Baking quality, seedling vigor, and mineral composition of small grains in Montana as affected by fertilizer N source, P placement, K placement, and K rate
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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University

Abstract:
Fertilizer management influences yields of small grains. The relationship between fertilizer management and grain quality is not as clear. Our objective was to investigate and identify relationships between grain quality and fertilizer management. Field fertility trials were performed comparing N forms (anhydrous ammonia vs. ammonium nitrate), P placements (knifed vs. banded), and K rates and placements (surface vs. knifed), at eight sites over two years. Grains studied were spring wheat (four sites), barley (two sites), and winter wheat (two sites). Greenhouse and laboratory determinations of yield, test weight, grain protein, speed of emergence index, dry weight per plant, grain content of P, Ca, Mg, K, Fe, Zn, Cu, and Mn, and for the hard red wheat, flour yield, flour ash, farinograph peak and stability, flour protein, and loaf volume were performed.

Wheat yields were generally higher with ammonium nitrate. Anhydrous ammonia produced generally higher protein contents, and, for the few responses observed, generally better baking quality., Of eight sites, four had higher Ca; three had higher Zn with anhydrous ammonia. Knifed P gave generally higher wheat yields and protein contents. For barley, higher mineral contents were generally associated with knifed P. Knifed K tended to produce higher yield and lower protein in winter wheat. For spring wheat, protein in wheat and flour was generally higher with surface K, bub the differences were small. Test weights were higher with knifed K. Dough strength was improved with knifed K. Flour ash was lower and loaf volumes were higher at higher rates of K. In general, when improved quality was observed with rate of K, it occurred at the lower additions, with quality decreasing at the higher rates, underscoring the importance of fertilizer "balance" when adding K. K rate treatments regularly affected seedling vigor, and to a lesser extent grain mineral content.

Small grain yields in Montana are related to fertilizer management practices (source of N, placement of P and K),. Baking quality is related to source of N and placement and rate of K. Rate of K appears to have a strong relationship to seedling vigor, but more research will be necessary to reveal the nature of the relationship.

BAKING QUALITY, SEEDLING VIGOR, AND MINERAL COMPOSITION OF SMALL GRAINS IN MONTANA AS AFFECTED BY FERTILIZER N SOURCE, P PLACEMENT, K PLACEMENT, AND K RATE

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ABSTRACT

Fertilizer management influences yields of small grains. The relationship between fertilizer management and grain quality is not as clear. Our objective was to investigate and identify relationships between grain quality and fertilizer management. Field fertility trials were performed comparing N forms (anhydrous ammonia vs. ammonium nitrate), P placements (knifed vs. banded), and K rates and placements (surface vs. knifed), at eight sites over two years. Grains studied were spring wheat (four sites), barley (two sites), and winter wheat (two sites). Greenhouse and laboratory determinations of yield, test weight, grain protein, speed of emergence index, dry weight per plant, grain content of P, Ca, Mg, K, Fe, Zn, Cu, and Mn, and for the hard red wheat, flour yield, flour ash, farinograph peak and stability, flour protein, and loaf volume were performed.

Wheat yields were generally higher with ammonium nitrate. Anhydrous ammonia produced generally higher protein contents, and, for the few responses observed, generally better baking quality. Of eight sites, four had higher Ca; three had higher Zn with anhydrous ammonia. Knifed P gave generally higher wheat yields and protein contents. For barley, higher mineral contents were generally associated with knifed P. Knifed K tended to produce higher yield and lower protein in winter wheat. For spring wheat, protein in wheat and flour was generally higher with surface K, but the differences were small. Test weights were higher with knifed K. Dough strength was improved with knifed K. Flour ash was lower and loaf volumes were higher at higher rates of K. In general, when improved quality was observed with rate of K, it occurred at the lower additions, with quality decreasing at the higher rates, underscoring the importance of fertilizer "balance" when adding K. K rate treatments regularly affected seedling vigor, and to a lesser extent grain mineral content.

Small grain yields in Montana are related to fertilizer management practices (source of N, placement of P and K). Baking quality is related to source of N and placement and rate of K. Rate of K appears to have a strong relationship to seedling vigor, but more research will be necessary to reveal the nature of the relationship.

INTRODUCTION

Until recently, grain quality has not received the level of attention given to yield and protein. As production levels have reached a plateau more interest has been focused on "quality." Quality is defined in terms of the end-use of the grain. Quality is measured in terms of milling and bread baking for hard red wheats. High protein content and high glutenin protein fraction are desirable. These have direct effect on loaf and dough characteristics, as measured by loaf volume and farinograph values. Also desirable is good flour yield when wheat is milled. Seed quality is measured in terms of the vigor. Rapid emergence and seedling growth rate are among the indicators of good vigor. Mineral content is a measure of the quality of grain for human and/or animal consumption.

It is generally accepted that grain quality is affected by fertilizer application rates. However, little has been done to determine the relationship between fertilizer management and quality of grain, with the exception of N management on baking quality. This work was initiated as a continuation of a fertilizer management study, in order to investigate "quality" relationships. The research was undertaken to determine if important grain quality aspects can be influenced by various fertilizer management practices.

LITERATURE REVIEW

The work presented in this thesis covers topics that range from those that have been extensively researched to those that have not been considered at all. Therefore, the purpose of this review will only be to discuss literature which applies to fertilizer comparisons specific to this study. Other topics, such as effects of N on yield, will not be covered in depth, except to point out inconsistencies and areas with limited research.

Yield, Test Weight, and Protein

Form of Nitrogen

Most of the research conducted comparing forms of N has been with solution culture rather than in field studies. The researchers who have compared forms of N in field studies often emphasized the placement of N as much as the form when discussing their results.

Just prior to and during the period of World War II, there was considerable interest in the possibility of crop production in solution culture, which led to experimentation with the effects of forms of N in nutrient solution (Arnon, 1939). These early studies reported that growth was poorer with ammonium forms of N, due to ammonium toxicity, and related problems. More recent solution culture experiments have suggested that plants grow faster (Schrader et al., 1972) and produce higher yields (Cox and Reisenauer, 1971) when they are grown on a combination of nitrate and ammonium forms of N. Warncke and Barber (1973) grew corn plants with five differing rates of N and five different NH_4:NO_3 ratios and concluded that the plants seemed to prefer a balance of the two.

Engelstad and Allen (1971), in a greenhouse study, found that total N uptake was greater with ammonium-N than with nitrate-N. Reports from field studies indicated that anhydrous ammonia (with deep placement) produced significantly greater yields and protein (Leikam, 1983; Reinertsen et al., 1984), especially in dry years (Cochran et al., 1978), as compared to forms of N which were surface or shallow applied.

Placement of Phosphorus

Many studies concerning the placement of P fertilizer have been conducted. Theoretically, based on recent reviews (Murphy, 1983), there are at least three main advantages to deep placement of P: (1) knifing (or deep placement) makes the nutrient "positionally available," (2) placement in a concentrated band reduces the risk of fixation, and (3) moisture is available for longer periods in deeper zones; therefore, nutrient uptake occurs for longer periods.

Barber (1958) compared banded application of P with broadcast/incorporation of P. He reported that there was an increase in P uptake from row application at early growth stages. Row applications increased yields most at the lowest soil P level and their effect decreased as soil P level increased. Macleod et al. (1975) and Leikam et al. (1983) have reported that grain yields were higher when P was knifed, or banded below the seed.

Several researchers have suggested that knifing P with anhydrous ammonia was superior due to a synergistic effect between the ammonium form of N and P (Leikam et al., 1978; Leikam et al., 1979; Englestad and Allen, 1971). However, this was not always true (Skogley, unpublished results), and was probably dependent on soil type (Hanson and Westfall, 1985). Engelstad and Allen (1971) concluded that the N effect on P may be a "starter effect" and may not affect yield.

Placement and Rate of Potassium

Effects of K fertilizer management on agronomic responses have been extensively investigated. Many researchers have reported positive yield response to rate of K (Mengel and Kirkby, 1980). Under certain conditions, K fertilizer can improve cereal yields. Koch and Mengel (1977) found K fertilization increased every major yield component of wheat. Barber (1959) investigated placements of K and concluded that row applied K was as effective as incorporated K treatments in supplying K to plants.

In general, only a small fraction of K in the soil is available to plants, which take up K from the soil solution. Transport of K to plant roots in and through the soil solution is achieved mainly by mass flow and diffusion, with diffusion accounting for most (88-96%) of the transport (Tisdale et al., 1985). Diffusion of nutrients through the soil solution is affected by a number of factors, including temperature and moisture. Skogley and Haby (1981) reported that climatic conditions had profound influence on K fertilizer response in Montana and that soil K tests do not accurately predict K fertilizer response in Montana. Mengel and Kirkby (1980) point out that it is not possible to provide general K fertilizer recommendations that are applicable to different soils, climates, and crops. Similarly, after studying effects of rates of K on malting barley, Zubriski et al. (1970) concluded that soil test K was a poor indicator of response to K.

Grain Quality

Form of Nitrogen

Much has been done to determine the effects of N fertilization on grain quality. However, little has been done concerning the effects of the form of N. Most of this work has centered on how N affects protein in the grain, since percentage protein is the best indicator of baking quality (Phillips and Niernberger, 1976; Pomeranz et al., 1976). Hylnka (1964) stated that wheat must have at least 12% protein in order to make good yeast leavened bread. Positive correlation between grain protein and loaf volume has been established (Mangels and Sanderson, 1925). More recently, it was shown that 90% of the variation in loaf volume was due to percentage protein (Pomeranz et al., 1976). Nitrogen fertilization continued to increase percentage protein after it ceased to increase yields (McGuire et al., 1979). Cochran et al. (1978) found that although protein quantity and loaf volume were increased by the deep N treatment, quality was not improved.

Placement of Phosphorus

No literature was located which described effects of P fertilizer placement on wheat baking quality, or on protein fractions. However, Pittman and Tipples (1978) determined the quality variables of grain grown under two rates of P, and reported that protein and quality were unaffected by P.

Placement and Rate of Potassium

Potassium is necessary to protein synthesis, as well as amino acid synthesis, and is beneficial to translocation of photosynthates (Mengel and Kirkby, 1980). Potassium fertilization is often associated with improved baking quality. According to Chevalier (1976), K often produced higher quality grain even though percentage protein may not have been affected. Increases in the glutelin protein fraction in response to K fertilizer have been frequent (Kolbe and Muller, 1983; Chevalier, 1976; Koch and Mengel, 1977). However, K did not always affect quality (Legros, 1973).

Seed and Seedling Vigor

Generally, vigor is defined in terms of good germination and rapid growth and establishment, or in terms of susceptibility to adverse conditions (Delouche and Caldwell, 1960). It is widely assumed that seedling vigor plays an important role in crop establishment and yield (Evans and Bhatt, 1977). Differences in vigor are most obvious under adverse conditions. Seed vigor and seed deterioration are reciprocal, dimensioned "properties" (Association of Official Seed Analysts [AOSA], 1983).

Unfortunately, it is difficult to identify the cause and effect of a specific deteriorative response which could be used as a quantitative parameter for vigor testing (AOSA, 1983). Moore (1968) concluded that each test in use is capable of revealing some aspects of seed weakness while concealing others, and that therefore testing programs must be tailored to the problem and the crop. Similarly, Burris et al. (1969) concluded that one rapid, simple chemical test for vigor may never be developed, since the assay of any one particular enzyme, etc., will not give overall information.

Form of Nitrogen

Much work has been done to determine the relationship between seedling vigor and protein content of the seed (Lowe et al., 1972; Schweizer and Ries, 1969; Torres and Paulsen, 1982; Ries et al., 1970; Ching and Rynd, 1978; Ayres et al., 1976; Lopez and Grabe, 1973; Bullisani and Warner, 1980). In general, seeds that contain more protein develop into larger, more vigorous seedlings (Schweizer and Ries, 1969; Ayres et al., 1976). High protein seed is also reported to improve stand establishment (Torres and Paulsen, 1982). However, it appears that differences in vigor due to seed protein were eliminated if enough N fertilizer was added (Bullisani and Warner, 1980; Ries et al., 1970). Literature specific to the effect of N source on subsequent seedling vigor was not found.

Placement of Phosphorus

Literature was not found concerning the vigor of seeds from plants grown under differing P fertilizer management. There are reports of immediate effects of placement of P on seedling dry weight (Bullen et al., 1983; Strong and Soper, 1974), but not on vigor of subsequent grain.

Placement and Rate of Potassium

Ison (1980) found in initial investigation that seed K content was positively correlated with seedling vigor of french beans. Further study revealed that increased rates of K improved the vigor of harvested seed. No literature was found concerning effects of K placement on seed and/or seedling vigor.

Mineral Composition

Several factors appear to influence mineral composition of grains. These include location (Schrenk and King, 1948; Erdman and Moul, 1982; El Gindy et al., 1957; Schrenk, 1955; Peterson et al., 1983; Dikeman et al., 1982; Davis et al., 1984), rainfall (El Gindy et al., 1957; Dikeman et al., 1982), grain type (Erdman and Moul, 1982; Lorenz and Loewe, 1977; Peterson et al., 1983; Davis et al., 1984), cultivar (Peterson et al., 1983; El Gindy et al., 1957; Dikeman et al., 1982; Davis et al., 1984), and fertilizer application (Schrenk, 1955; El Gindy et al., 1957). However, there are also reports that rainfall (Schrenk and King, 1948) and cultivar (Schrenk and King, 1948; Erdman and Moul, 1982) do not affect mineral composition. It appears that grain types differ in mineral content, and that cultivars within grain types vary in mineral content but to a lesser extent. Location and fertilizer application have generally influenced composition of grain. Researchers disagree as to which of these factors (cultivar, location, fertilizer, etc.) exert the strongest influence.

Form of Nitrogen

A few authors have reported correlation between content of various minerals and percentage protein in the grain, or flour (Peterson et al., 1983; Dikeman et al., 1982; Pomeranz and Dikeman, 1983; Lorenz and Loewe, 1977). Logically, form of N may be expected to affect content of some minerals since it affects uptake of N (Engelstad and Allen, 1971; Leikam, 1983; Reinertsen et al., 1984; Cochran et al., 1978) and the protein content varies with N uptake, and content of some minerals can be correlated to percentage protein. While some information specific to effects of form of N on mineral content is available, results were not consistent. Blair et al. (1970) found that NH_4 as the source of N produced greater uptake in corn of Mg, P, and S. Uptake of K was not affected by form of N. Narada et al. (1968) found that NO_3 produced higher K, Ca, and Mg content and lower P content than NH_4.

Placement of Phosphorus

Cox and Reisenauer (1971) reported that P decreased uptake of Ca and Mg. Lamond and Moyer (1983) found that P and K uptake were increased in wheat with knifed application of fertilizer (N and P). No literature was located which discussed effects of P fertilizer placement on micronutrient composition.

Placement and Rate of Potassium

The effects of K fertilizer management on nutrient content have been investigated for a few nutrients. It is widely reported that K decreases uptake of Mg (McLean and Carbonell, 1972; Adams and Henderson, 1962; York et al., 1954). Potassium also appears to depress uptake of Ca (York et al., 1953) and increase Mn content (York et al., 1954).

MATERIALS AND METHODS

Fertility Trials

The grain used in this work was produced in a series of field experiments over two years at eight sites. A list of sites for 1982 and 1983 is found in Table 1, along with the crops grown and soils information. The cooperators were the same for both years for the spring wheat experiments; however, the experiments were planted into different fields in 1982 and 1983. Therefore, they are referred to as separate sites. Soil samples were taken at each site prior to planting. Standard soil test analysis was conducted on 0-15 cm depth samples, and nitrate-N analysis on samples taken to 120 cm depth. Rates of applied N and P fertilizers were determined from these soil test results and expected moisture and yield goals. Four rates of K fertilizer were used, ranging from 0 to 100 kg/ha, at all sites except R082 (spring wheat site, Teton County, 1982), where K rates were increased to range between 0 and 150 kg/ha because the site was irrigated.

The field experiments were conducted using a specially designed and constructed small plot seed/fertilizer drill that accurately applies selected rates of liquid fertilizers and/or anhydrous ammonia. Liquid fertilizers can be applied through the anhydrous shanks, with the seed, or on the soil surface.

These fertility trials were designed to compare rate and placement of K, source of N, and placement of P, using a total of 40 fertilizer

Table 1. Experimental cooperators, and crops and soils information for the field sites.

ACRONYM	COOPERATOR	YEAR	COUNTY	CROP#	VARIETY	LEGAL DESCRIPTION	SOIL SERIES*	SOIL CLASSIFICATION
R082	R. Ostberg	1982	Teton	HRS Wheat	Wampum	NW¼, SE¼, S.26, T22N, R2W	Rothiemay clay loam	Rothiemay: fine-loamy, mixed. Aridic Calciboroll.
R083	R. Ostberg	1983	Teton	HRS Wheat	Wampum	NW¼, SE¼, S.26, T22N, R2W	same as above	same as above
J082	J. Olsen	1982	Chouteau	HRS Wheat	Marberg	SW¼, SE¼, S.31, T24N, R7E	Evanston loam	Fine-loamy, mixed. Aridic Argiboroll.
J083	J. Olsen	1983	Chouteau	HRS Wheat	Pondera	SE¼, NE¼, S.30, T24N, R7E	Ethridge silty clay loam	Fine, montmorillonitic. Aridic Argiboroll.
PN82	D. Roehm	1982	Cascade	Barley	Hector	SE¼, NE¼, S.11, T20N, R5E	Gerber silty clay loam	Fine-montmorillonitic. Vertic Argiboroll.
PN83	D. Roehm	1983	Cascade	Barley	Morex	SE¼, NE¼, S.10, T20N, R5E	Gerber silty clay loam	same as above
VV83	C. VanVost	1983	Lake	SWW Wheat	Nugaines	NW¼, NW¼, S.7, T22N, R20W	Truscreek-Polson complex; silt loam	Truscreek: fine-silty, mixed, frigid. Calcic Haploxeroll. Polson: fine-silty, mixed, frigid. Typic Natrixeroll.
WG83	W. Gorton	1983	Flathead	SWW Wheat	Luke	SW¼, SW¼, S.33, T29N, R20W	Creston silt loam**	Coarse-silty, mixed. Udic Haploboroll.

#HRS = Hard Red Spring; SWW = Soft White Winter.
*The soils information has not been verified in the field; it was collected from Soil Survey Reports.
**Creston silt loam is an inactive soil series name. The name has probably been changed to reflect reclassification as a Haploxeroll.

combinations. The treatments which involved deep placement with the anhydrous ammonia were applied first and then at a later time the plots were seeded and the remaining fertilizer treatments applied simultaneously. Potassium was applied as a KCl liquid suspension, N as either an ammonium nitrate solution (banded with the seed or on the surface) or anhydrous ammonia, and P was supplied by commercial grade phosphoric acid. The fertilizer combinations were replicated four times at each site. The grain was harvested using a small plot combine, and collected keeping the replications separate. These grain samples were subjected to the various quality measurements.

Yield, Test Weight and Protein

Grain samples were cleaned, weighed, and yields were determined. Test weights were determined using a torsion balance. Protein analyses were performed using Near Infrared Spectroscopy. The results from these analyses are reported in an appropriate section for both barley and winter wheat. Since test weight and protein analyses are routine in baking quality determinations, yield for spring wheat is reported and discussed in the baking quality section.

Greenhouse Seedling Vigor Experiments

Speed of emergence was determined in greenhouse experiments for the grain from each of the sites identified in Table 1. Fifty seeds from each treatment were planted in flats and the number of seedlings that emerged each day was counted until emergence was complete, or for six days. The speed of emergence index was calculated as according to

Carleton et al. (1968), as follows:

$$SEI = \frac{\#\ \text{normal seedlings day 1}}{1} + \ldots + \frac{\#\ \text{seedlings nth day}}{n} .$$

When determined in this way, a value of 50 would represent 100 percent emergence on the first day, and a value of zero would represent no emergence. After six weeks growth, the plants were counted, harvested, oven dried and weighed, and dry weight per plant was calculated.

Grain Quality Analysis

Grain from only the locations in Teton and Chouteau Counties, where spring wheat was raised, was analyzed for baking and milling quality. Grain from the other locations was inappropriate for this type of analysis. Eight variables were analyzed (test weight, flour yield, flour ash, farinograph peak, farinograph stability, wheat protein, flour protein, and loaf volume) that relate to milling and/or baking quality.

Test weight was determined using a torsion balance on a dockage-free sample. All the samples were cleaned with a Carter Dockage Tester. The original moisture content of the wheat was determined using a Steinlite Moisture Meter.

The flour was produced using a pneumatic Buhler Mill, AACC Method 26-20 (American Association of Cereal Chemists, 1983). The samples were tempered to 16% moisture for spring wheat and 15% moisture for winter wheat approximately 18-20 hours before milling. Thirty minutes before milling, 0.5% more water was added. The flour was collected and weighed, as were the bran and "shorts"; percentages were then calculated.

The protein analyses were performed on a Near Infrared Spectrometer on the flour sample produced in the milling process and on the ground wheat sample, AACC method 39-10.

The dough properties were tested by using a Brabender farinograph, AACC method 54-21. Farinograph peak time and stability time were recorded as measures of dough strength. Percentage ash in the flour was determined by incinerating an accurately weighed flour sample at 575°C for 18 hours until a light gray ash was obtained. The ash was weighed after it had cooled to room temperature.

The experimental baking test used was modified from McNeal et al. (1971): 0.10% malted barley flour was used in place of 0.25% diamalt in the McNeal procedure. Loaf volume was determined using the rape seed displacement apparatus, as described in McNeal et al. (1971).

Mineral Analysis

Levels of P, Ca, Mg, K, Fe, Zn, Cu, and Mn were determined. The ground grain was dry ashed and the ash digested with hydrochloric acid. The P determination was made colorimetrically using a phosphovanadomolybdic complex (Jackson, 1958). The grain ash/HCl solution was diluted and reacted with a known volume of vanadamolybdic acid. This solution was analyzed on a colorimeter at 440 nm. A standard curve was used to determine the P concentration. A known amount of a 1% solution of SrCl was added to the ash solution that was analyzed for P, which was then analyzed by atomic absorption spectroscopy for the other elements.

Statistical Analysis

Grain from 16 of the original 40 treatments used in the fertilizer trials was used as the experimental material in the current work (Table 2). The number of treatments studied was reduced in this way to provide for manageable sample handling, and for simplified statistical analysis. For a complete listing of the fertilizer treatments in the original field experiments, refer to Appendix A.

Table 2. Selected fertilizer treatment combinations.

