 | 25.3 |
| 8 | 5 | 10 | 28.1* | 17.6 | 23.9 |
| 9 | 5 | 20 | 25.6 | 18.2* | 26.2* |
| 10 | 5 | 30 | 29.4* | 18.6* | 24.2 |
| LSD (.05) | | | 3.9 | 3.0 | 4.7 |

1/ All treatments had 40 lb. N and 25 lb. K/A, topdressed in the spring.

2/ All treatments with-the-seed were also applied for the 1967 crop at Power and Froid.

* Significant at the .05 level compared with treatment 4.

Power and Froid and the second at Denton. There were two sets of broadcast treatments for the 1969 crop year which differed primarily by year of application. One set consisting of 10, 20, 30, 60, and 90 lb. P per acre was broadcast for the 1967 crop. The second set consisting of 10, 20, and 30 P was applied for the 1969 crop in addition to 1967 making totals of 20, 40, and 60 P, respectively. The influence of starter on the 1969 crop was evaluated for these treatments.

Figure 5 indicated practically no additional response was shown at the Power location due to starter fertilizer as compared with no starter, except a small increase at the 0 and 10 lb. P-rate. Note the increased grain yield with only 10 lb. P per acre after two years; this increase was not significant at the levels tested. Yield increases were significant at 20, 60, and 90 lb. P per acre applied for the 1967 crop as compared with the check treatment, No. 3; complete data are in Table 12.

The comparisons for the second set of treatments were also included on this same figure to observe the additive effects of two broadcast applications, 1967 plus 1969. Rates of 10, 20, and 30 lb. P per acre were applied broadcast in 1967 and again in 1969 and yields are shown with the other designated lines. These treatments totaled 20, 40, and 60 lb. P per acre for the two years.

Applications of 20 lb. P (10 P for 1967 plus 10 P for 1969) showed a greater yield increase from starter fertilizer than did one application.

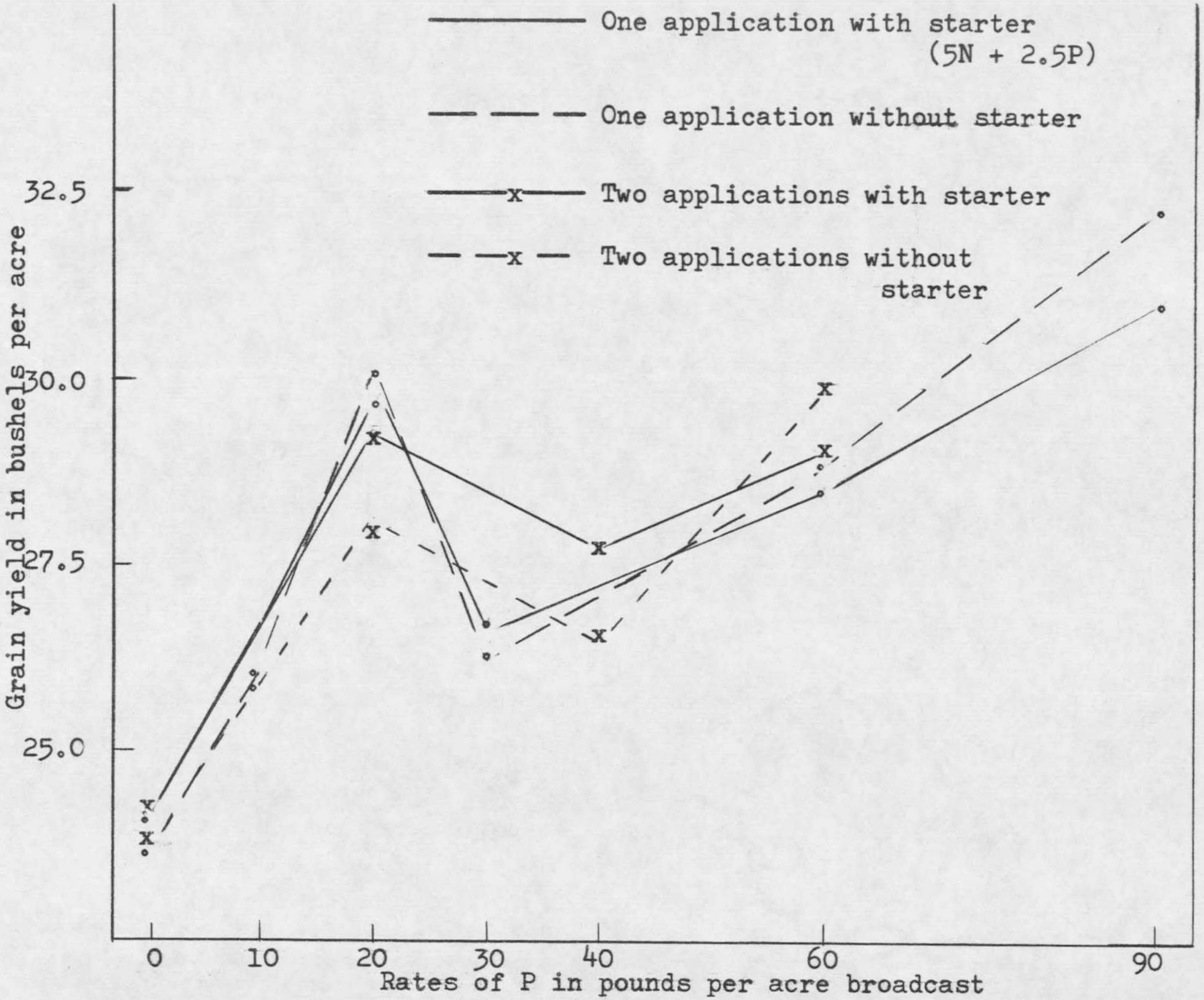


Figure 5. Grain yield comparisons for broadcast P for one application for 1967 and two applications (one for 1967 and one for 1969) with and without starter fertilizer - Power, 1969; winter wheat (Tr. had 4C lb. N & 25. lb. K).

of 20 or 30 lb. P applied in 1967. The same occurred at 40 lb. P (20 P plus 20 P) but added response was not noted at 60 lb. P (30 P plus 30 P). However, overall yields showed the same general trend with one application of 20, 30, and 60 lb. P per acre as with two applications of 10 P, 20 P, or 30 P, respectively.