	R083 and J083				All Other Locations			
Treatment No.	Rate[a] K	Form[b] N	Placement[c] P	Placement[c] K	Rate[d] K	Form N	Placement P	Placement K
13	0	AN	Band	Knif	0	AN	Band	Surf
14	25	↓	↓	↓	25	↓	↓	↓
15	50	↓	↓	↓	50	↓	↓	↓
16	100	↓	↓	↓	100	↓	↓	↓
21	0	NH_3	Band	Knif	0	NH_3	Band	Surf
22	25	↓	↓	↓	25	↓	↓	↓
23	50	↓	↓	↓	50	↓	↓	↓
24	100	↓	↓	↓	100	↓	↓	↓
33	0	NH_3	Knif	Surf	0	NH_3	Knif	Surf
34	25	↓	↓	↓	25	↓	↓	↓
35	50	↓	↓	↓	50	↓	↓	↓
36	100	↓	↓	↓	100	↓	↓	↓
37	0	NH_3	Knif	Knif	0	NH_3	Knif	Knif
38	25	↓	↓	↓	25	↓	↓	↓
39	50	↓	↓	↓	50	↓	↓	↓
40	100	↓	↓	↓	100	↓	↓	↓

[a]Rates of K are in kg/ha.

[b]AN = ammonium nitrate; NH_3 = anhydrous ammonia.

[c]Band = banded with the seed; knif = knifed at 15cm depth; surf = applied in a band on the surface.

[d]Rates of K for R082 were 0, 50, 100, and 150.

Statistical analyses were performed using predominantly the analysis of variance (ANOV). All of the analyses were done using the MSUSTAT statistical package (Lund, 1978). The treatment comparisons analyzed are listed in Table 3. The comparison between rates of K was analyzed as a second factor in each of the comparisons listed in this table. The basic forms of the ANOV for these comparisons are presented in Table 4 for individual locations and in Table 5 for analysis over all locations. Although the basic form of the analysis of variance is the same for these comparisons, the number of degrees of freedom is reduced in the analysis of the baking data, as seen in Tables 4 and 5, due to two factors: (1) all of the locations were not included in the determination of milling and baking quality, and (2) the replications had to be combined in order to have large enough samples from all of the treatments for the milling process, thus reducing the number of replications in the milling/baking quality tests to two.

Table 3. Main treatment comparisons.

Desired Comparison	Treatment Numbers Used: R083 and J083	Treatment Numbers Used: All Other Locations
AN	13 - 16	13 - 16
vs.		
NH_3	21 - 24	21 - 24
P Banded	21 - 24	21 - 24
vs.		
P Knifed	37 - 40	33 - 36
K Surface	33 - 36	33 - 36
vs.		
K Knifed	37 - 40	37 - 40

Table 4. Basic form of the analysis of variance and degrees of freedom, for analysis of data averaged over replications, using locations as blocks.

	Degrees of Freedom	
	Milling and Baking Quality	Vigor and Mineral Analysis
Blocks	3	7
Main Comparison	1	1
Rate of K	3	3
Interaction	3	3
Residual	21	49

Table 5. Basic form of the analysis of variance and degrees of freedom, for analysis on a single location, using replications as blocks.

	Degrees of Freedom	
	Milling and Baking Quality	Vigor and Mineral Analysis
Blocks	1	3
Main Comparison	1	1
Rate of K	3	3
Interaction	3	3
Residual	7	21

RESULTS AND DISCUSSION

Introduction

The results from the field experiments and laboratory determinations are divided into sections according to the type of grain. Within these sections the soil and climatic data are presented, followed by the results of the various analyses. These results vary considerably in many cases between the two years, even where the locations were essentially the same. The climatic conditions were considerably different between these two seasons, a factor that could conceivably account for much of the observed differences in the results from year-to-year.

In spite of the variability between locations and years, a few response variables did express significant differences when analyzed over all sites, as was outlined in Table 4. These variables are given in Table 6. As might have been expected, the majority of them are grain quality variables, since only the four spring wheat locations were involved in those analyses.

The majority of the grain quality variables in Table 6 showed significant differences for only the form of N comparison: test weight, grain protein, flour protein, farinograph peak, and stability. Ammonium nitrate gave a higher test weight, while anhydrous ammonia produced higher proteins and longer farinograph times. Knifing (or deep banding below the seed) of P produced a higher test weight in spring wheat, as compared to banding with the seed. Knifing of K gave a higher test

Table 6. Variables showing significant differences due to treatment comparisons when analyzed over locations.

Response Variables	Treatment Comparisons		
(a) Grain Quality*	AN	NH_3	LSD .05
Test weight (lb/bu)	61.09	60.29	0.28
Grain protein (%)	12.94	14.16	0.37
Flour protein (%)	11.07	12.57	0.53
Farinograph peak (min)	6.40	8.20	1.20
Farinograph stability (min)	12.30	14.60	2.20
	P band	P knif	LSD .05
Test weight (lb/bu)	60.29	60.88	0.32
	K surf	K knif	LSD .05
Test weight (lb/bu)	60.57	61.05	0.28
Flour ash (%)	0.467	0.448	0.016
Farinograph stability (min)	12.50	13.90	1.30
(b) Seed/Seedling Vigor	K surf	K knif	LSD .05
Dry weight/plant (mg)	0.51	0.54	0.02
(c) Mineral Composition	AN	NH_3	LSD .05
Percent calcium	0.019	0.020	0.0007
ppm manganese	29.70	31.60	0.70
	P band	P knif	LSD .05
Percent magnesium	0.068	0.070	0.0019
Percent phosphorus	0.371	0.382	0.010
	K surf	K knif	LSD .05
ppm manganese	32.70	31.90	0.60

*Analyses from spring wheat locations only.

weight, a lower percentage of ash in the flour, and a higher farinograph stability time as compared to surface application. The only grain quality response variable which showed a difference for all three main comparisons was test weight, and the differences were small.

Of the two variables used to determine seed/seedling vigor, dry weight per plant was significantly greater when K was knifed (deep banded below the seed) as compared to surface application.

Concentration of both Ca and Mn in the grain was higher when the form of N was anhydrous ammonia as compared with ammonium nitrate. Magnesium and P levels in the grain were both greater when P was knifed as compared to banded. Finally, the concentration of Mn in the grain was greater when K was surface applied as compared to knifing.

Hard Red Spring Wheat

Soil Test Results and Climatic Data

Soil test results and climatic data for the four spring wheat sites are provided in Table 7. As stated previously, the results of the soil tests, along with yield goals based in part on moisture, were used to determine appropriate rates of the N and P fertilizers. At the 1982 Teton County site, R082, 80 kg N/ha (both forms) and 20 kg P/ha (either application) were applied. At the 1983 Teton County site, R083, 120 kg N/ha and 20 kg P/ha were applied. At the 1982 Chouteau County site, J082, 120 kg N/ha and 20 kg P/ha were applied, while at the 1983 Chouteau County site, J083, 100 kg N/ha and 20 kg P/ha were applied. At the 1982 sites, the liquid N solution was banded with the seed, while at the 1983 sites it was banded on the surface.

Table 7. Soil test results and climatic data for spring wheat sites.

		Location			
		R082	R083	J082	J083
(a) Soil Test Results					
NO3-N = 0-15cm		6	6	--	3
ppm = 15-30		7	7	--	4
P = 0-15cm		20	20	14	12
ppm = 15-30		2	2	3	3
K = 0-15cm		360	360	524	520
ppm = 15-30		191	191	293	285
pH = 0-15cm		7.9	7.9	7.3	7.2
15-30		8.3	8.3	8.1	8.0
EC = 0-15cm		0.9	0.9	0.9	0.9
mmhos = 15-30		1.1	1.1	0.8	0.7
OM = 0-15cm		3.6	3.6	2.4	2.5
% = 15-30		2.2	2.2	1.8	1.9
(b) Growing Season Precipitation (cm)					
April		--	0.64	--	0.25
May		6.15	3.20	15.16	4.29
June		8.33	4.93	5.84	8.48
July		2.39	7.14	1.55	9.19
Total		16.87	15.91	22.55	22.21
(c) Monthly Average Temperature (F)					
April	(max)	--	56.0	--	60.7
	(min)	--	28.4	--	27.0
May	(max)	63.9	64.8	66.2	70.0
	(min)	36.1	38.0	38.3	39.0
June	(max)	72.4	72.0	78.2	77.7
	(min)	47.2	46.4	48.5	47.8
July	(max)	79.1	78.5	83.6	83.1
	(min)	50.3	49.6	50.9	51.0

The 1982 Teton County site, R082, was irrigated, and the field was infected with Take-All (*Gaeumannomyces graminis*) root rot. This disease is characteristically "patchy" in the field, giving rise to considerable non-uniformity, explaining at least in part the high variability at this site. However, disease ratings were determined at harvest and were found to be uninfluenced by fertilizer and unrelated to yield. At the 1983 Teton County site, R083, no irrigation water was applied. Take-All was still present and the disease ratings showed some significant differences when analyzed with fertilizer treatment (see Appendix B).

At both the 1983 Teton and 1983 Chouteau County sites, R083 and J083, respectively, the early part of the season experienced drought-like conditions, with heavier-than-normal rains coming later. This abnormal rainfall distribution had the greatest impact on J083, since at R083 the soil moisture was limited at seeding. At the 1982 Chouteau County site, J082, a large storm in late May dropped in excess of 10 cm of precipitation.

Yield and Grain Quality

Form of nitrogen.

(1) R082 site: Form of N had a significant effect on five of nine response variables in spite of the large variability at this site (Table 8). Grain yield with ammonium nitrate was significantly higher than with anhydrous ammonia. Farinograph peak was improved with the anhydrous ammonia form of N as were both wheat and flour percentage protein. Test weight was significantly lower with the anhydrous ammonia. Flour percentage ash and farinograph stability time showed significant differences

Table 8. Yield and grain quality variables for 1982 and 1983 Teton County sites as affected by form of N and rate of K.

	R082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
AN(#)	3614	68.9	0.463	5.0	8.9	61.31	10.89	9.887	786.
NH_3(+)	3174	67.0	0.476	6.1	10.4	60.56	11.73	10.61	774.
LSD	395*	ns	ns	0.903*	ns	0.74*	0.48**	0.62**	ns
0 kg	3266	68.3	0.488 bc	5.2	8.6a	60.62	11.25	10.05	774.
50	3524	69.5	0.500 c	5.6	8.9ab	61.03	11.20	10.15	787.
100	3268	67.0	0.465 b	6.0	12.3 b	60.85	11.45	10.45	787.
150	3517	67.1	0.425a	5.5	8.8ab	61.25	11.32	10.35	772.
LSD	ns	ns	0.0260**	ns	3.66**	ns	ns	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

= ammonium nitrate (AN)

\+ = anhydrous ammonia (NH_3)

Table 8--Continued

	R083								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
AN(#)	2896	67.5	0.476	8.2	14.6	60.29	13.94	11.65	807.
NH_3(+)	2881	67.9	0.435	7.5	12.3	60.06	14.41	12.25	795.
LSD	ns	ns	0.0407**	ns	ns	ns	0.26**	ns	ns
0 kg	2598	67.4	0.453	7.7	15.6	60.17	14.13	12.10	832. b
25	3110	68.1	0.467	7.3	12.0	60.27	14.22	11.38	771.a
50	2876	67.9	0.467	8.1	13.5	60.18	14.13	12.12	787.ab
100	2970	67.4	0.435	8.1	12.5	60.08	14.23	12.20	816.ab
LSD	ns	ns	ns	ns	ns	ns	ns	ns	54.0*

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\# = ammonium nitrate (AN)

\+ = anhydrous ammonia (NH_3)

due to form of N was not significant, an interaction occurred between form of N and rate of K for this variable (Figure 1).

(2) R083 site: Grain yield followed the trend set in 1982 (R082 above); however, the difference was not significant. This is probably due at least in part to the fact that responses to fertilization overall were not as dramatic in 1983 as a result of the abnormal rainfall distribution discussed earlier. Wheat percentage protein was significantly higher when anhydrous ammonia was the form of N, and flour percentage ash was lower. Loaf volume was significantly affected by rate of K. A significant interaction was found for wheat protein between form of N and rate of K (Figure 2). The ammonium nitrate treatment produced a lower percentage protein, which then increased with added K. This interaction is consistent with the finding of Rufty (1982), that NH_4 inhibits uptake of NO_3, and that K reduced the inhibition.

(3) J082 site: Grain yields at this site were dramatically increased through the use of fertilizer. However, there was no significant yield difference due to form of N applied (Table 9), although results do follow the trend of higher yield with ammonium nitrate as compared to anhydrous. Seven of eight of the quality response variables were affected by form of N. Anhydrous ammonia produced significantly higher levels of wheat and flour protein. Accordingly, the farinograph peak and stability times and loaf volume were also improved when anhydrous ammonia was the form of N. In contrast to the result at R083, percentage ash was higher when anhydrous ammonia was the form of N. Test weight was significantly lower with anhydrous ammonia, as opposed to ammonium nitrate, in agreement with the result from R082. Grain yield

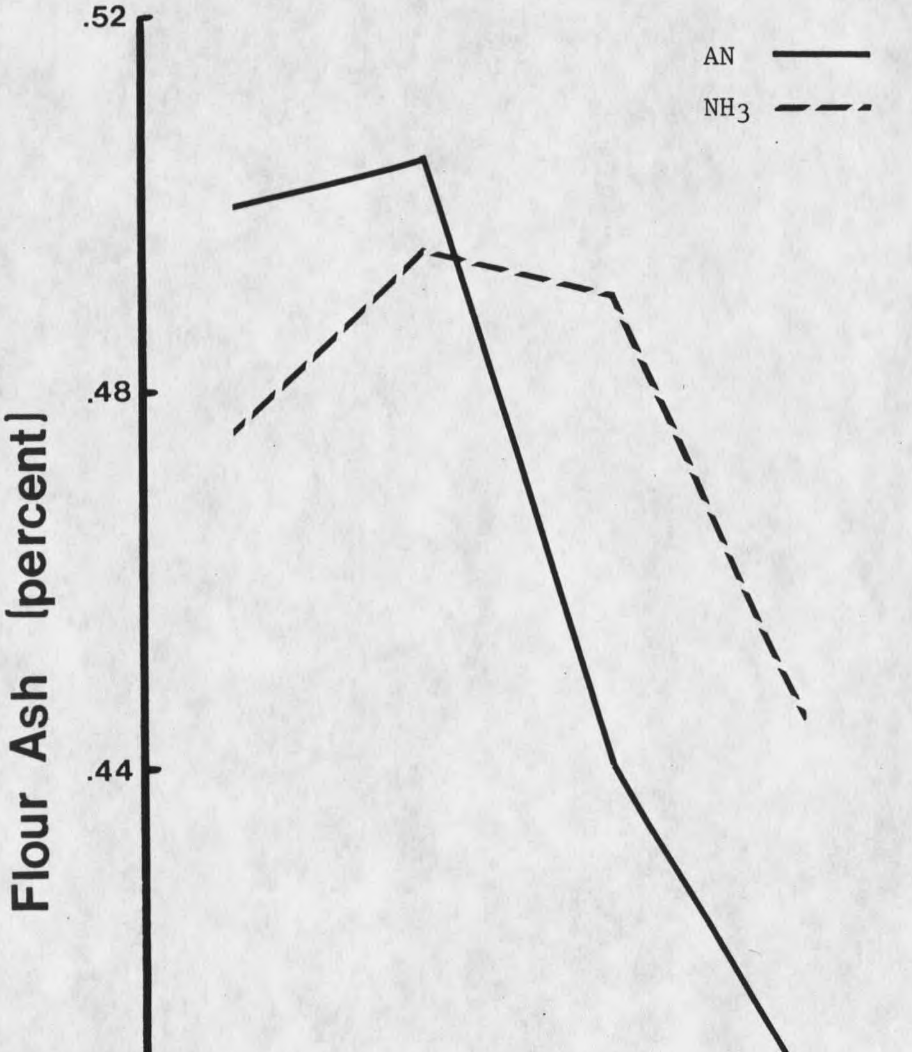

Figure 1. Interaction on percent ash in flour at R082 between form of N and rate of K treatments.

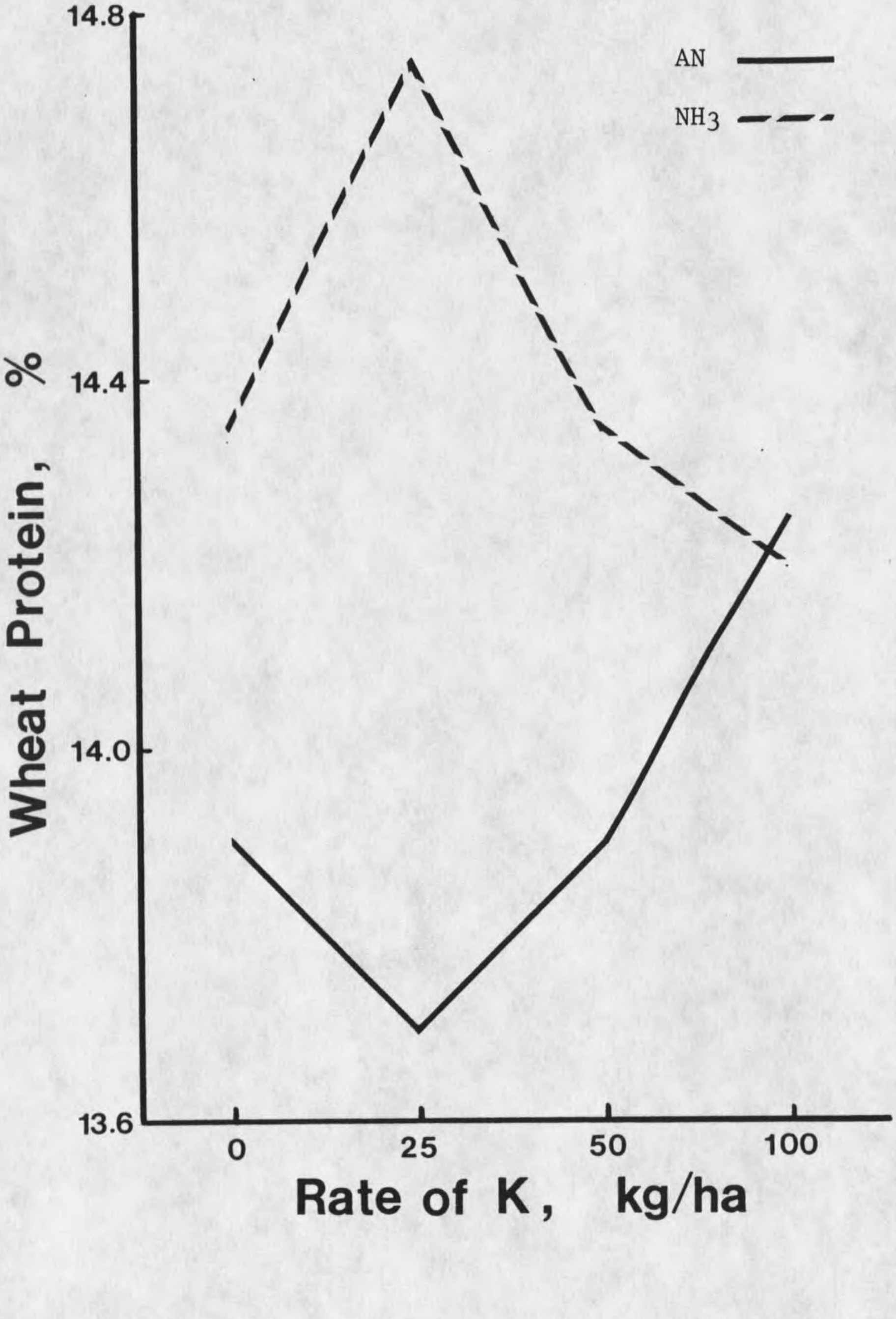

Figure 2. Interaction on wheat percent protein at R083 between form of N and rate of K treatments.

Table 9. Yield and grain quality variables for 1982 and 1983 Chouteau County sites as affected by form of N and rate of K.

	J082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
AN(#)	1976	69.4	0.429	2.5	8.2	11.50	61.33	8.562	700.
NH_3(+)	1909	69.5	0.455	8.3	16.0	13.61	60.52	11.76	846.
LSD	ns	ns	0.0113**	1.021**	4.247**	0.93**	0.34**	0.596**	41.1**
0 kg	1898a	69.8	0.448ab	5.7	13.6	12.55	60.62a	10.55 b	813. b
25	2031 b	69.5	0.450 b	5.6	11.1	12.65	61.00 b	10.25 ab	768.ab
50	1921ab	69.1	0.435a	5.2	12.4	12.35	61.00 b	9.825a	756.ab
100	1919a	69.4	0.435a	5.0	11.3	12.67	61.08 b	10.02 ab	755.a
LSD	110*	ns	0.0128*	ns	ns	ns	0.38*	0.675*	58.2**

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\# = ammonium nitrate (AN)

\+ = anhydrous ammonia (NH_3)

Table 9--Continued

	J082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
AN(#)	1299	62.1	0.534	9.8	17.3	15.45	61.44	14.20	954.
NH_3(+)	1134	63.5	0.549	10.9	19.7	16.87	60.01	15.66	967.
LSD	140**	ns	ns	ns	ns	0.85**	0.52**	1.14**	ns
0 kg	1171	63.2	0.613 b	9.3	18.9	16.40	60.42	14.85	952.
25	1298	63.6	0.560ab	10.7	18.1	16.05	60.58	15.35	948.
50	1201	62.5	0.502a	10.9	18.5	16.20	60.93	14.67	954.
100	1195	61.7	0.490a	10.4	18.4	16.00	60.97	14.85	988.
LSD	ns	ns	0.1074*	ns	ns	ns	ns	ns	ns

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\# = ammonium nitrate (AN)

\+ = anhydrous ammonia (NH_3)

at this site showed significant differences due to the rate of K. The yield was highest with the first increment of added K, a trend which also applied at the other spring wheat sites when yield as affected by rate of K is analyzed as the second factor with form of N, although the differences were not significant. Four of the quality response variables were affected by rate of K, flour ash had the greatest response with the 25 kg/ha addition, both flour protein and loaf volume were greatest with no added K, while test weight was lowest. Another significant interaction occurred between form of N and rate of K for flour percentage ash (Figure 3), although the nature of the interactions seems to be different (Figures 1 and 3).

(4) J083 site: Grain yields were quite low at this site, due in part to low rainfall amount and poor distribution, and limited stored moisture at seeding. However, yield was again greater with the ammonium nitrate form of N. Wheat and flour protein, and test weight were the only quality response variables to show significant differences due to form of N. The protein levels were higher, while test weight was lower when the form of N was anhydrous ammonia, in agreement with results from other sites. The only variable which showed significant differences due to rate of K was flour percentage ash. A significant interaction was found for test weight between form of N and rate of K (Figure 4).

The apparent superiority for yield of ammonium nitrate as a source of N is difficult to explain. Several authors (Leikam et al., 1983; Cochran et al., 1978; Reinertsen et al., 1984) have reported that knifing anhydrous ammonia was superior to other forms of N. However, Warncke and Barber (1973) reported that corn seedlings appeared to

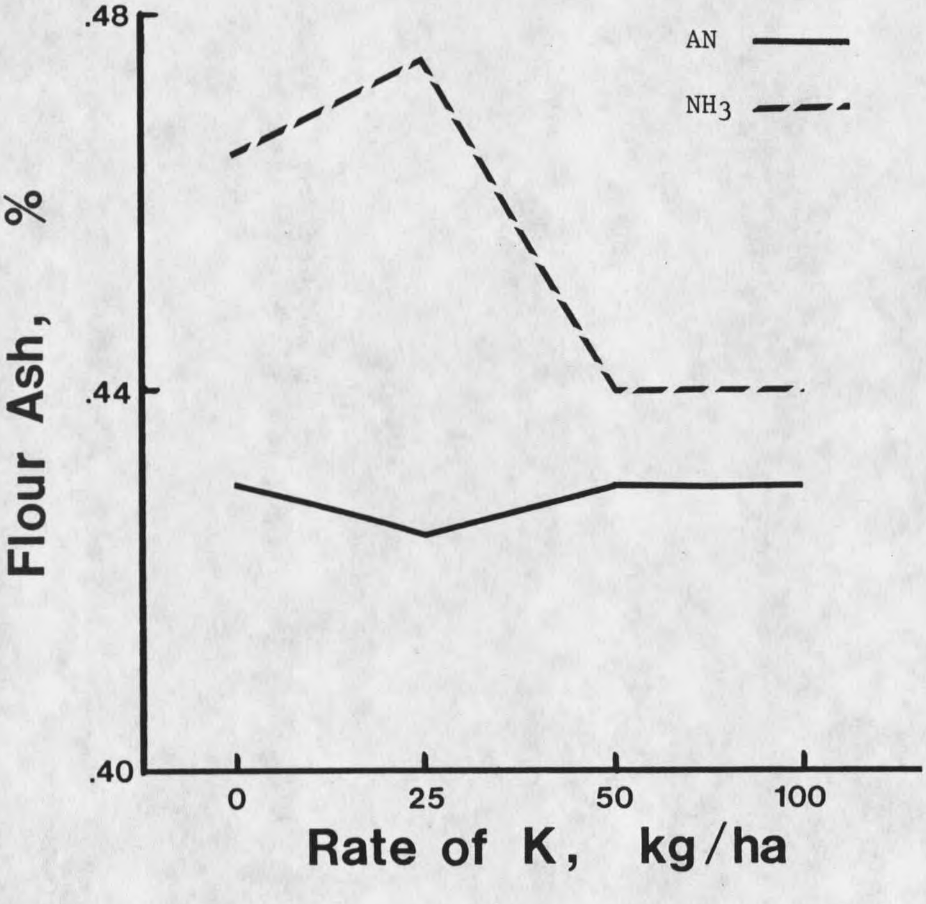

Figure 3. Interaction on percent ash in flour at J082 between form of N and rate of K treatments.

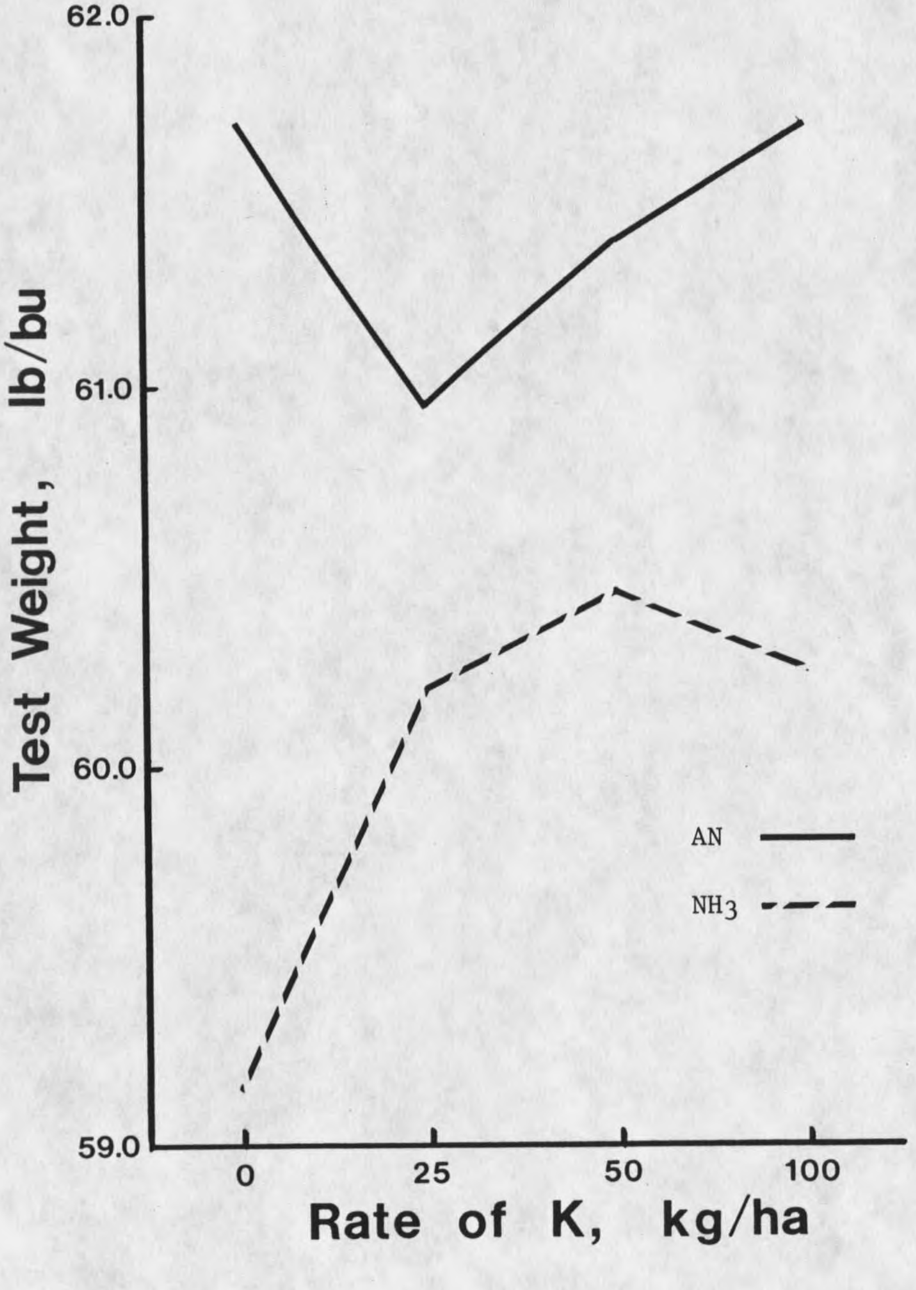

Figure 4. Interaction on test weight at J083 between form of N and rate of K treatments.

prefer a balance of ammonium and nitrate ions, when available. Therefore, the apparent superiority of ammonium nitrate may be a result of the presence of both forms of N, as compared to only ammonium, at least during the early part of the growing season.

Overall, protein in the flour and wheat was consistently greater with the anhydrous ammonia, while test weight was lower. In general, farinograph times are longer for flour milled from the wheat produced on the anhydrous. When rate of K is the second factor in the form of N comparison, flour percentage ash is consistently lower with the larger rates of K application.

Placement of phosphorus.

(1) R082 site: Grain yield was increased significantly when P was knifed (Table 10). Flour protein and farinograph stability time were significantly greater when P was banded with the seed, as compared to knifing. In contrast, loaf volume was improved when P was knifed. Flour yield and test weight were both significantly greater when P was knifed. Flour yield, farinograph stability and flour protein showed significant differences due to rate of K analyzed as the second factor. However, the increases and/or decreases of a variable(s) did not occur consistently for the same rate(s) of K. Significant interaction was observed for flour yield between placement of P and rate of K (Figure 5).

(2) R083 site: Although grain yield response to fertilizer was limited at this site, due to climatic conditions previously discussed, grain yield was significantly higher when P was knifed as compared to banded. Flour protein content was greater when P was knifed, in contrast

Table 10. Yield and grain quality variables for 1982 and 1983 Teton County sites as affected by placement of P and rate of K.

	R082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
Pband(#)	3174	67.0	0.476	6.1	10.4	60.56	11.73	10.61	774.
Pknif(+)	4086	70.1	0.503	5.7	8.7	61.87	11.57	10.39	797.
LSD	504**	0.62**	0.0244*	ns	1.455*	0.87**	ns	0.22*	22.6*
0 kg	3560	69.3 b	0.487	6.0	8.5a	61.10	11.55	10.25a	778.
50	3765	67.8a	0.497	5.6	9.5ab	61.33	11.65	10.52ab	802.
100	3444	68.5ab	0.500	6.3	11.3 b	61.20	11.70	10.57ab	792.
150	3750	68.5ab	0.472	5.5	8.7ab	61.25	11.70	10.65 b	771.
LSD	ns	0.88**	ns	ns	2.569**	ns	ns	0.38**	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\# = banded with the seed

\+ = knifed at 15 cm depth

Table 10--Continued

	R083								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
Pband(#)	2881	67.9	0.435	7.4	12.3	14.41	60.06	12.25	795.
Pknif(+)	3880	68.0	0.422	8.5	13.1	14.23	60.62	12.73	832.
LSD	485**	ns	ns	ns	ns	ns	ns	0.46*	34.3**
0 kg	3174.	68.3	0.420	6.9	12.7	14.40	60.40	12.75 b	812.
25	3277	68.1	0.447	7.9	13.1	14.42	60.45	12.08a	804.
50	3246	67.8	0.420	8.4	12.9	14.25	60.20	12.80 b	812.
100	3666.	67.5	0.427	8.6	12.0	14.20	60.33	12.32ab	827.
LSD	ns	ns	ns	ns	ns	ns	ns	0.65*	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\# = banded with the seed

\+ = knifed at 15 cm depth

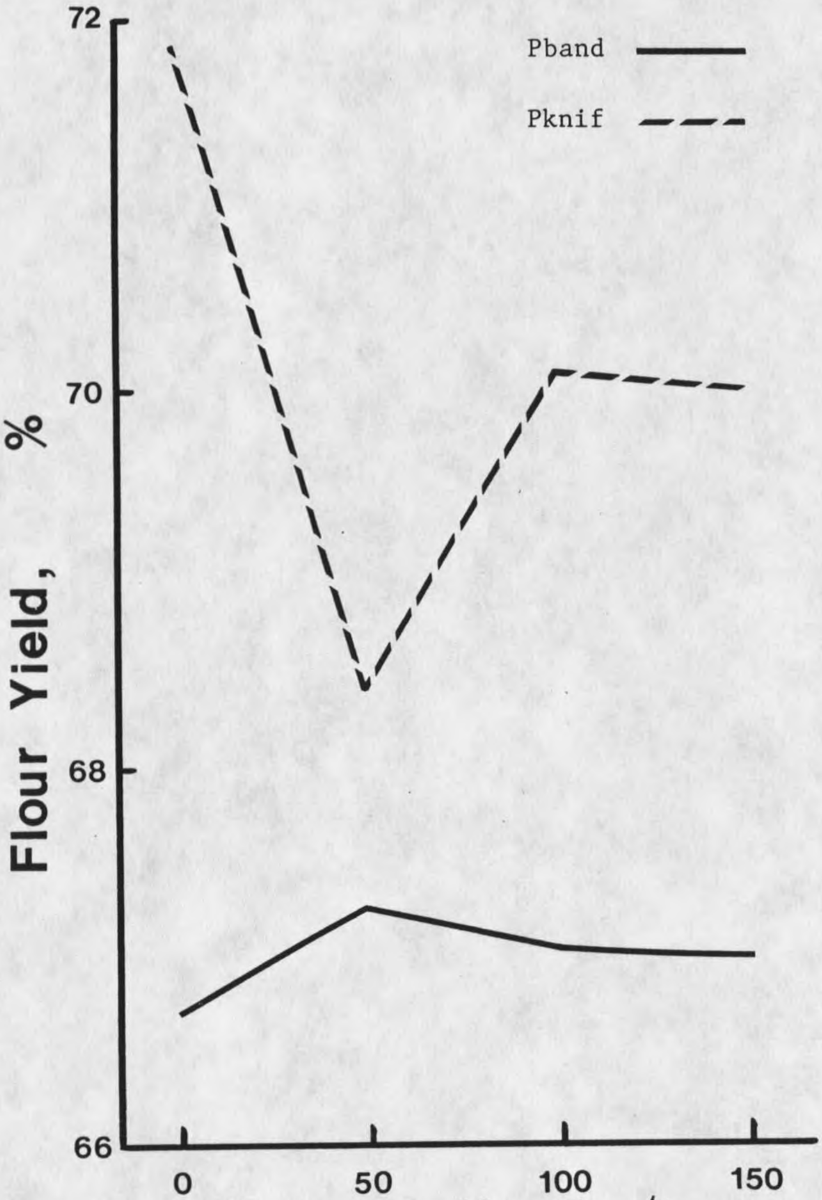

Figure 5. Interaction of flour percent yield at R082 between placement of P and rate of K treatments.

to results from R082. Loaf volume was also greater when P was knifed. Flour protein showed significant differences due to rate of K, but the interaction was not significant.

(3) J082 site: Knifing of P produced higher grain yield as compared to banding with the seed (Table 11). Both flour yield and loaf volume were greater when P was knifed, with agrees with the results at R082. Flour percentage ash was lower when P was knifed. Five of eight grain quality response variables (flour yield, flour ash, farinograph peak and stability, and loaf volume) showed significant differences due to rate of K. However, the effects are not consistent from variable to variable. Interactions between placement of P and rate of K (Figures 6 and 7) were significant for flour ash and farinograph peak.

(4) J083 site: Flour yield, flour ash and loaf volume all were greater when P was banded with the seed as compared to knifed. Test weight was less when the P was banded. Rate of K had a significant positive effect on loaf volume, for which a significant interaction between placement of P and rate of K was observed (Figure 8).

In summary, the importance for grain yield of placing P in a position which allows greater availability to the growing plant is supported by these data. Although protein usually decreases as yield increases, both yield and protein were increased at J082 with knifed P.

The results between these locations do not provide consistent evidence for the superiority for baking quality of knifing P. Also, responses to rate of K weren't consistent: increases and/or decreases in the variables measured, though significant, did not occur on a

Table 11. Yield and grain quality variables for 1982 and 1983 Chouteau County sites as affected by placement of P and rate of K.

	J082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
Pband(#)	1909	69.5	0.455	8.3	16.0	13.61	60.52	11.76	846.
Pknif(+)	2212	71.1	0.438	8.2	14.4	14.25	60.39	11.57	804.
LSD	112**	0.48**	0.0089**	ns	ns	ns	ns	ns	40.4**
0 kg	1989	70.8 b	0.453 bc	7.5a	14.0a	13.65	60.27	11.77	855. b
25	2104	70.4ab	0.455 c	8.0ab	14.1a	14.15	60.45	11.82	835.ab
50	2049	70.3ab	0.440ab	8.5ab	18.4 b	13.85	60.80	11.40	801.a
100	2099	69.8a	0.437a	9.1 b	14.2a	14.07	60.30	11.67	810.ab
LSD	ns	0.69**	0.0126**	1.610**	3.86*	ns	ns	ns	45.8*

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\# = banded with the seed

\+ = knifed at 15 cm depth

Table 11--Continued

	J082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
Pband(#)	1134	63.5	0.549	10.8	19.6	16.87	60.01	15.66	966.
Pknif(+)	1101	60.3	0.479	10.1	18.5	16.85	60.74	15.60	951.
LSD	ns	2.57**	0.0647**	ns	ns	ns	0.61*	ns	13.9*
0 kg	1041	62.1	0.547	9.6	19.0	17.37	60.15	15.65	941.a
25	1163	62.9	0.515	10.4	16.6	16.48	60.40	15.68	931.a
50	1097	61.9	0.490	10.8	18.5	16.50	60.65	15.45	962. b
100	1167	60.6	0.502	11.2	22.2	17.10	60.30	15.75	1001. c
LSD	ns	ns	ns	ns	ns	ns	ns	ns	19.6**

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\# = banded with the seed

\+ = knifed at 15 cm depth

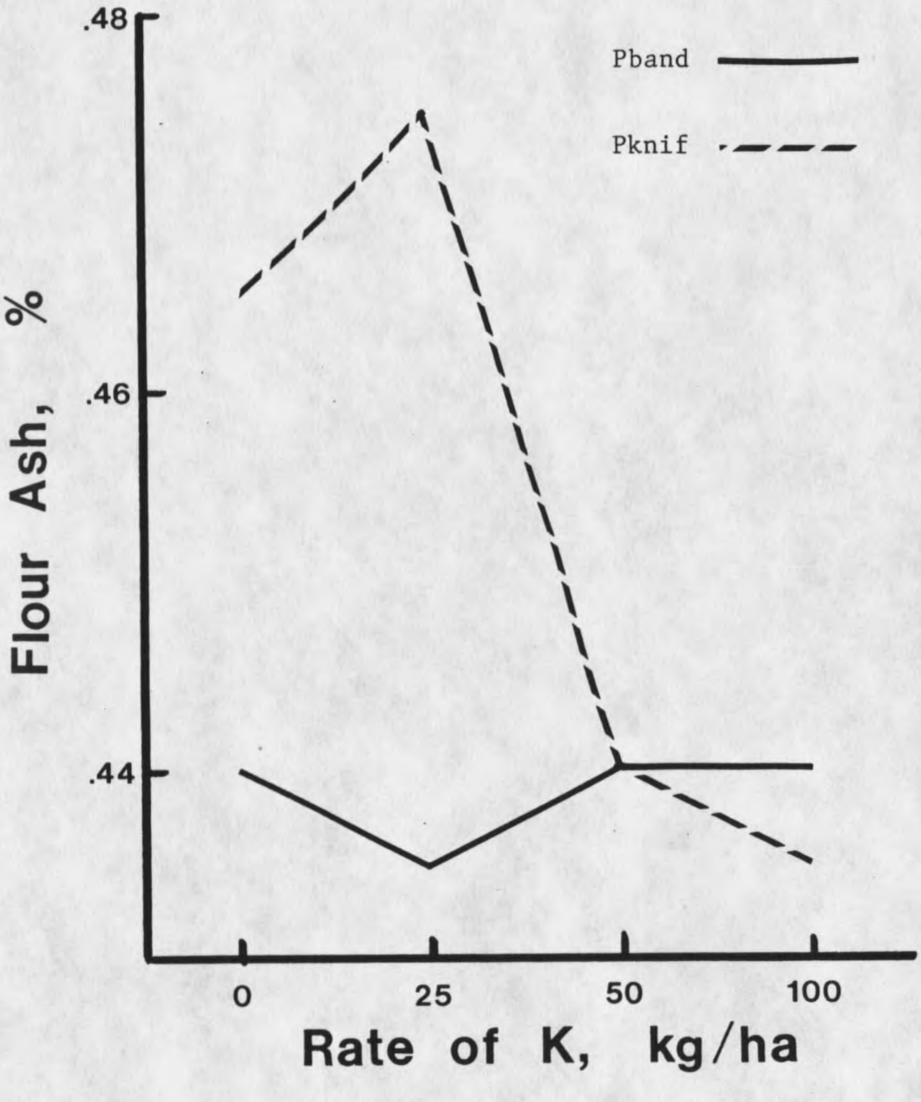

Figure 6. Interaction on flour ash at J082 between placement of P and rate of K treatments.

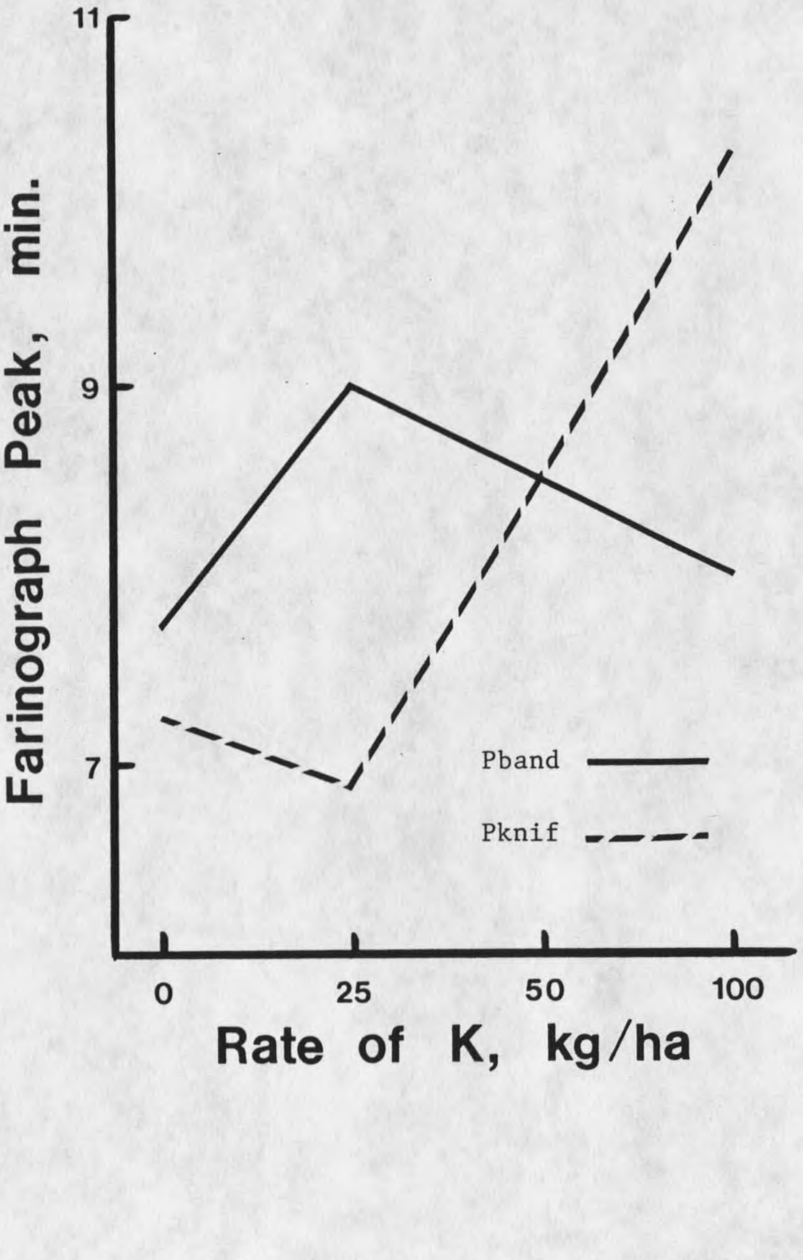

Figure 7. Interaction on farinograph peak at J082 between placement of P and rate of K treatments.