Figure 6 is the result of plotting the corresponding data for spring wheat at Froid. Complete data are in Table 14. A significant response was shown for starter at the residual P levels produced by P applied in 1967. Yields at the 20 lb. P per acre level were out of line and not explainable as compared with the check treatment No. 3. Two applications of P (10 P for 1967 plus 10 P for 1969) produced over two bushels more wheat than the comparable rate of 20 lb. P per acre applied for the 1967 crop.

Starter effects were virtually identical whether P was all residual or a combination of residual and currently applied fertilizer, except at 60 lb. P per acre (30 P plus 30 P) where starter produced no measurable increase in yields. This indicates there was no great loss of availability of the P applied for the 1967 crop.

The Denton grain yields are plotted with rates of P broadcast in Figure 7. Treatments at this location included only the one-year application of broadcast P for the 1969 crop. The trends for 1969 were very similar to those of 1968 for the Denton data as were shown in Figure 2, with the influence of starter dropping to zero at 30 lb. P/A broadcast.

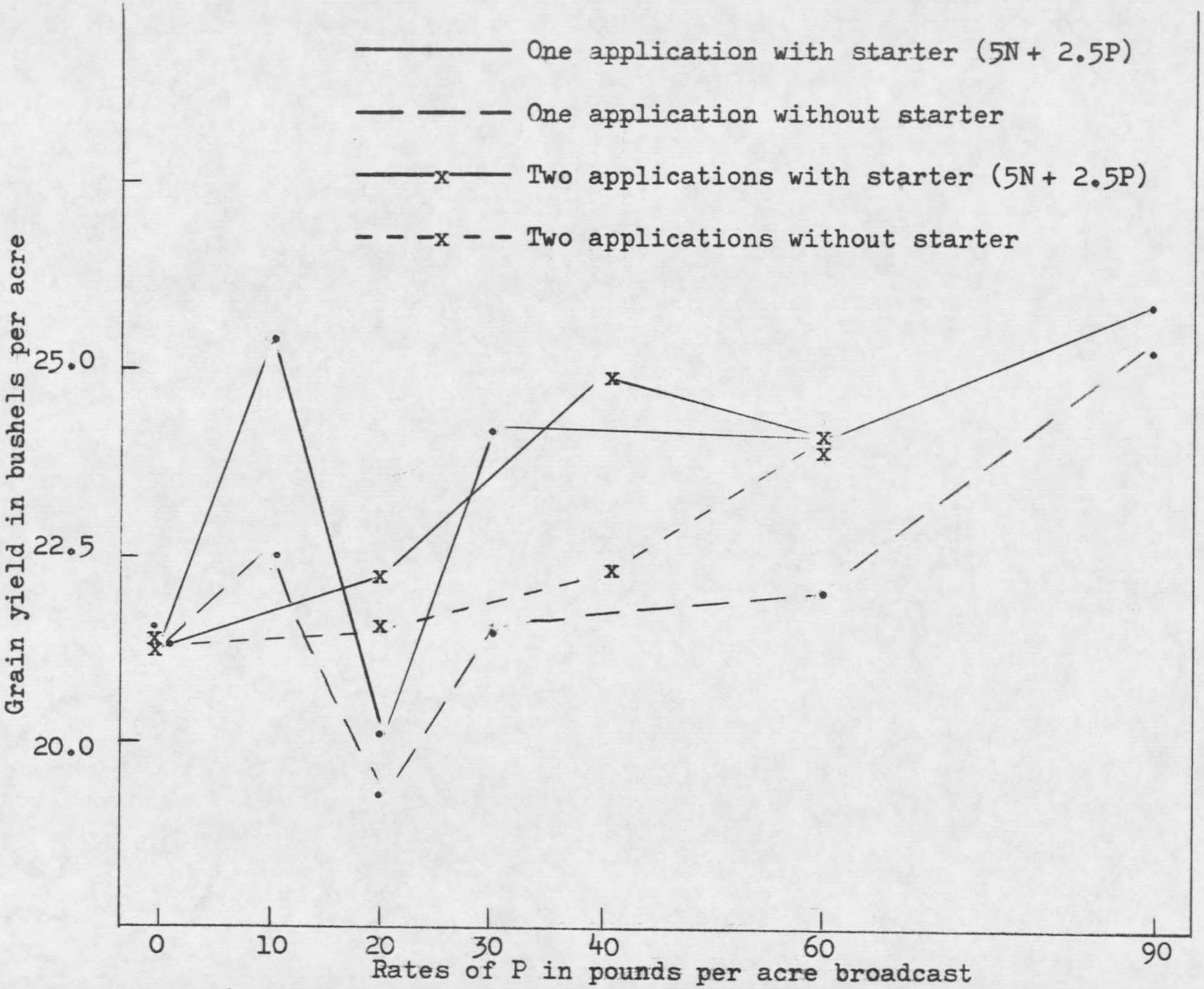


Figure 6. Grain yield comparisons for broadcast P for one application for 1967 and two applications (one for 1967 and one for 1969) with and without starter fertilizer - Froid, 1969; spring wheat (Tr. had 40 lb. N & 25 lb. K).