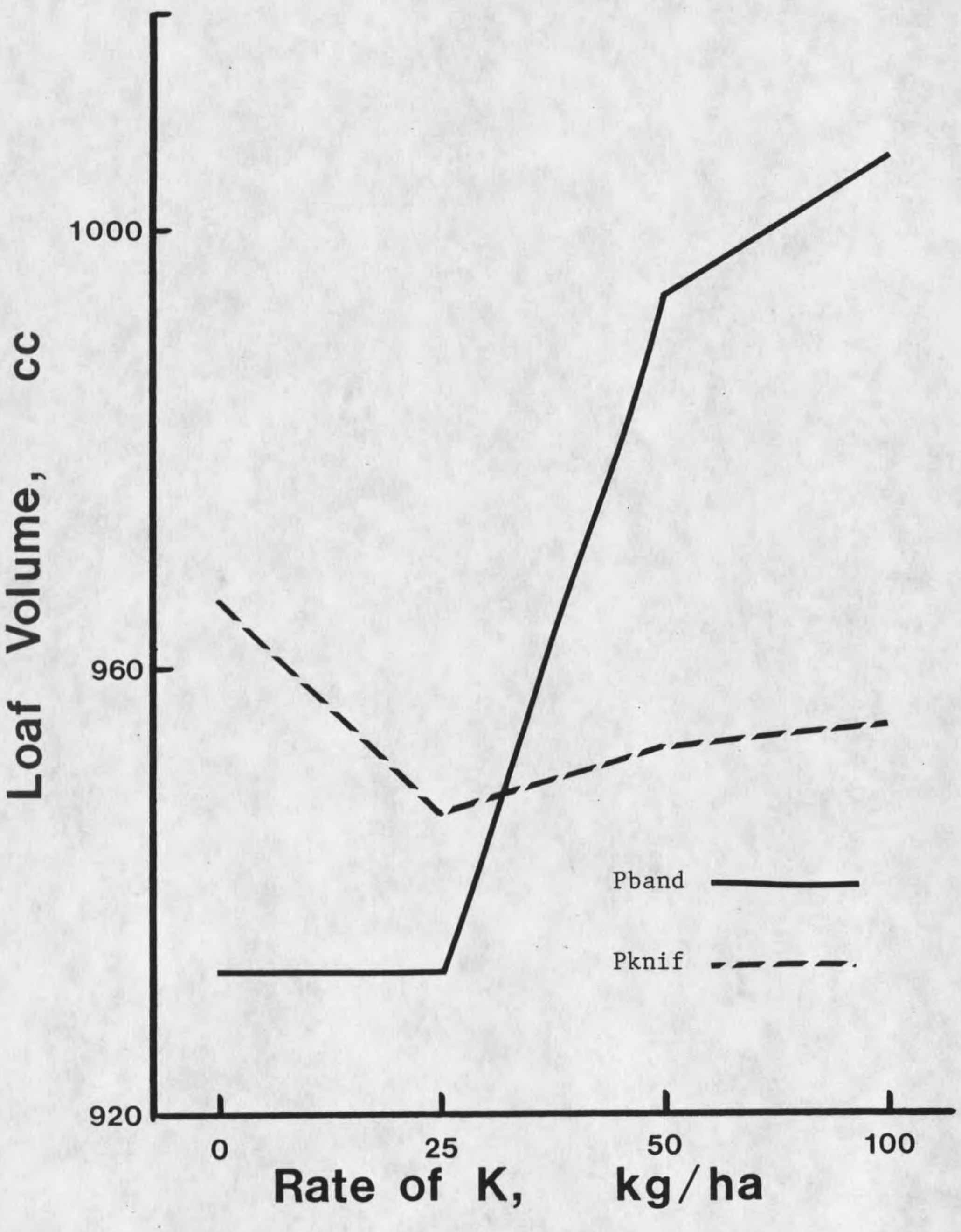

Figure 8. Interaction on loaf volume at J083 between placement of P and rate of K treatments.

consistent basis at a given rate(s) of K, when rate of K was analyzed as the second factor statistically in the placement of P comparison.

Placement of Potassium.

(1) R082 site: Surface placement of K, as compared to knifing, produced greater percentage protein in both the wheat and flour (Table 12). Accordingly, the farinograph peak time was greater with surface application. However, in a reversal, the farinograph stability was over a minute longer for the samples receiving knifed K rather than banded. Flour percentage ash was greater when K was surface applied. Four variables showed significant differences for the rate of K comparison: wheat and flour protein, farinograph stability, and flour yield. Of these, the first three mentioned showed improvement upon the addition of K, although the patterns are not consistent after the 50 kg/ha addition. Flour yield showed significant decrease with the 50 kg/ha addition of K. Two significant interactions occurred between placement and rate of K (Figures 9 and 10).

(2) R083 site: Knifed application of K at this site was superior to banded for both flour protein and farinograph peak. This trend is also observed for wheat protein, test weight, loaf volume, and stability, although the differences were not significant. Rates of K significantly affected flour protein and loaf volume.

(3) J082 site: Flour yield and loaf volume both were increased significantly when K was knifed (Table 13). Rate of K affected both flour yield and flour percentage ash. The effects were consistent, showing a decline with the first increment, then increasing with greater rates.

Table 12. Yield and grain quality variables for 1982 and 1983 Teton County sites as affected by placement and rate of K.

	R082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
Ksurf(#)	4086	70.0	0.503	5.7	8.7	61.87	11.57	10.39	797.
Kknif(+)	3913	69.5	0.451	5.1	9.7	61.76	11.31	10.17	781.
LSD	ns	ns	0.0358**	0.505**	0.770**	ns	0.17**	0.18**	ns
0 kg	4095	70.8 b	0.492	5.4	7.8a	61.85	11.30a	10.07a	771.
50	3969	68.9a	0.470	5.2	9.2 b	61.48	11.57 b	10.45 b	790.
100	3905	69.8ab	0.477	5.6	10.4 b	62.00	11.47ab	10.22ab	798.
150	4028	69.8ab	0.467	5.2	9.4 b	61.95	11.42ab	10.37 b	796.
LSD	ns	0.99**	ns	ns	1.089*	ns	0.25**	0.26**	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\# = applied in a band on the soil surface

\+ = knifed at 15 cm depth

Table 12--Continued

	R083								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
Ksurf(#)	3381	68.1	0.408	6.9	11.5	13.99	59.95	12.18	812.
Kknif(+)	3800	68.0	0.422	8.5	13.1	14.23	60.62	12.73	832.
LSD	ns	ns	ns	1.141**	ns	ns	ns	0.40**	ns
0 kg	3562	68.4	0.410	7.5	11.3	14.35	60.27	12.85 b	802.a
25	3600	67.9	0.422	8.5	12.6	14.07	60.08	12.15a	821.ab
50	3398	67.9	0.410	7.2	12.9	13.92	60.15	12.95 b	832.ab
100	3803	68.0	0.420	7.6	12.3	14.07	60.65	11.85a	835. b
LSD	ns	ns	ns	ns	ns	ns	ns	0.57**	32.8*

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

= applied in a band on the soil surface

\+ = knifed at 15 cm depth

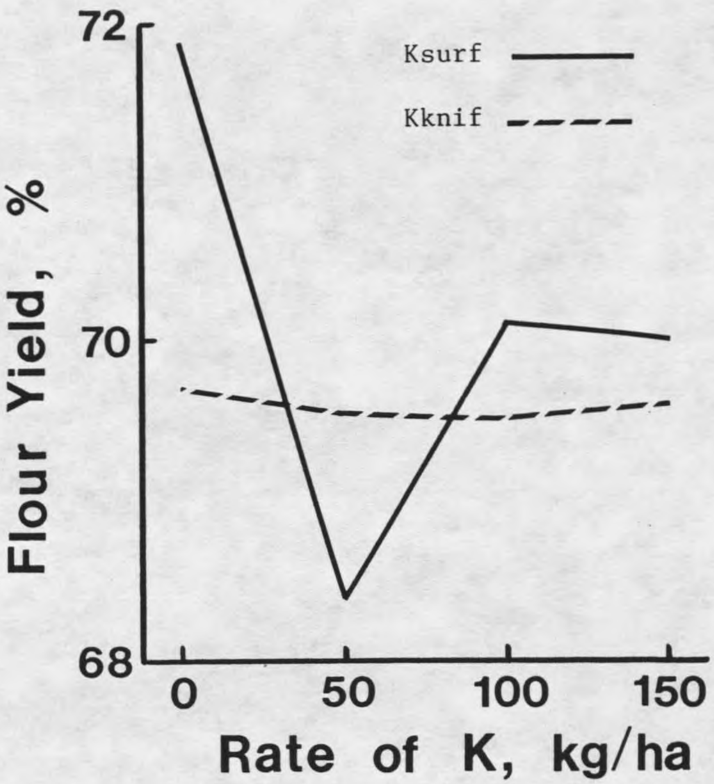

Figure 9. Interaction on flour yield at R082 between placement and rate of K treatments.

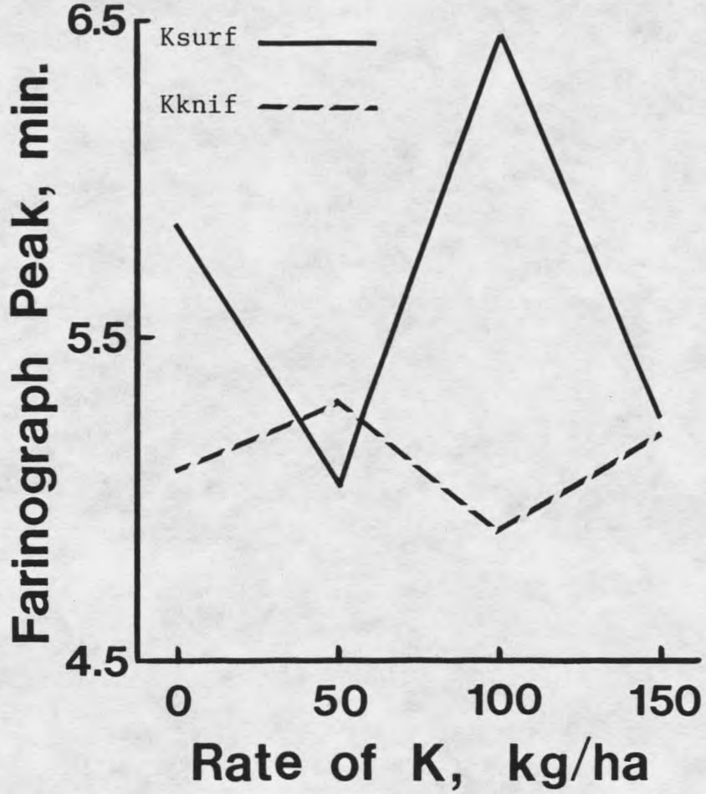

Figure 10. Interaction on farinograph peak at R082 between placement and rate of K treatments.

Table 13. Yield and grain quality variables for 1982 and 1983 Chouteau County sites as affected by placement and rate of K.

	J082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
Ksurf(#)	2212	71.1	0.437	8.2	14.3	14.25	60.39	11.57	804.
Kknif(+)	2104	70.5	0.437	8.7	14.0	13.97	61.09	11.29	855.
LSD	ns	0.53**	ns	ns	ns	ns	ns	ns	29.2**
0 kg	2041	71.1 b	0.435ab	7.6	12.6	14.02	60.65	11.52	830.
25	2271	70.3a	0.432a	8.0	12.3	14.20	60.80	11.28	840.
50	2191	71.1 b	0.440ab	8.8	17.6	14.13	60.93	11.32	822.
100	2129	70.6ab	0.443 b	9.5	14.2	14.10	60.58	11.60	826.
LSD	ns	0.60*	0.0083*	ns	ns	ns	ns	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\# = applied in a band on the soil surface

\+ = knifed at 15 cm depth

Table 13--Continued

	J082								
	Yield (kg/ha)	Flour Yield (%)	Flour Ash (%)	Farin Peak (min)	Farin Stab (min)	Test Wt (lb/bu)	Wheat Prot (%)	Flour Prot (%)	Loaf Vol (cc)
Ksurf(#)	899	60.8	0.520	9.2	15.4	17.05	60.16	16.18	954.
Kknif(+)	1101	60.3	0.478	10.1	18.5	16.85	60.74	15.60	951.
LSD	89**	ns	0.0358*	ns	ns	ns	ns	ns	ns
0 kg	982	61.4	0.515	10.4	18.0	17.05	60.75	15.93	957.
25	1024	60.4	0.482	9.8	15.3	16.40	60.48	15.55	937.
50	962	60.4	0.497	9.3	16.9	16.95	60.33	15.97	941.
100	1031	60.0	0.502	9.2	17.5	17.40	60.25	16.10	975.
LSD	ns	ns	ns	ns	ns	ns	ns	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\# = applied in a band on the soil surface

\+ = knifed at 15 cm depth

(4) J083 site: Grain yield was higher when K was knifed as compared to surface application. Flour percentage ash was the only quality parameter at this site for which a significant effect was observed for placement of K. The flour ash was higher when K was surface applied, as compared to knifed. There was no response at this site to rate of K.

To summarize, few responses were observed at these sites to K fertilizer management, with the exception of R082. Protein in the flour and grain was generally greater when K was surface applied, although all differences were not significant. Test weight was generally greater when K was knifed. It would appear that especially under drought conditions (1983 locations), knifed K produced longer farinograph times, indicating greater dough strength, although the differences were small.

Seed and Seedling Vigor

Form of nitrogen. Speed of emergence index at the R083 site responded to rate of K with the greatest vigor at the highest rate of K (Table 14). There were no significant differences due to form of N at this site. At the J082 site the highest speed of emergence index occurred at the 50 kg/ha rate of K. Form of N did not produce an effect on either variable at this site. A significant interaction occurred for speed of emergence index between form of N and rate of K (Figure 11). Speed of emergence index at the J083 site was significantly greater when anhydrous ammonia was the form of N. Rate of K also affected speed of emergence index at this site, with the greatest vigor at 0 kg/ha. Figure 12 shows the significant interaction between form of N and rate of K for speed of emergence index.

Table 14. Seed vigor variables for spring wheat sites as affected by form of N and rate of K.

Fertilizer	R082(#) SEI	R082(#) D Wt/ Plant (mg)	R083 SEI	R083 D Wt/ Plant (mg)
AN(+)	26.59	0.49	19.37	0.74
NH_3(@)	26.13	0.45	17.78	0.74
LSD	ns	ns	ns	ns
0 kg K	28.04	0.48	18.63ab	0.70
25	25.30	0.44	16.87a	0.78
50	26.26	0.46	17.94ab	0.72
100	25.85	0.49	20.87 b	0.75
LSD	ns	ns	3.31**	ns

Fertilizer	J082 SEI	J082 D Wt/ Plant (mg)	J083 SEI	J083 D Wt/ Plant (mg)
AN(+)	29.89	0.51	14.85	0.62
NH_3(@)	27.82	0.50	18.59	0.64
LSD	ns	ns	3.28*	ns
0 kg K	25.06a	0.49	18.71 b	0.66
25	28.71ab	0.51	16.56ab	0.63
50	32.68 b	0.52	13.80a	0.61
100	28.96ab	0.52	17.82ab	0.62
LSD	4.71**	ns	4.64*	ns

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\# = Rates of K for R082 were 0, 50, 100, and 150 kg/ha.

\+ = ammonium nitrate (AN)

@ = anhydrous ammonia (NH_3)

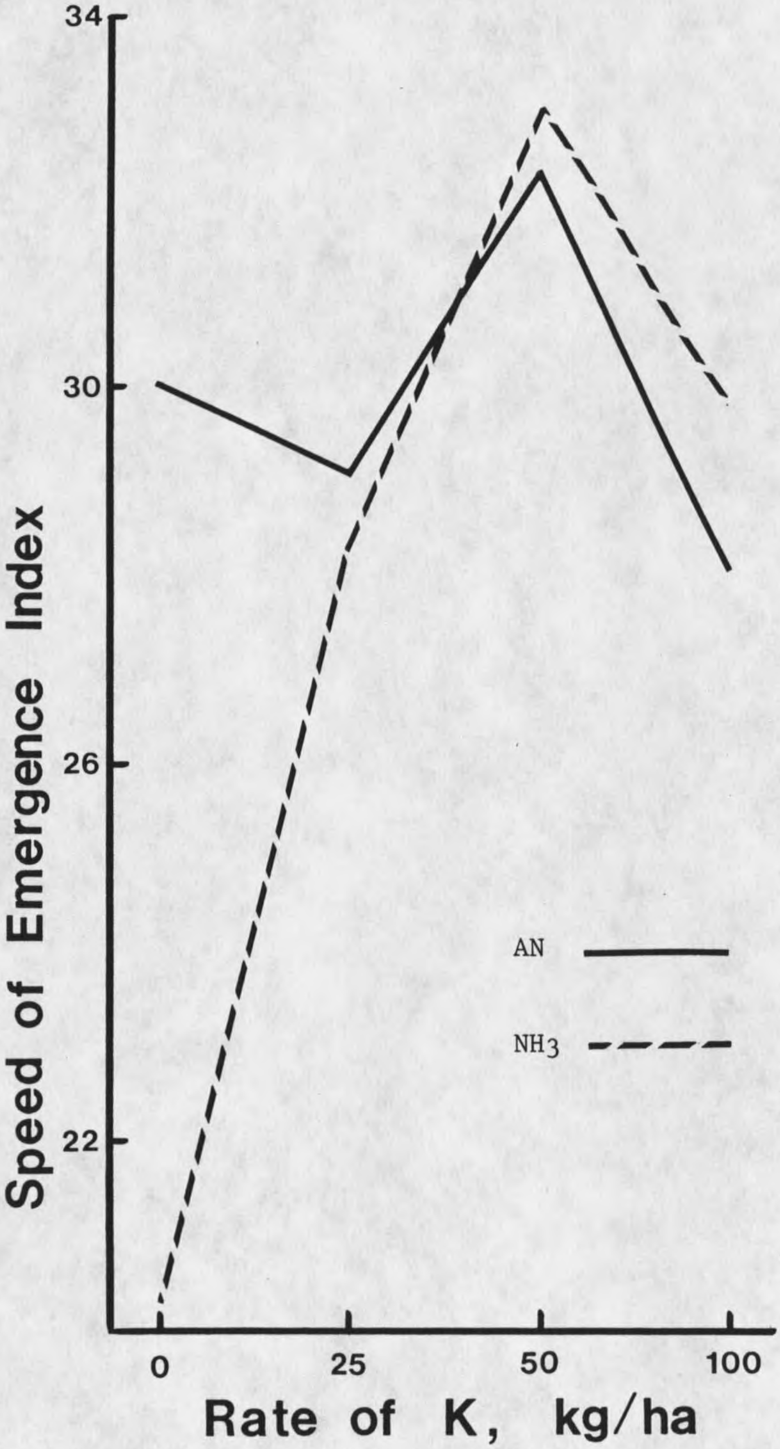

Figure 11. Interaction on speed of emergence index at J082 between form of N and rate of K treatments.

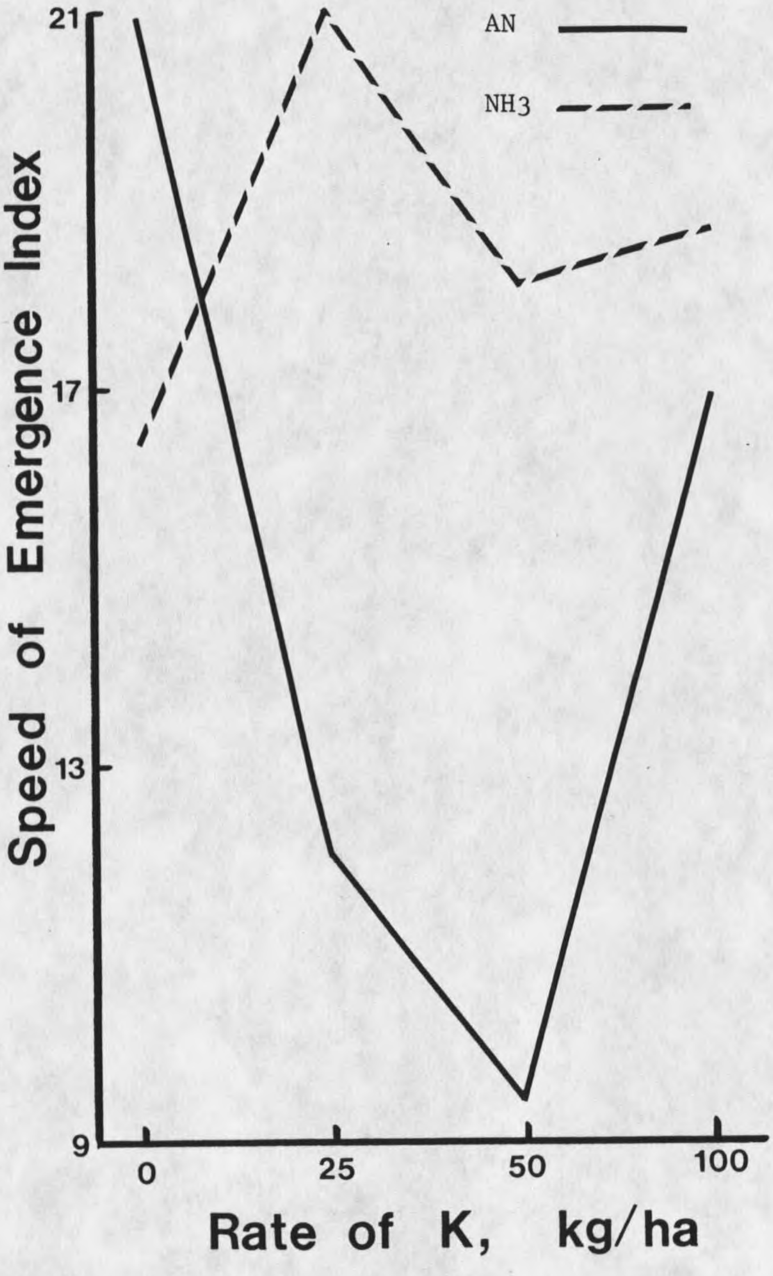

Figure 12. Interaction on speed of emergence index at J083 between form of N and rate of K treatments.

Placement of phosphorus.

(1) R082 site: Although there were no responses of seedling vigor to placement of P at this site, speed of emergence index was greatest for the grain from this site at the two lowest rates of K application (Table 15).

(2) R083 site: Dry weight per plant showed significant differences due to rate of K. However, this response is not consistent with the response at R082.

(3) J082 site: A significant increase occurred in dry weight per plant due to knifing of P at this site. It was also the only site for which percentage protein significantly responded to placement of P (compare Table 9). Both percentage protein and dry weight per plant were greater when P was knifed as compared to banded with the seed. This agrees with findings in the literature that grain protein and vigor are positively correlated (Ayres et al., 1976; Schweizer and Ries, 1969). Both seed vigor variables at this site responded positively to rate of K application. As before, these responses bear little resemblance to others observed. Significant interaction occurred on speed of emergence index between placement of P and rate of K (Figure 13).

(4) J083 site: There were no significant responses at this site to either of these comparisons. Significant interaction occurred between placement of P and rate of K for speed of emergence index (Figure 14).

Placement of potassium. There were no significant responses at the spring wheat sites to placement of K (Table 16). Although three of the

Table 15. Seed vigor variables for spring wheat sites as affected by placement of P and rate of K.

	R082(#)		R083	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
Pband(+)	26.13	0.45	17.78	0.74
Pknif(@)	27.09	0.43	19.13	0.79
LSD	ns	ns	ns	ns
0 kg K	28.38 b	0.46	20.10	0.71a
25	28.05 b	0.42	17.79	0.84 b
50	25.59ab	0.45	18.45	0.71a
100	24.42a	0.44	17.47	0.80ab
LSD	3.57*	ns	ns	0.1166**

	J082		J083	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
Pband(+)	27.82	0.50	18.59	0.64
Pknif(@)	28.04	0.60	17.23	0.68
LSD	ns	0.0631**	ns	ns
0 kg K	24.15a	0.54ab	17.94	0.62
25	30.66 b	0.61 b	16.93	0.67
50	28.65ab	0.53ab	19.88	0.68
100	28.27ab	0.52a	16.89	0.67
LSD	5.04**	0.0738*	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\# = Rates of K for R082 were 0, 50, 100, and 150 kg/ha.

\+ = banded with the seed

@ = knifed at 15 cm depth

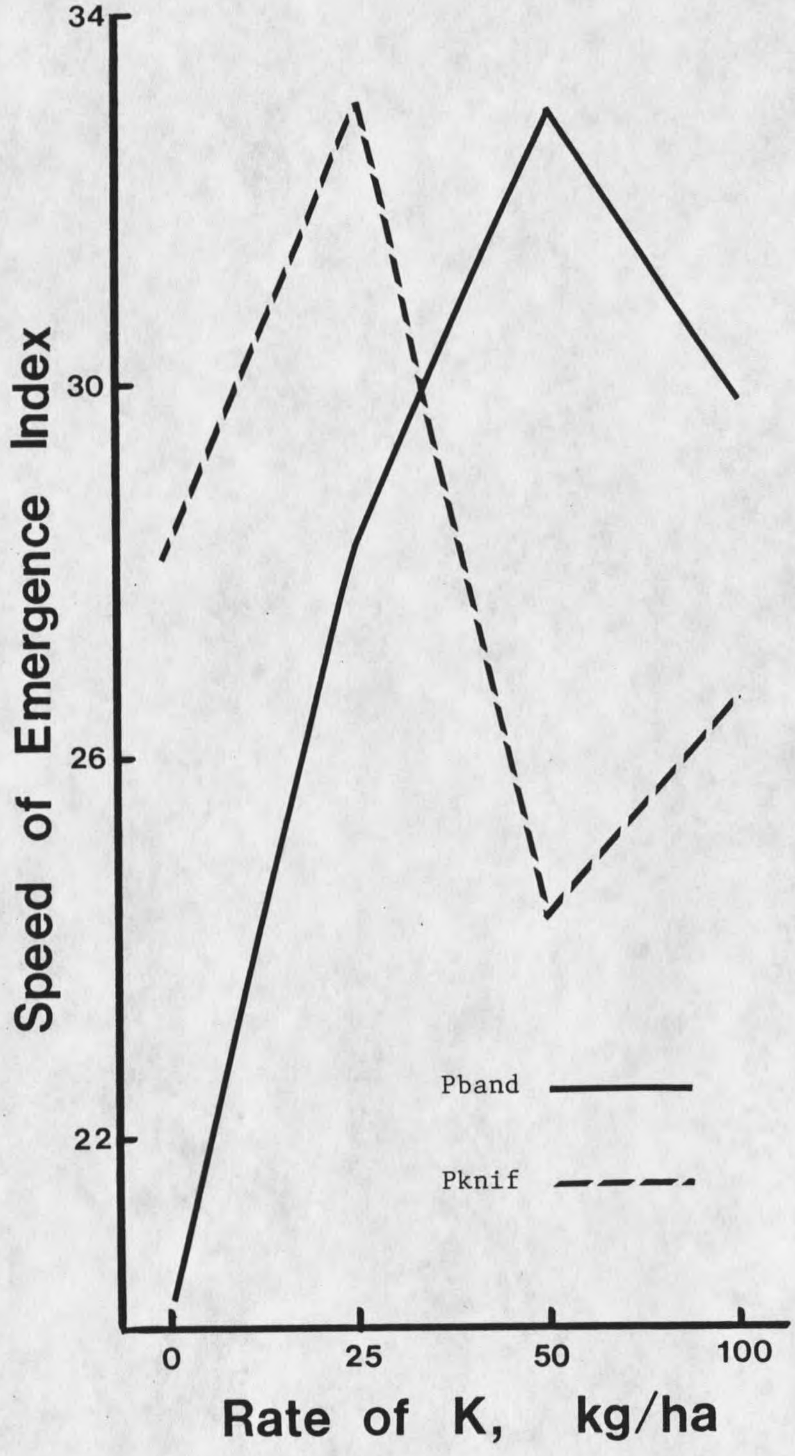

Figure 13. Interaction on speed of emergency index at J082 between placement of P and rate of K treatments.

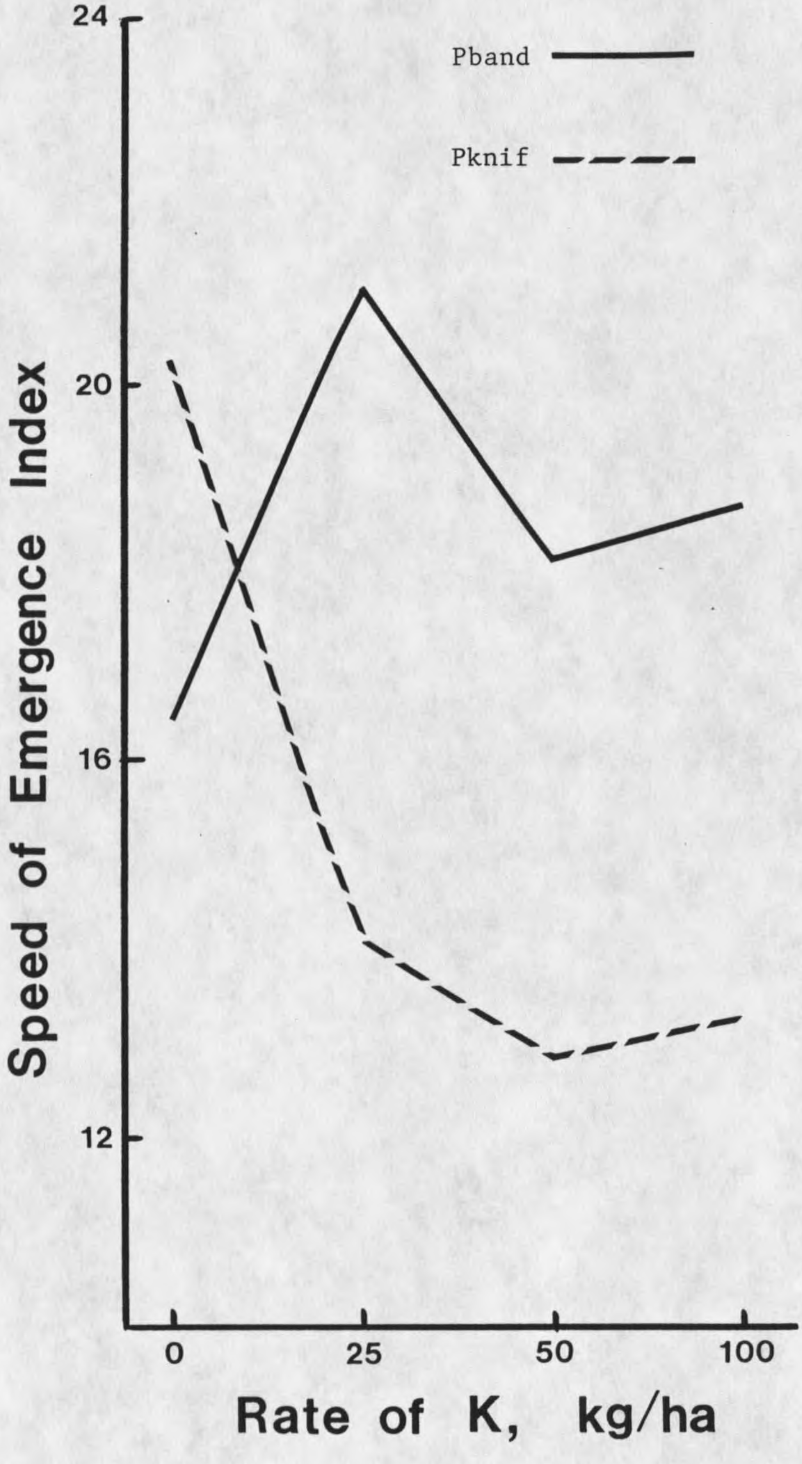

Figure 14. Interaction on speed of emergence index at J083 between placement of P and rate of K treatments.

Table 16. Seed vigor variables for spring wheat sites as affected by placement and rate of K.

	R082(#)		R083	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
Ksurf(+)	27.09	0.43	19.43	0.78
Kknif(@)	26.94	0.48	19.13	0.79
LSD	ns	ns	ns	ns
0 kg K	27.15	0.43	19.57	0.76a
25	28.95	0.44	18.81	0.88 b
50	26.06	0.48	20.57	0.72a
100	25.90	0.46	18.16	0.80ab
LSD	ns	ns	ns	0.1132**

	J082		J083	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
Ksurf(+)	28.04	0.59	15.10	0.63
Kknif(@)	28.97	0.60	17.23	0.68
LSD	ns	ns	ns	ns
0 kg K	28.27	0.57ab	19.83 b	0.59a
25	30.53	0.62ab	13.44a	0.64ab
50	26.68	0.65 b	17.23ab	0.64ab
100	28.55	0.55a	14.17ab	0.75 b
LSD	ns	0.0851*	6.27**	0.1490**

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\# = Rates of K for R082 were 0, 50, 100, and 150 kg/ha.

\+ = applied in a band on the soil surface

@ = knifed at 15 cm depth

four sites showed a significant response for one or both of these variables to rate of K, these effects were not consistent, even within a site. A significant interaction occurred at J082 between placement and rate of K for dry weight per plant (Figure 15).

Mineral Composition

Form of nitrogen.

(1) R082 site: No significant responses occurred in mineral content at this site to form of N. However, percentage Mg increased and contents of Zn, Cu, and Fe decreased significantly with added K (Table 17).

(2) R083 site: Potassium and P responded to form of N. For both of these nutrients, the level was higher when ammonium nitrate was the form of N, as compared to anhydrous ammonia. Zinc concentration was greater in the grain grown using ammonium nitrate. Potassium, Mg, and Cu were significantly increased by rate of K.

(3) J082 site: Calcium and P in the grain were significantly affected by form of N (Table 18). Percentage Ca was greater when anhydrous ammonia was the form of N, while percentage P was greater when ammonium nitrate was used. Both Zn and Cu were higher when anhydrous ammonia was the form of N. Calcium, P, Cu, an Fe responded significantly to rate of K at this site.

(4) J083 site: Calcium, Mg, Mn, and Fe were higher when anhydrous ammonia was the form of N. This trend applied to every nutrient measured at this site, although the differences are not all significant. Six of eight nutrients (K, Ca, Mg, P, Zn, and Mn) showed significant

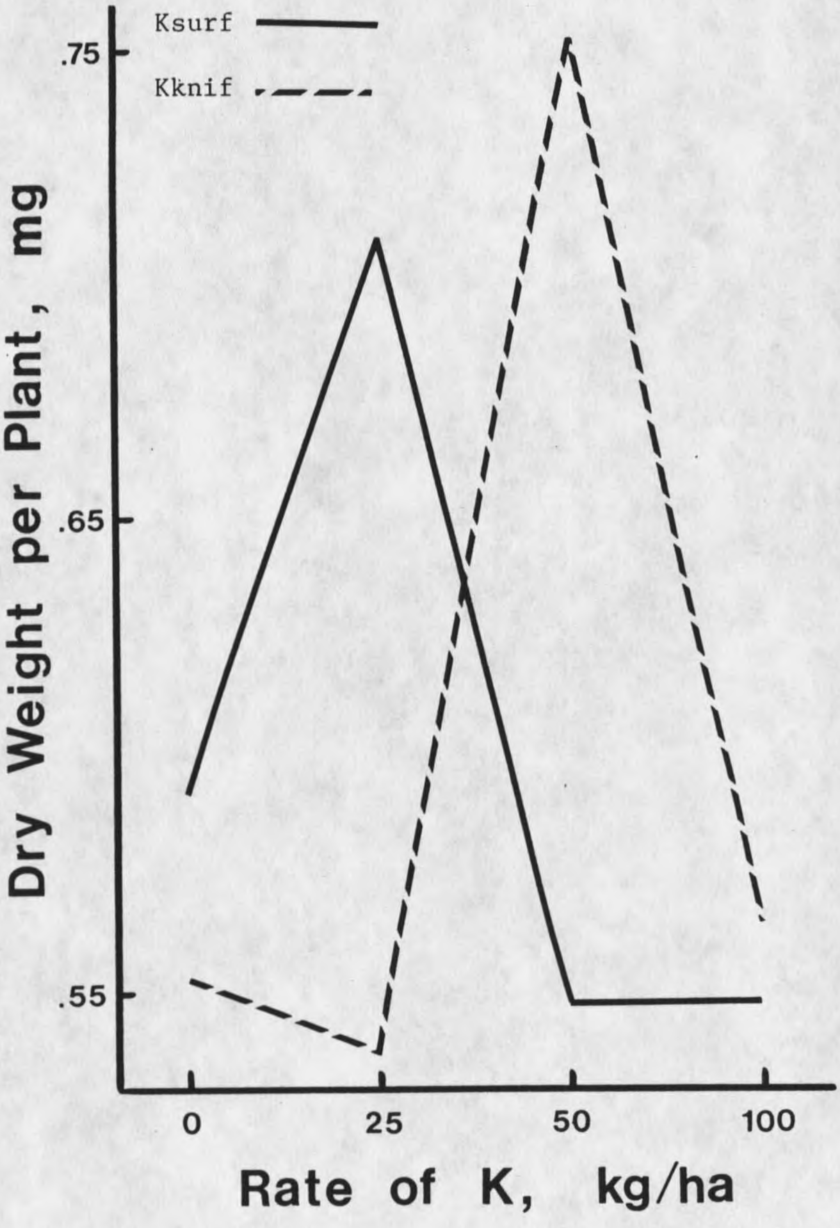

Figure 15. Interaction on dry weight per plant at J082 between placement and rate of K treatments.

Table 17. Mineral composition of spring wheat from the 1982 and 1983 Teton County sites as affected by form of N and rate of K.

	R082							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
AN(+)	0.209	0.022	0.060	0.318	20.9	5.1	20.7	39.5
NH_3(#)	0.219	0.023	0.065	0.333	21.2	5.3	21.3	39.4
LSD	ns	ns	ns	ns	ns	ns	ns	ns
0 kg K	0.201	0.022	0.058a	0.312	22.6 b	5.6 b	20.4	45.2 b
50	0.211	0.022	0.062ab	0.328	20.7ab	5.1ab	21.2	39.1ab
100	0.217	0.024	0.062ab	0.323	20.0a	5.1ab	20.6	37.3ab
150	0.227	0.024	0.067 b	0.339	20.9ab	4.9a	21.7	36.3a
LSD	ns	ns	0.0082*	ns	2.50**	0.610**	ns	8.45*

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

+ = ammonium nitrate (AN)

= anhydrous ammonia (NH_3)

Table 17--Continued

Fertilizer	R083							
	%				ppm			
	K	Ca	Mg	P	Zn	Cu	Mn	Fe
AN(+)	0.204	0.024	0.069	0.353	20.5	3.9	32.5	53.4
NH_3(#)	0.195	0.024	0.067	0.336	17.9	4.0	33.8	51.0
LSD	0.0060**	ns	ns	0.0145**	2.47*	ns	ns	ns
0 kg K	0.196ab	0.024	0.066a	0.338	21.4	3.7a	32.0	57.9
25	0.194a	0.024	0.067ab	0.342	18.7	4.0ab	32.5	47.7
50	0.203 b	0.023	0.068ab	0.349	18.3	4.2 b	34.0	49.3
100	0.204 b	0.024	0.071 b	0.349	18.3	4.1ab	34.1	54.0
LSD	0.0085**	ns	0.0038*	ns	ns	0.394*	ns	ns

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = ammonium nitrate (AN)

\# = anhydrous ammonia (NH_3)

Table 18. Mineral composition of spring wheat from the 1982 and 1983 Chouteau County sites as affected by form of N and rate of K.

	J082							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
AN(+)	0.196	0.010	0.072	0.399	30.3	4.3	44.1	52.6
NH_3(#)	0.199	0.014	0.072	0.350	35.7	4.8	46.6	52.3
LSD	ns	0.0023**	ns	0.0237**	2.78**	0.365**	ns	ns
0 kg K	0.203	0.010a	0.073	0.383ab	33.2	4.7 b	45.7	58.4 b
50	0.202	0.011ab	0.074	0.388 b	34.2	4.6ab	45.8	53.1ab
100	0.197	0.014 b	0.071	0.375ab	33.6	4.7 b	45.6	52.9ab
150	0.187	0.011ab	0.681	0.350a	30.9	4.1a	44.3	45.7a
LSD	ns	0.0032**	ns	0.0336**	ns	0.517**	ns	11.12**

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = ammonium nitrate (AN)

\# = anhydrous ammonia (NH_3)

Table 18--Continued

	J083							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
AN(+)	0.183	0.014	0.083	0.495	71.5	4.2	46.0	70.9
NH_3(#)	0.187	0.016	0.088	0.512	75.2	4.6	49.6	79.6
LSD	ns	0.0014*	0.0042*	ns	ns	ns	2.27**	7.26**
0 kg K	0.192 b	0.014ab	0.087ab	0.516 b	74.1ab	4.9	48.5ab	75.7
25	0.175a	0.013a	0.080a	0.479a	69.8a	4.1	45.7a	72.4
50	0.184ab	0.017 b	0.086ab	0.498ab	76.8 b	4.3	47.8ab	80.0
100	0.189 b	0.016ab	0.088 b	0.522 b	72.8ab	4.3	49.3 b	72.7
LSD	0.0127**	0.0025**	0.0073**	0.0321**	5.85*	ns	3.21	ns

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = ammonium nitrate (AN)

\# = anhydrous ammonia (NH_3)

differences due to rate of K. In each case, the level was lowest with the 25 kg/ha addition of K. Significant interaction occurred between form of N and rate of K for Fe (Figure 16).

Placement of phosphorus.

(1) R082 site: Copper was higher when P was banded with the seed, as compared to knifed (Table 19). The other nutrient concentrations at this site follow this trend, but the differences were not significant. Percentage Mg was significantly increased by rate of K.

(2) R083 site: Percentage of K and Mg were greater when P was applied in a band with the seed. Potassium, Mg, P, Cu, Mn, and Fe responded to rate of K at this site. The lowest level for each of these minerals was with either no K or with the smallest (25 kg/ha) addition.

(3) J082 site: Percentage P, Zn, and Mn were greater when P was knifed, as compared to banded (Table 20). Calcium and Cu levels responded significantly to rate of K, although the responses were not similar. Significant interaction occurred between placement of P and rate of K for Fe (Figure 17).

(4) J083 site: Copper was the only nutrient at this location which responded significantly to placement of P. The level of Cu in the grain was much higher when P was banded. Percentage Ca and P showed significant response to rate of K, although the responses were not similar. Figures 18 and 19 show the significant interactions between placement of P and rate of K for percentage K and Cu content.

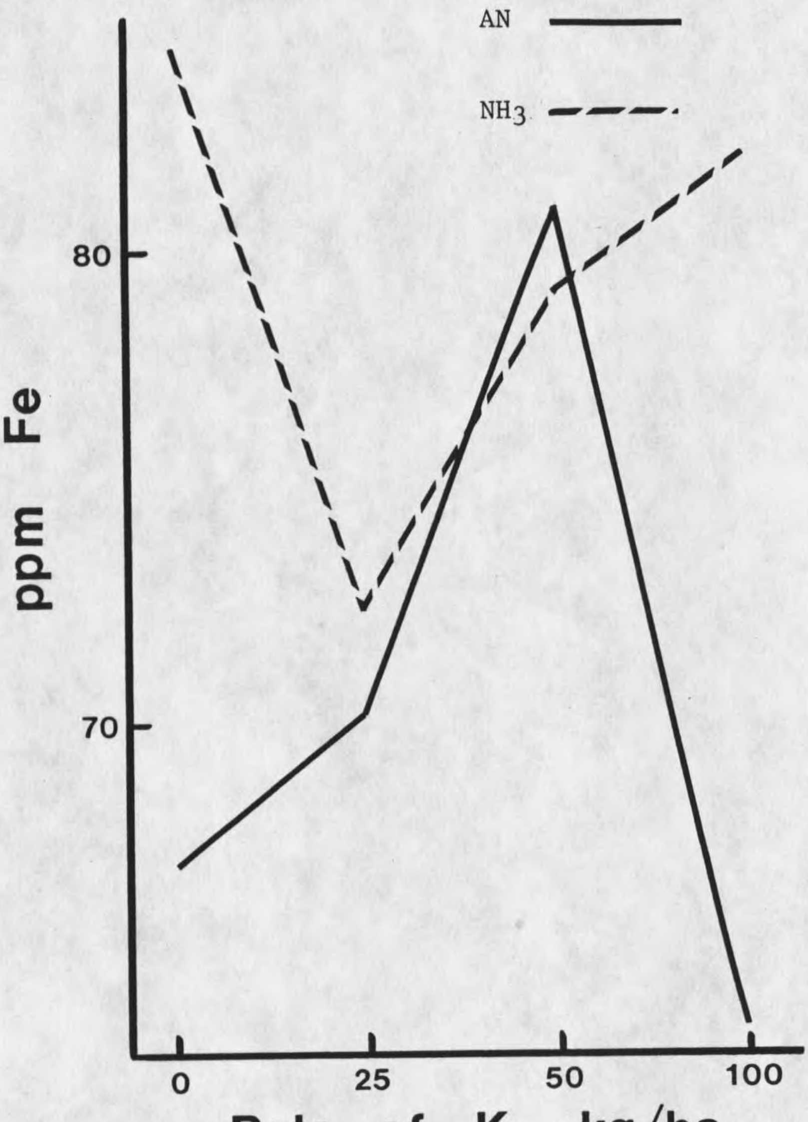

Figure 16. Interaction on ppm Fe at J083 between form of N and rate of K treatments.

Table 19. Mineral composition of spring wheat from the 1982 and 1983 Teton County sites as affected by placement of P and rate of K.

R082								
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Pband(+)	0.219	0.024	0.065	0.333	21.2	5.3	21.3	39.4
Pknif(#)	0.212	0.023	0.065	0.330	20.1	4.7	21.2	37.6
LSD	ns	ns	ns	ns	ns	0.309**	ns	ns
0 kg K	0.218	0.024	0.066ab	0.343	21.5	5.1	21.2	39.2
50	0.213	0.023	0.064ab	0.322	20.2	4.9	20.9	40.6
100	0.211	0.024	0.062a	0.322	20.6	5.2	21.4	38.6
150	0.220	0.023	0.067 b	0.339	20.3	4.9	21.5	35.7
LSD	ns	ns	0.0046**	ns	ns	ns	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = banded with the seed

\# = knifed at 15 cm depth

Table 19--Continued

	R083							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Pband(+)	0.195	0.024	0.067	0.336	17.9	4.0	33.8	51.0
Pknif(#)	0.191	0.024	0.064	0.345	17.8	4.1	34.6	45.8
LSD	0.0037*	ns	0.0025**	ns	ns	ns	ns	ns
0 kg K	0.188a	0.024	0.064a	0.329a	17.4	3.7a	33.0a	43.7a
25	0.188a	0.023	0.064a	0.328a	17.5	3.8ab	33.2ab	44.4a
50	0.199 b	0.025	0.067ab	0.372 b	18.0	4.4 b	35.5 b	47.4ab
100	0.198 b	0.024	0.069 b	0.334ab	18.5	4.2ab	35.2ab	58.4 b
LSD	0.0063**	ns	0.0035**	0.0416*	ns	0.585**	2.35*	12.78**

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = banded with the seed

\# = Knifed at 15 cm depth

Table 20. Mineral composition of spring wheat from the 1982 and 1983 Chouteau County sites as affected by placement of P and rate of K.

	J082							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Pband(+)	0.199	0.014	0.071	0.350	35.7	4.8	46.6	52.3
Pknif(#)	0.198	0.012	0.072	0.384	39.9	4.7	51.6	53.6
LSD	ns	ns	ns	0.0337*	2.82**	ns	3.43**	ns
0 kg K	0.199	0.011a	0.072	0.358	37.8	4.8ab	48.7	52.1
25	0.204	0.011a	0.074	0.371	37.9	4.8ab	49.6	50.2
50	0.197	0.016 b	0.073	0.389	38.8	4.9 b	49.4	54.7
100	0.194	0.012ab	0.069	0.348	36.4	4.2a	48.5	54.9
LSD	ns	0.0049**	ns	ns	ns	0.557**	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = banded with the seed

\# = knifed at 15 cm depth

Table 20--Continued

	J083							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Pband(+)	0.187	0.016	0.088	0.512	75.2	4.6	49.6	79.5
Pknif(#)	0.182	0.015	0.088	0.507	73.5	2.9	47.7	72.8
LSD	ns	ns	ns	ns	ns	0.816**	ns	ns
0 kg K	0.186	0.014a	0.090	0.523 b	72.1	3.7	47.5	75.1
25	0.179	0.014a	0.085	0.488a	72.1	3.5	47.6	72.0
50	0.183	0.017 b	0.087	0.505ab	76.4	3.8	48.8	76.6
100	0.188	0.016ab	0.090	0.523 b	76.7	3.9	50.6	81.0
LSD	ns	0.0025**	ns	0.0223**	ns	ns	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = banded with the seed

\# = knifed at 15 cm depth

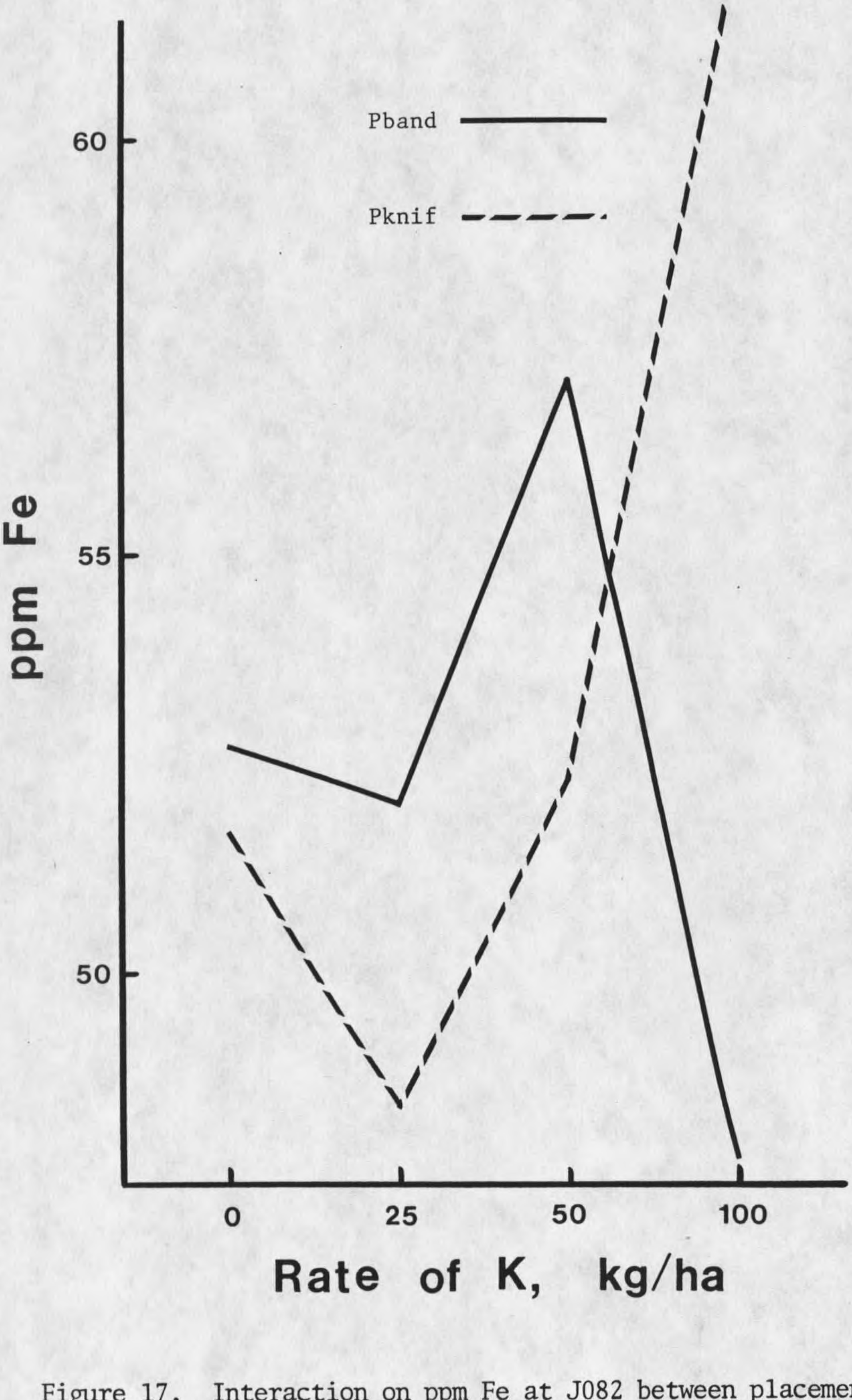

Figure 17. Interaction on ppm Fe at J082 between placement of P and rate of K treatments.

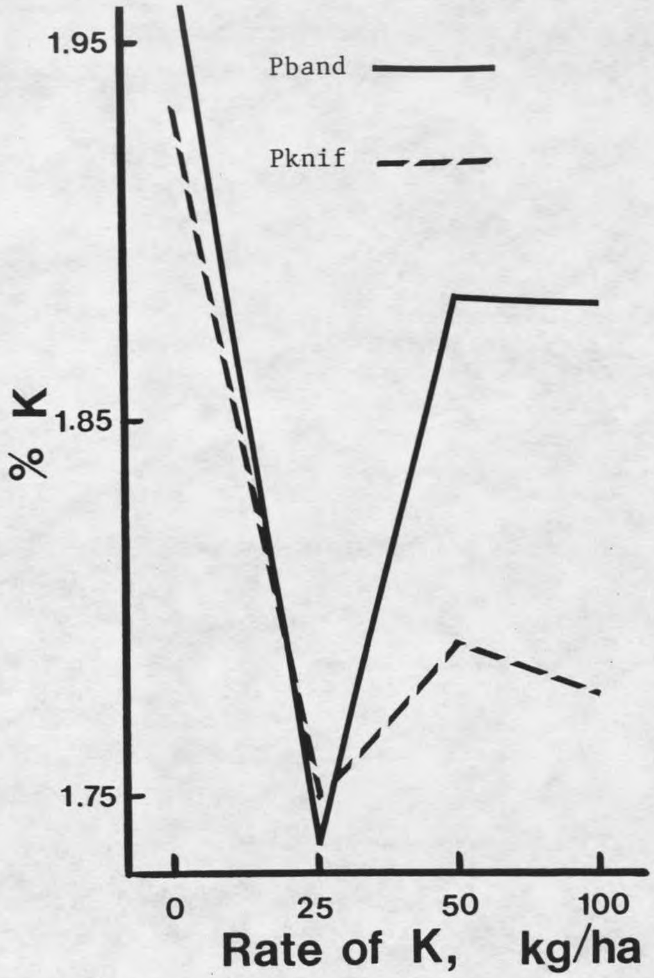

Figure 18. Interaction on percent K at J083 between placement of P and rate of K treatments.

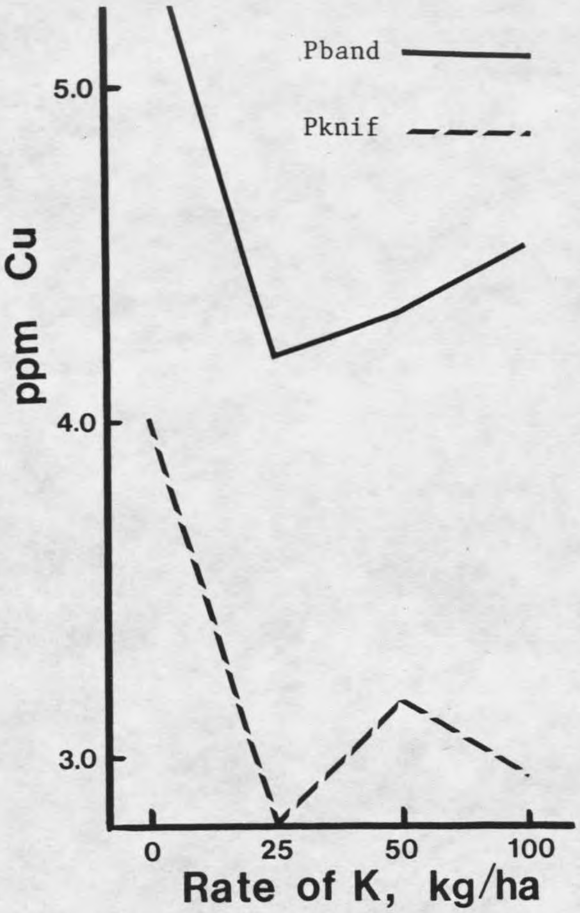

Figure 19. Interaction on ppm Cu at J083 between placement of P and rate of K treatments.

Placement of potassium.

(1) R082 site: All macronutrients analyzed were in significantly higher concentration when K was knifed as compared to surface applied (Table 21). Potassium in the grain was significantly affected by rate of K application, showing the highest concentration with the lowest (50 kg K/ha) addition.

(2) R083 site: Manganese level in the grain was higher when K was knifed. Phosphorus and Fe were influenced by rate of K, although the responses were not consistent. Several significant interactions between placement and rate of K occurred at this site. They were for Ca, Mg, Zn, Mn, and Fe (Figures 20, 21, 22, 23, and 24, respectively).

(3) J082 site: No responses occurred at this site to placement of K (Table 22). Iron in the grain responded, however, to rate of K. Significant interaction occurred between placement and rate of K for percentage K (Figure 25).

(4) J083 site: Surface application of K had a significant positive effect on Mn in the grain. This trend applies for the other micronutrients measured, although the differences are not significant. No response occurred to rate of K.

Barley

Soil Test Results and Climatic Data

Soil test results and climatic data are presented in Table 23 for the 1982 and 1983 Cascade County sites (PN82 and PN83). The levels of N and P fertilizers applied were chosen based in part on the soil test.

Table 21. Mineral composition of spring wheat from the 1982 and 1983 Teton County sites as affected by placement and rate of K.

	R082							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Ksurf(+)	0.212	0.023	0.064	0.330	20.1	4.7	21.2	37.6
Kknif(#)	0.226	0.024	0.068	0.342	21.7	4.8	20.2	44.9
LSD	0.0080**	0.0011**	0.0025*	0.0103*	ns	ns	ns	ns
0 kg K	0.221ab	0.024	0.066	0.333	21.5	4.6	20.5	36.4
50	0.222 b	0.024	0.066	0.341	20.9	4.8	20.4	43.2
100	0.212a	0.023	0.064	0.336	20.3	4.8	21.1	45.2
150	0.219ab	0.023	0.067	0.333	21.1	4.8	20.9	40.3
LSD	0.0094*	ns	ns	ns	ns	ns	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = applied in a band on the soil surface

\# = knifed at 15 cm depth

Table 21--Continued

	R083							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Ksurf(+)	0.191	0.025	0.064	0.322	18.2	4.0	33.2	48.5
Kknif(#)	0.191	0.024	0.065	0.345	17.8	4.0	34.7	45.8
LSD	ns	ns	ns	ns	ns	ns	1.27*	ns
0 kg K	0.189	0.024	0.064	0.323ab	17.6	4.0	33.4	38.3a
25	0.194	0.026	0.066	0.330ab	18.5	3.9	33.7	49.7ab
50	0.195	0.025	0.065	0.364 b	18.2	4.2	34.4	48.2ab
100	0.186	0.024	0.062	0.317a	17.8	4.1	34.3	52.5 b
LSD	ns	ns	ns	0.0418*	ns	ns	ns	12.80**

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = applied in a band on the soil surface

\# = knifed at 15 cm depth

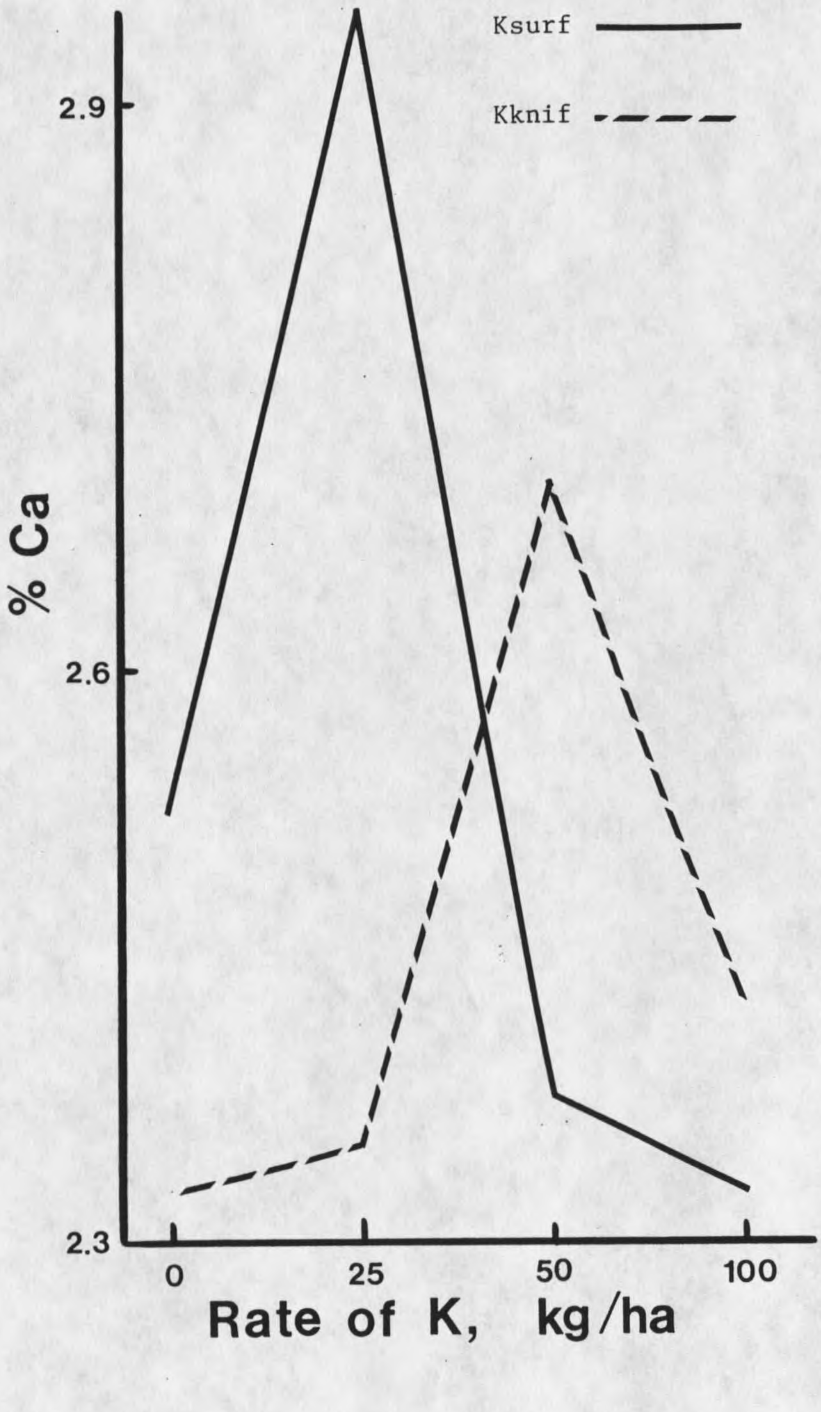

Figure 20. Interaction on percent Ca at R082 between placement and rate of K treatments.

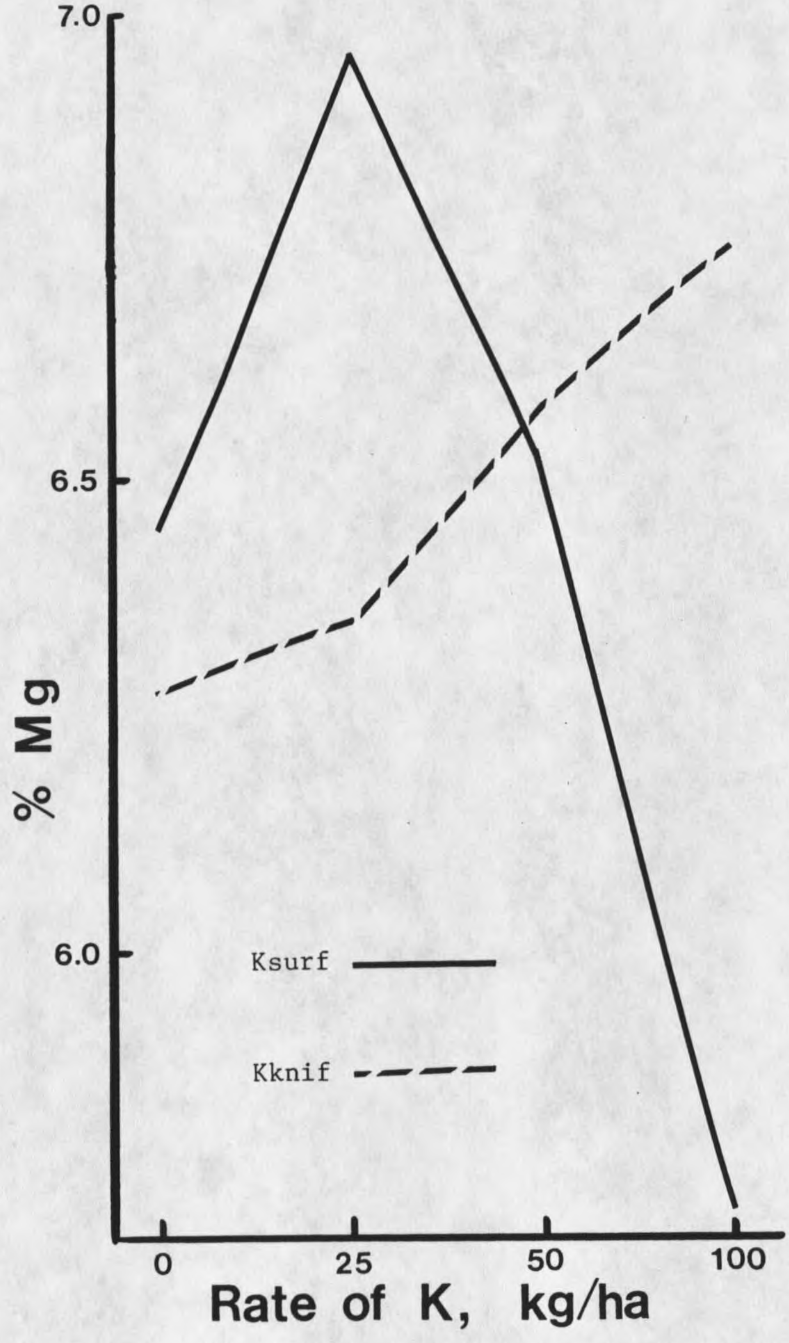

Figure 21. Interaction on percent Mg at R083 between placement and rate of K treatments.

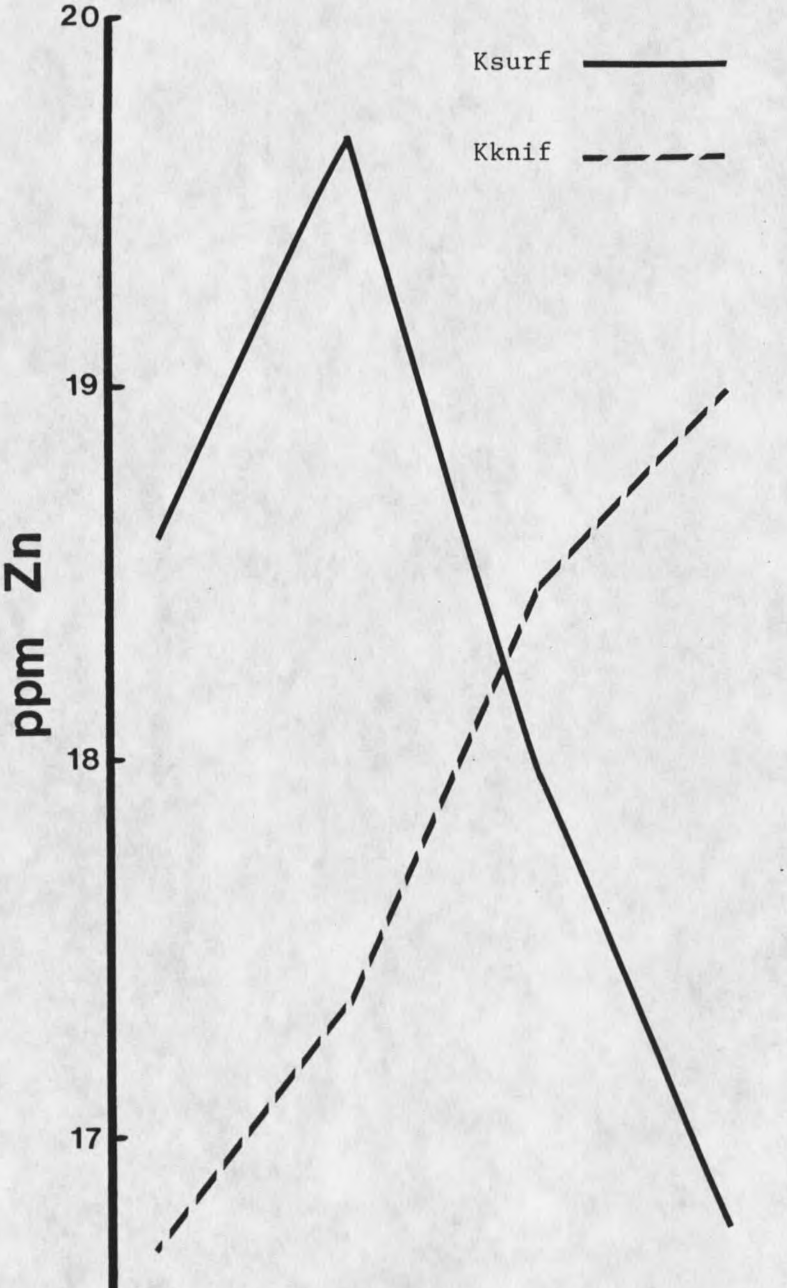

Figure 22. Interaction on ppm Zn at R083 between placement and rate of K treatments.

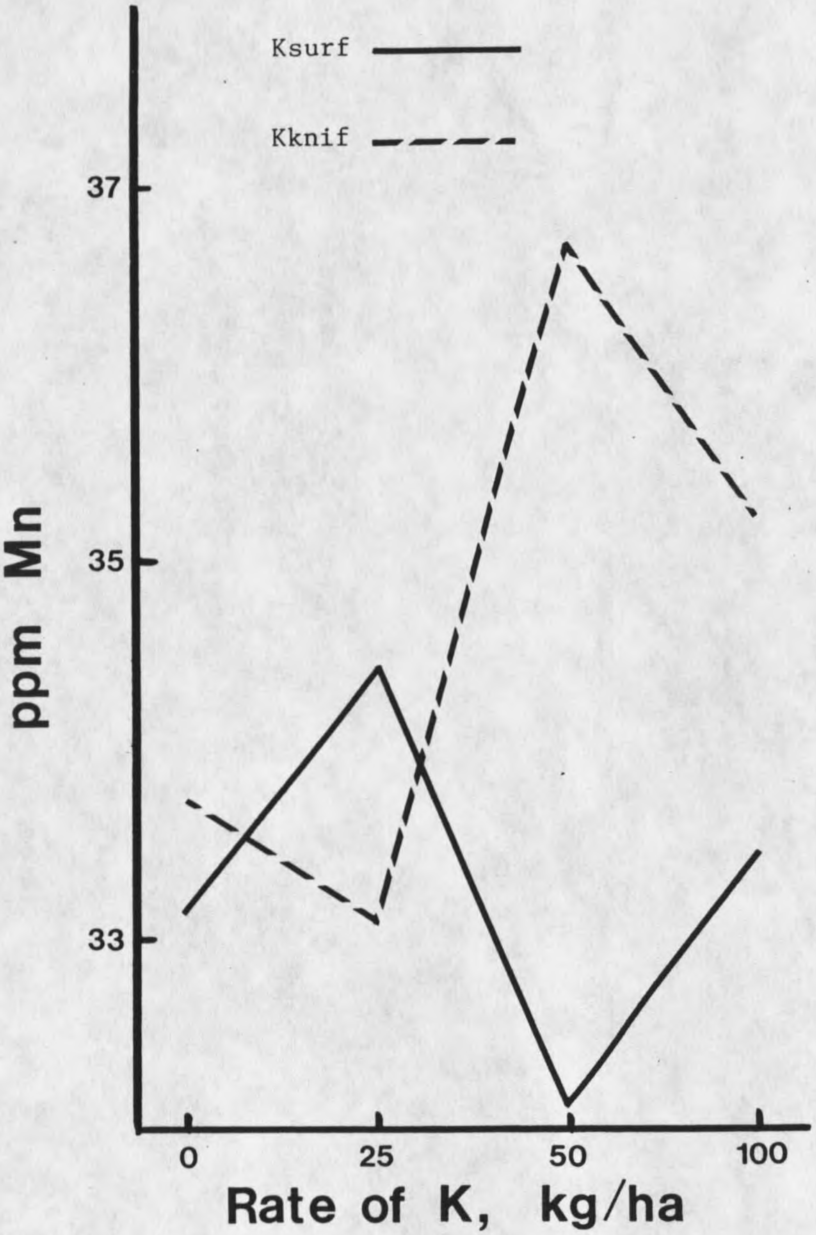

Figure 23. Interaction on ppm Mn at R083 between placement and rate of K treatments.

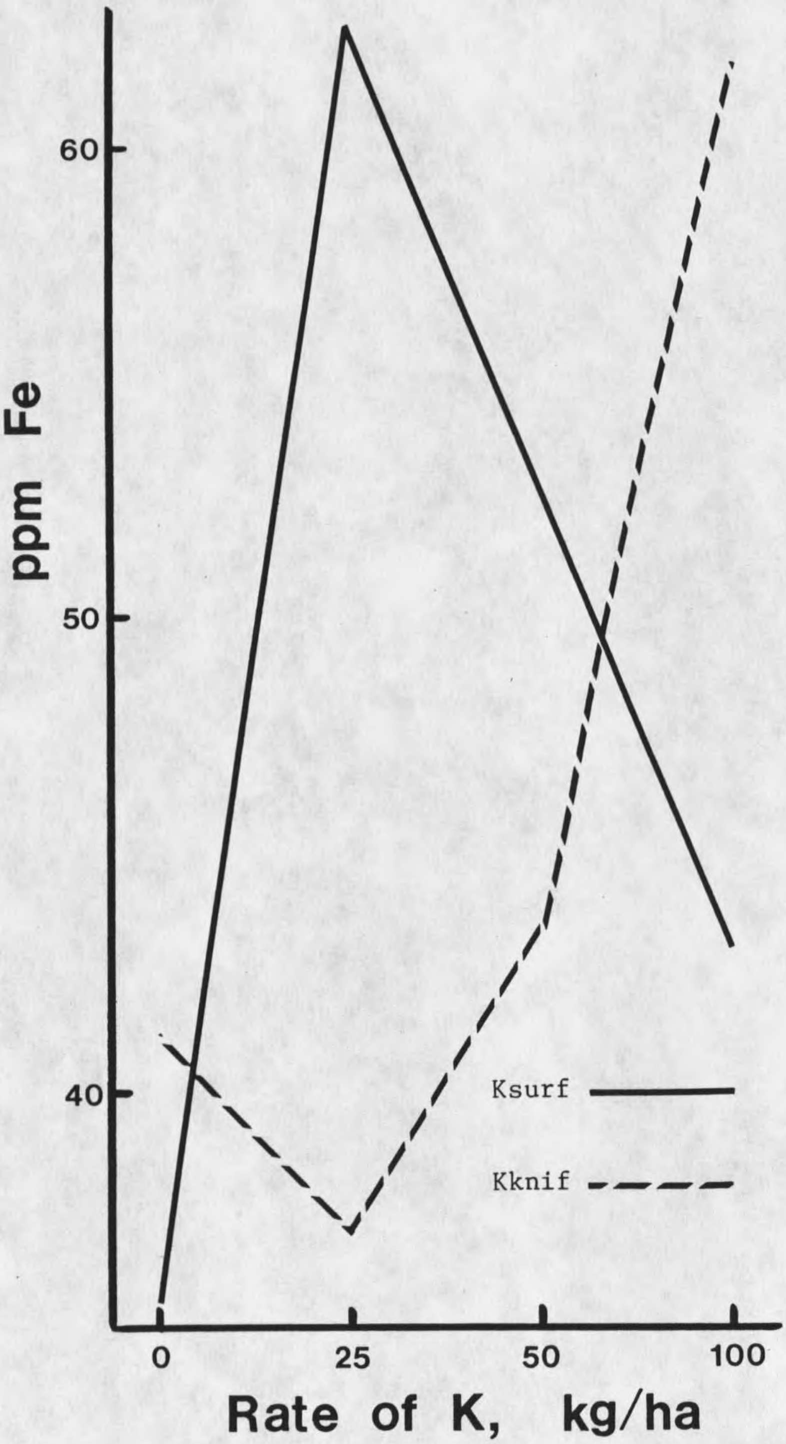

Figure 24. Interaction on ppm Fe at R083 between placement and rate of K treatments.

Table 22. Mineral composition of spring wheat from the 1982 and 1983 Chouteau County sites as affected by placement and rate of K.

	J082							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Ksurf(+)	0.198	0.012	0.072	0.383	39.8	4.6	51.5	53.6
Kknif(#)	0.200	0.011	0.072	0.369	39.5	4.6	50.8	57.7
LSD	ns	ns	ns	ns	ns	ns	ns	ns
0 kg K	0.203	0.011	0.073	0.365	39.5	4.6	50.1	57.7 b
25	0.199	0.010	0.072	0.373	38.9	4.6	50.7	50.4a
50	0.196	0.012	0.072	0.398	40.6	4.8	52.2	53.9ab
100	0.199	0.011	0.071	0.369	39.6	4.5	51.7	60.6 b
LSD	ns	ns	ns	ns	ns	ns	ns	7.14

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

+ = applied in a band on the soil surface

= knifed at 15 cm depth

Table 22--Continued

	J083							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Ksurf(+)	0.181	0.014	0.088	0.512	75.8	3.1	50.9	75.2
Kknif(#)	0.182	0.015	0.088	0.507	73.5	2.9	47.7	72.8
LSD	ns	ns	ns	ns	ns	ns	2.98*	ns
0 kg K	0.183	0.015	0.089	0.515	72.4	2.9	46.7	71.0
25	0.180	0.015	0.087	0.500	75.8	2.8	49.7	72.0
50	0.179	0.015	0.089	0.506	71.8	3.2	50.1	76.5
100	0.183	0.015	0.088	0.518	78.5	3.1	50.7	76.4
LSD	ns	ns	ns	ns	ns	ns	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = applied in a band on the soil surface

\# = knifed at 15 cm depth

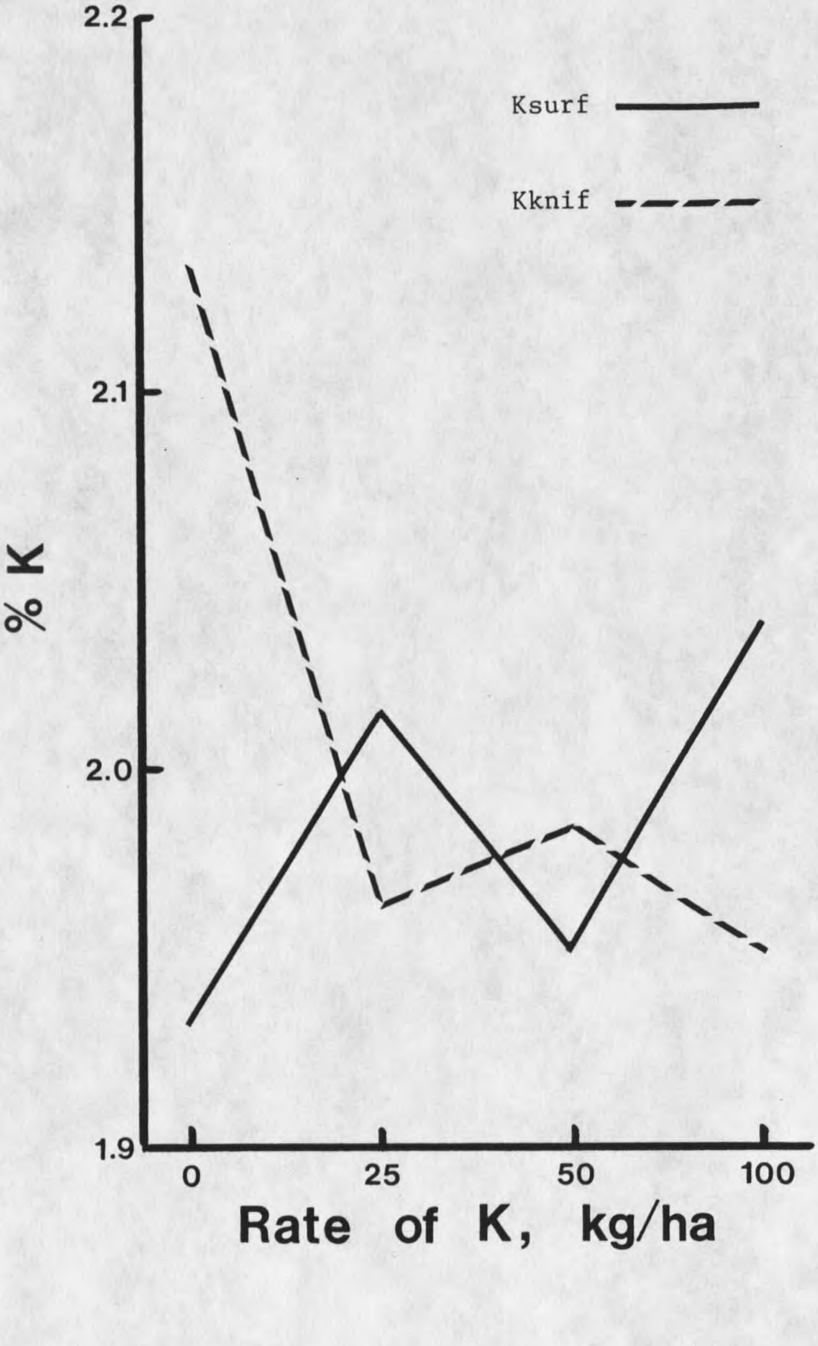

Figure 25. Interaction on percent K at J082 between placement and rate of K treatments.

Table 23. Soil test results and climatic data for barley sites.

		Location	
		PN82	PN83
(a) Soil Test Results			
NO_3-N	= 0-15cm	--	5
ppm	= 15-30	--	6
P	= 0-15cm	22	30
ppm	= 15-30	12	10
K	= 0-15cm	1363	750
ppm	= 15-30	583	325
pH	= 0-15cm	7.8	7.8
	15-30	7.8	7.8
EC	= 0-15cm	0.7	0.7
mmhos	= 15-30	0.8	0.8
OM	= 0-15cm	2.8	2.9
%	= 15-30	2.5	2.4
(b) Growing Season Precipitation (cm)			
April		--	0.66
May		9.22	3.40
June		7.85	7.70
July		1.68	9.60
	Total	18.75	21.36
(c) Monthly Average Temperature (F)			
April	(max)	--	55.2
	(min)	--	28.2
May	(max)	59.5	63.4
	(min)	37.3	38.0
June	(max)	71.6	72.1
	(min)	48.8	48.0
July	(max)	80.7	80.1
	(min)	52.8	51.5

The rate of N selected for the 1982 site was 180 kg N/ha, based on good soil moisture and high yield potential, as no analysis was performed in 1982. In practice, 216 kg N/ha were applied due to slower tractor ground speed than intended. In 1983, 120 kg N/ha were applied. In 1982, the liquid ammonium nitrate solution was banded with the seed, and in 1983 it was banded on the surface, in order to reduce the salt load near the seed. In 1982, 25 kg P/ha were applied to insure adequate P. In 1983, 20 kg P/ha were applied.

The rainfall distribution between the two years was considerably different, although the total rainfall was not. Rainfall distribution was relatively normal in 1982, with good moisture at seeding. Unfortunately, a hailstorm struck several days before harvest, causing an estimated 30% loss, and an increase in variability at this site. In 1983, drought-like conditions prevailed early in the season, with heavier rains coming in July, too late to have substantial impact on yield. However, the site had good soil moisture at seeding, which helped to offset the effects of the early dry period.

Yield, Test Weight and Protein

Form of nitrogen.

(1) PN82 site: Barley protein content and test weight both responded significantly to form of N (Table 24). Percentage protein was higher when anhydrous ammonia was used, as compared to ammonium nitrate, while test weight was lower. No response occurred due to rate of K analyzed as the second factor.

Table 24. Grain yield, test weight, and protein for barley sites as affected by form of N and rate of K.

Fertilizer	PN82			PN83		
	Yield (kg/ha)	Grain Prot (%)	Test Wt (lb/bu)	Yield (kg/ha)	Grain Prot (%)	Test Wt (lb/bu)
none(+)	1325	11.70	51.80	1163	10.90	51.60
AN(#)	2015	12.52	52.17	1865	11.28	51.52
NH_3(@)	1753	13.42	50.72	2367	11.35	51.17
LSD	ns	0.29**	0.73**	274**	ns	ns
0 kg K	1853	12.90	51.65	1976	11.20	50.90
25	1611	12.95	51.00	2086	11.00	50.95
50	2047	13.05	51.45	2258	11.30	51.75
100	2025	13.00	51.70	2142	11.75	51.80
LSD	ns	ns	ns	ns	ns	ns

* = significant at P < 0.10; ** = significant at P < 0.05; ns = not significant

\+ = check plots with no fertilization

\# = ammonium nitrate (AN)

@ = anhydrous ammonia (NH_3)

(2) PN83 site: Anhydrous ammonia produced a higher yield than did ammonium nitrate. Although the differences in test weight and protein are slight, due to form of N, they follow the trends set in 1982. Again, rate of K as the second factor produced no response.

Placement of phosphorus.

(1) PN82 site: Both yield and protein content of barley responded to placement of P fertilizer (Table 25). Yield was higher when P was knifed, while percentage protein was greater when P was banded with the seed. There were no responses at this site to rate of K analyzed as a second factor.

(2) PN83 site: Barley yield was significantly greater when P was banded, contrary to the result from PN82. Test weight was also greater with P applied in a band with the seed. There were no significant responses to rate of K.

Placement of potassium. At the PN83 site, knifed application of K produced significantly greater percentage protein and test weight in barley (Table 26). Barley yield, protein, and test weight did not respond to rate of K at either site.

Seedling Vigor

Form of nitrogen. Only dry weight per plant at PN82 responded to form of N (Table 27). Ammonium nitrate produced a higher dry weight per plant than did anhydrous ammonia. Seed vigor did not respond to rate of K analyzed as a second factor in the form of N comparison.

Table 25. Grain yield, test weight, and protein for barley sites as affected by placement of P and rate of K.

Fertilizer	PN82 Yield (kg/ha)	PN82 Grain Prot (%)	PN82 Test Wt (lb/bu)	PN83 Yield (kg/ha)	PN83 Grain Prot (%)	PN83 Test Wt (lb/bu)
none(+)	1325	11.70	51.80	1163	10.90	51.60
Pband(#)	1753	13.42	50.72	2367	11.35	51.17
Pknif(@)	2258	13.18	51.12	2142	11.52	49.83
LSD	280**	0.23**	ns	204**	ns	1.07**
0 kg K	2111	13.45	51.25	2138	11.75	50.05
25	1832	13.25	50.75	2337	11.25	50.70
50	1998	13.25	50.50	2266	11.20	50.90
100	2081	13.25	51.20	2276	11.55	50.35
LSD	ns	ns	ns	ns	ns	ns

* = significant at $P < 0.10$; ** = significant at $P < 0.05$; ns = not significant

\+ = check plots with no fertilization

\# = banded with the seed

@ = knifed at 15 cm depth

Table 26. Grain yield, test weight, and protein for barley sites as affected by placement and rate of K.

Fertilizer	PN82 Yield (kg/ha)	PN82 Grain Prot (%)	PN82 Test Wt (lb/bu)	PN83 Yield (kg/ha)	PN83 Grain Prot (%)	PN83 Test Wt (lb/bu)
none(+)	1325	11.70	51.80	1163	10.90	51.60
Ksurf(#)	2258	13.18	51.12	2142	11.52	49.83
Kknif(@)	2223	13.12	51.52	2597	12.00	51.45
LSD	ns	ns	ns	201**	ns	0.96**
0 kg K	2183	13.20	51.70	2371	12.10	50.35
25	2176	13.25	51.30	2377	11.65	51.30
50	2422	13.20	50.90	2395	11.80	50.15
100	2181	12.95	51.40	2333	11.50	50.75
LSD	ns	ns	ns	ns	ns	ns

* = significant at $P < 0.10$; ** = significant at $P < 0.05$; ns = not significant

\+ = check plots with no fertilization

\# = applied in a band on the soil surface

@ = knifed at 15 cm depth

Table 27. Seed vigor variables for spring barley sites as affected by form of N and rate of K.

	PN82		PN83	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
AN(+)	26.67	0.69	18.49	0.54
NH_3(#)	28.09	0.62	17.08	0.55
LSD	ns	0.0597**	ns	ns
0 kg K	28.85	0.67	18.21	0.52
25	27.40	0.63	17.39	0.57
50	27.61	0.67	18.76	0.56
100	25.66	0.63	16.77	0.54
LSD	ns	ns	ns	ns

* = significant at $P < 0.10$
** = significant at $P < 0.05$
ns = not significant
\+ = ammonium nitrate (AN)
\# = anhydrous ammonia (NH_3)

Placement of phosphorus. Speed of emergence index or dry weight per plant did not respond to placement of P at either site (Table 28). At the 1982 site, however, both variables responded to rate of K application. The pattern of response of the two variables is somewhat similar, with the highest vigor observed with no added K and 50 kg K/ha added. The lowest vigor occurred at the 25 kg K/ha addition.

Placement of potassium. Seed vigor did not respond to placement of K, but both response variables at the PN82 site showed significant effect due to rate of K (Table 29). However, the response of these variables did not follow a consistent pattern.

Table 28. Seed vigor variables for spring barley sites as affected by placement of P and rate of K.

	PN82		PN83	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
Pband(+)	28.09	0.62	17.08	0.55
Pknif(#)	28.64	0.66	18.07	0.50
LSD	ns	ns	ns	ns
0 kg K	29.93 b	0.68 b	16.20	0.55
25	25.56a	0.60a	17.86	0.53
50	29.27ab	0.68 b	17.62	0.47
100	28.69ab	0.61a	18.61	0.56
LSD	3.97**	0.0661*	ns	ns

* = significant at $P < 0.10$
** = significant at $P < 0.05$
ns = not significant
\+ = banded with the seed
\# = knifed at 15 cm depth

Mineral Composition

Form of nitrogen.

(1) PN82 site: Percentage Ca in the barley was greater when anhydrous ammonia was the form of N, as compared to ammonium nitrate (Table 30). Two micronutrients, Zn and Mn, were increased by form of N. Magnesium, Zn, and Fe were affected significantly by rate of K and

showed identical responses. Interactions occurred at this site for Zn and Fe between form of N and rate of K (Figures 26 and 27).

Table 29. Seed vigor variables for spring barley sites as affected by placement of K and rate of K.

	PN82		PN83	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
Ksurf(+)	28.64	0.66	18.07	0.50
Kknif(#)	27.70	0.69	18.15	0.52
LSD	ns	ns	ns	ns
0 kg K	30.94 b	0.69 b	17.42	0.54
25	24.45a	0.65a	18.06	0.53
50	29.89 b	0.72 c	17.26	0.44
100	27.40ab	0.64a	19.69	0.54
LSD	4.42**	0.0090*	ns	ns

* = significant at $P < 0.10$
** = significant at $P < 0.05$
ns = not significant
\+ = applied in a band on the soil surface
\# = knifed at 15 cm depth

(2) PN83 site: None of the minerals in the grain from this site were different in concentration due to form of N. Zinc and Fe levels in the barley were both affected by rate of K. The pattern of each response was similar. Significant interactions occurred between form of N and rate of K for percentage P and Fe (Figures 28 and 29).

Table 30. Mineral composition of barley from the 1982 and 1983 Cascade County sites as affected by form of N and rate of K.

	PN82							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
AN(+)	0.243	0.020	0.071	0.398	27.1	10.9	15.9	54.7
NH_3(#)	0.250	0.022	0.070	0.384	31.9	11.0	17.3	54.6
LSD	ns	0.0011**	ns	ns	2.98**	ns	0.90**	ns
0 kg K	0.247	0.021	0.070ab	0.389	29.1ab	10.7	16.9	54.9ab
25	0.258	0.021	0.074 b	0.399	32.9 b	11.3	16.6	58.3 b
50	0.238	0.020	0.070ab	0.394	28.8ab	10.9	16.5	53.8ab
100	0.243	0.020	0.068a	0.383	27.1a	10.8	16.4	51.7a
LSD	ns	ns	0.0048**	ns	4.22**	ns	ns	5.58**

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = ammonium nitrate (AN)

\# = anhydrous ammonia (NH_3)

Table 30--Continued

	PN83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
AN(+)	0.246	0.026	0.071	0.455	43.5	8.7	18.5	61.6
NH_3(#)	0.238	0.026	0.071	0.457	37.2	8.6	19.0	56.7
LSD	ns	ns	ns	ns	ns	ns	ns	ns
0 kg K	0.244	0.026	0.071	0.454	34.1a	8.1	17.9	56.2a
25	0.244	0.026	0.073	0.465	41.0ab	9.1	19.3	57.5a
50	0.242	0.025	0.071	0.456	48.6 b	9.1	19.0	65.1 b
100	0.237	0.027	0.070	0.449	37.9ab	8.4	18.7	57.9ab
LSD	ns	ns	ns	ns	12.12**	ns	ns	7.46*

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = ammonium nitrate (AN)

\# = anhydrous ammonia (NH_3)

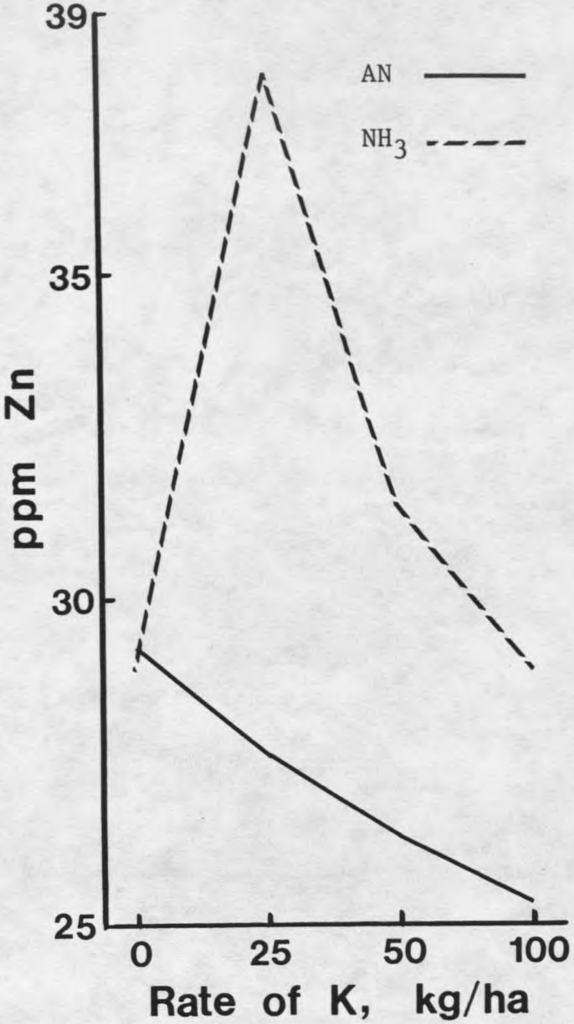

Figure 26. Interaction on ppm Zn at PN82 between form of N and rate of K treatments.

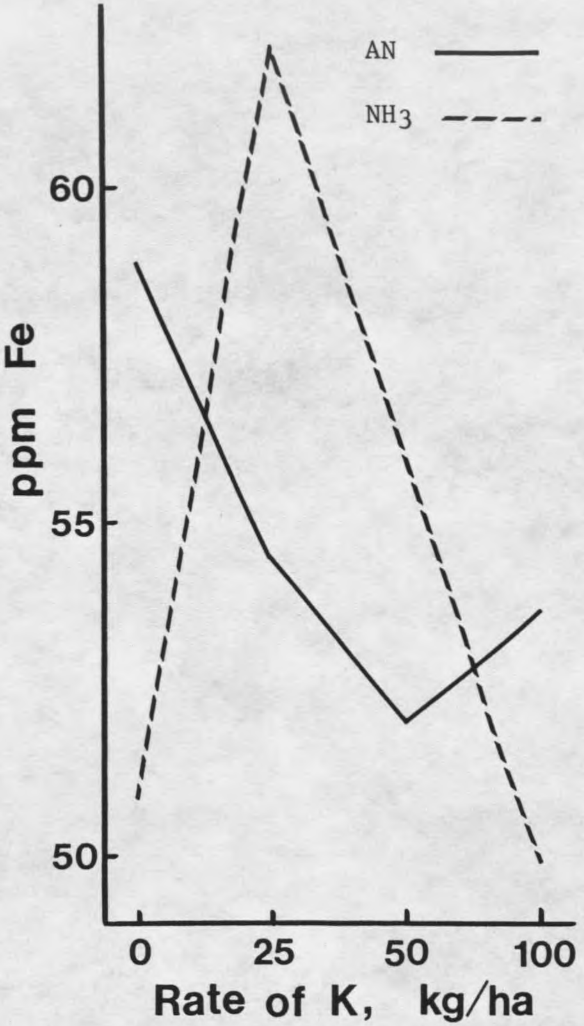

Figure 27. Interaction on ppm Fe at PN82 between form of N and rate of K treatments.

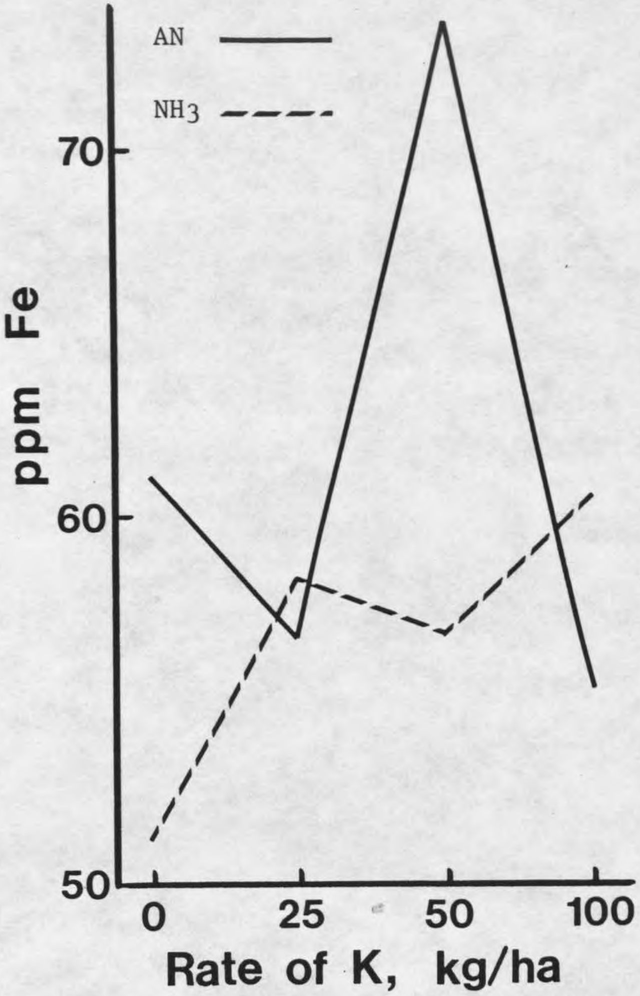

Figure 28. Interaction on percent P at PN83 between form of N and rate of K treatments.

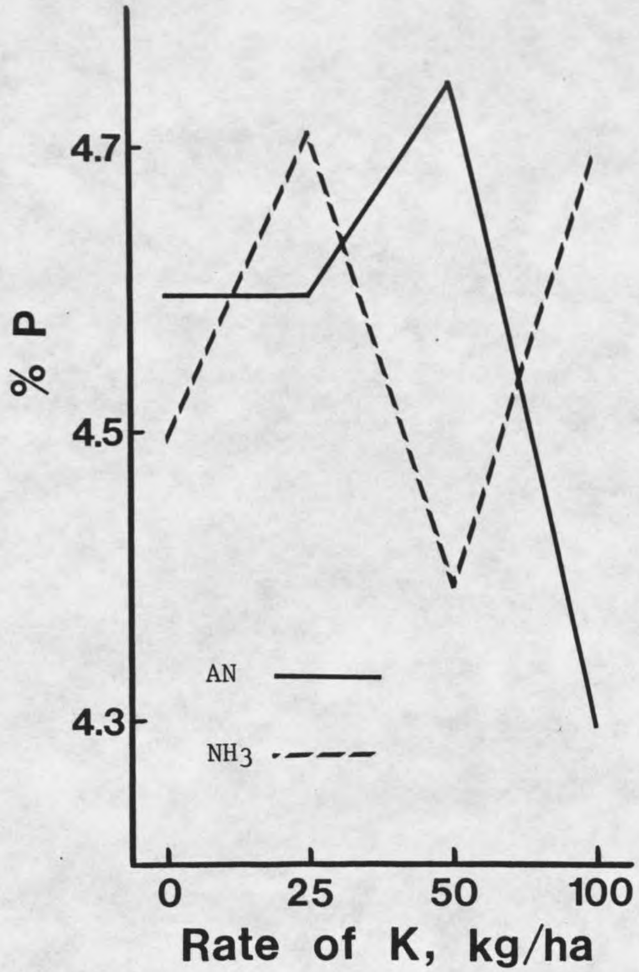

Figure 29. Interaction on ppm Fe at PN83 between form of N and rate of K treatments.

Placement of phosphorus.

(1) PN82 site: Percentage Mg was the only nutrient affected by placement of P (Table 31). Magnesium concentration was significantly greater when P was knifed as compared to banded with the seed. Rate of K produced significant effects on K and Fe in the barley. A pattern of response with increasing K application was very similar between these two nutrients. Significant interaction occurred between placement of P and rate of K for ppm Fe (Figure 30).

(2) PN83 site: Knifed application of P increased Ca, Zn, Cu, and Fe in the barley. Each of the other nutrients studied responded the same, although the differences were not significant. Zinc and Fe were significantly affected by rate of K.

Placement of potassium.

(1) PN82 site: Magnesium in barley from this site was higher when K was surface applied (Table 32). Rate of K significantly affected the K, Cu, and Fe levels in the grain. The pattern of response was similar for Cu and Fe. Significant interactions occurred for K, P, and Fe between placement and rate of K (Figures 31, 32, and 33, respectively).

(2) PN83 site: Surface application of K produced significantly higher levels of Ca and Cu in the barley. Each of the other nutrients analyzed were similarly affected, although the differences were not significant. Calcium, Zn, and Fe levels in the barley were affected by rate of K.

Table 31. Mineral composition of barley from the 1982 and 1983 Cascade County sites as affected by placement of P and rate of K.

	PN82							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Pband(+)	0.250	0.021	0.069	0.384	31.8	11.0	17.3	54.6
Pknif(#)	0.253	0.022	0.074	0.399	34.9	10.5	16.6	57.1
LSD	ns	ns	0.0037**	ns	ns	ns	ns	ns
0 kg K	0.252ab	0.022	0.073	0.394	31.5	10.4	17.2	49.3a
25	0.260 b	0.022	0.074	0.396	34.1	10.4	16.3	60.9 b
50	0.255 b	0.022	0.072	0.394	36.3	11.2	17.5	65.7 b
100	0.240a	0.021	0.070	0.382	31.7	11.1	16.7	51.6a
LSD	0.0139**	ns	ns	ns	ns	ns	ns	8.19**

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = banded with the seed

\# = knifed at 15 cm depth

Table 31--Continued

	PN83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Pband(+)	0.238	0.026	0.071	0.457	37.2	8.6	19.0	56.7
Pknif(#)	0.257	0.029	0.077	0.484	47.1	10.0	20.1	65.1
LSD	ns	0.0029*	ns	ns	8.69*	1.447**	ns	6.53**
0 kg K	0.237	0.026	0.071	0.452	41.9ab	8.6	18.9	56.3a
25	0.242	0.027	0.073	0.462	47.7 b	9.6	19.8	63.3ab
50	0.266	0.030	0.079	0.497	46.2 b	9.5	19.5	65.3 b
100	0.245	0.027	0.073	0.472	33.0a	9.7	20.0	59.8ab
LSD	ns	ns	ns	ns	12.29*	ns	ns	7.65*

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = banded with the seed

\# = knifed at 15 cm depth

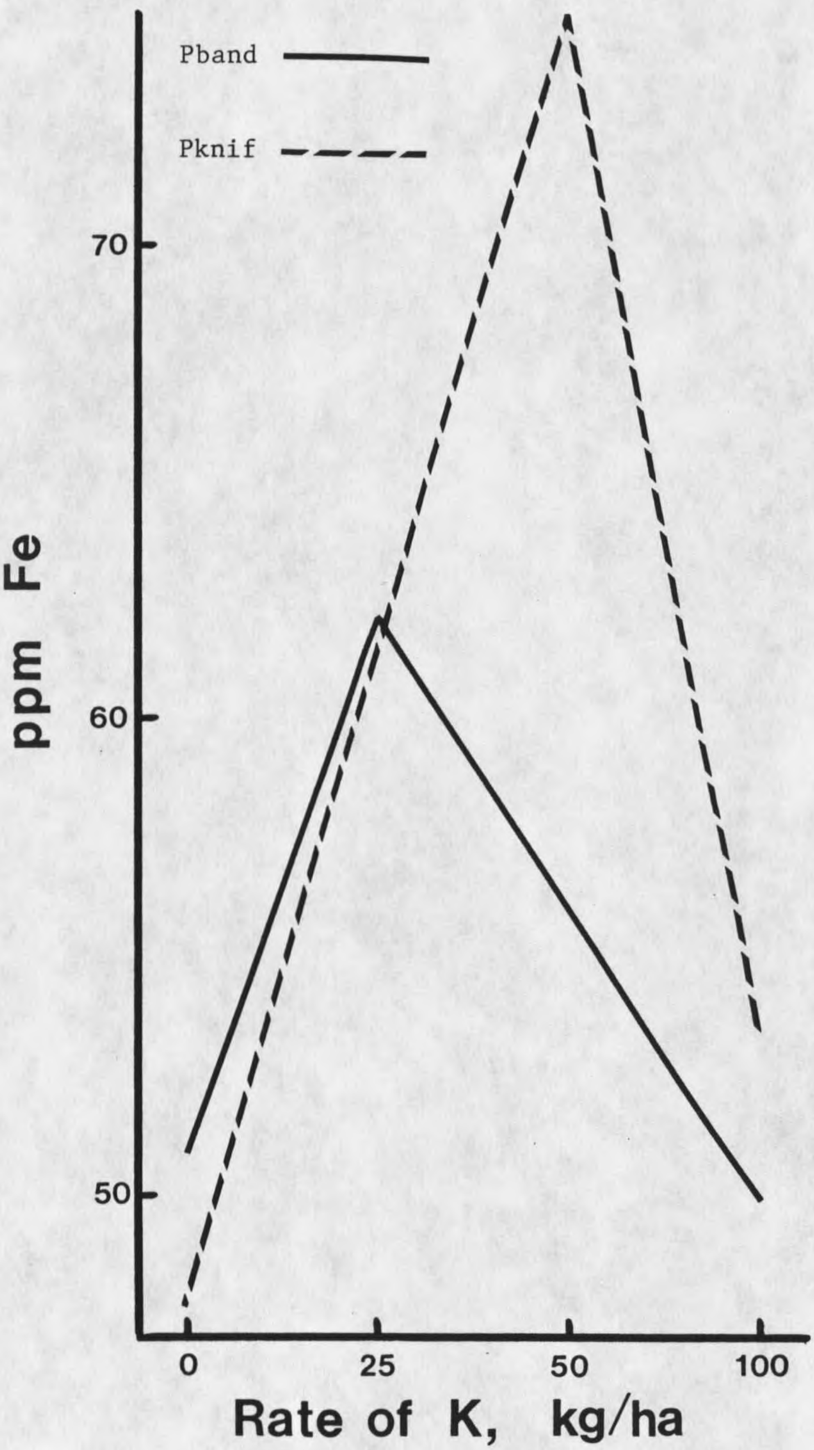

Figure 30. Interaction on ppm Fe at PN82 between placement of P and rate of K treatments.

Table 32. Mineral composition of barley from the 1982 and 1983 Cascade County sites as affected by placement and rate of K.

	PN82							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Ksurf[+]	0.253	0.022	0.074	0.399	34.9	10.5	16.6	59.1
Kknif[#]	0.247	0.022	0.069	0.389	37.1	11.1	16.2	55.9
LSD	ns	ns	0.0037**	ns	ns	ns	ns	ns
0 kg K	0.244ab	0.021	0.072	0.387	41.3	10.5ab	16.3	55.9ab
25	0.258 b	0.022	0.073	0.405	29.7	10.0a	15.7	54.4a
50	0.256ab	0.022	0.072	0.396	40.6	11.5 b	17.0	65.3 b
100	0.243a	0.022	0.070	0.387	32.5	11.3ab	16.7	54.4a
LSD	0.0131*	ns	ns	ns	ns	1.32*	ns	9.38*

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = applied in a band on the soil surface

\# = knifed at 15 cm depth

Table 32--Continued

	PN83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Ksurf(+)	0.257	0.029	0.077	0.484	47.1	10.0	20.1	65.1
Kknif(#)	0.238	0.026	0.071	0.455	40.1	8.4	19.6	60.4
LSD	ns	0.0029*	ns	ns	ns	0.641**	ns	ns
0 kg K	0.235	0.026a	0.071	0.447	43.3ab	9.2	19.9	57.2a
25	0.241	0.027ab	0.073	0.460	53.1 b	9.5	19.6	65.9 bc
50	0.270	0.031 b	0.081	0.505	40.2a	9.0	20.3	69.6 c
100	0.244	0.026ab	0.072	0.467	38.0a	9.3	19.7	58.3ab
LSD	ns	0.0042*	ns	ns	12.51*	ns	ns	8.43**

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = applied in a band on the soil surface

\# = knifed at 15 cm depth

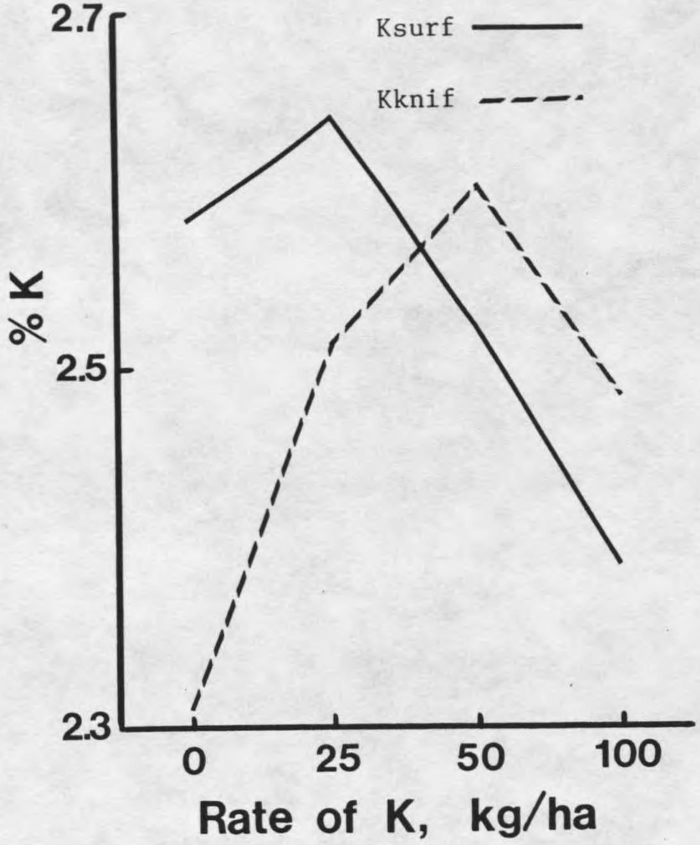

Figure 31. Interaction on percent K at PN82 between placement and rate of K treatments.

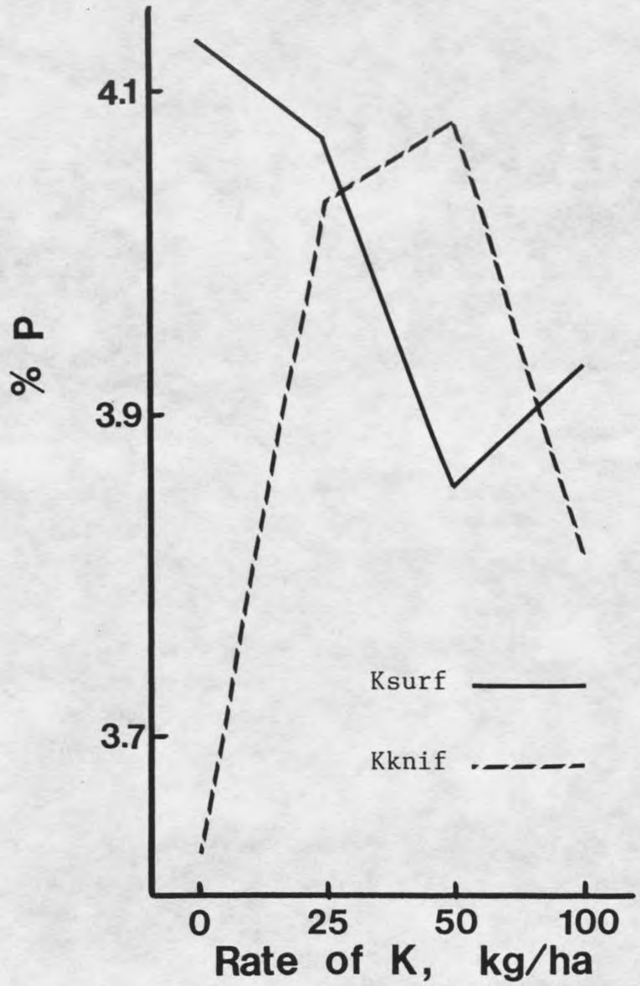

Figure 32. Interaction on percent P at PN82 between placement and rate of K treatments.

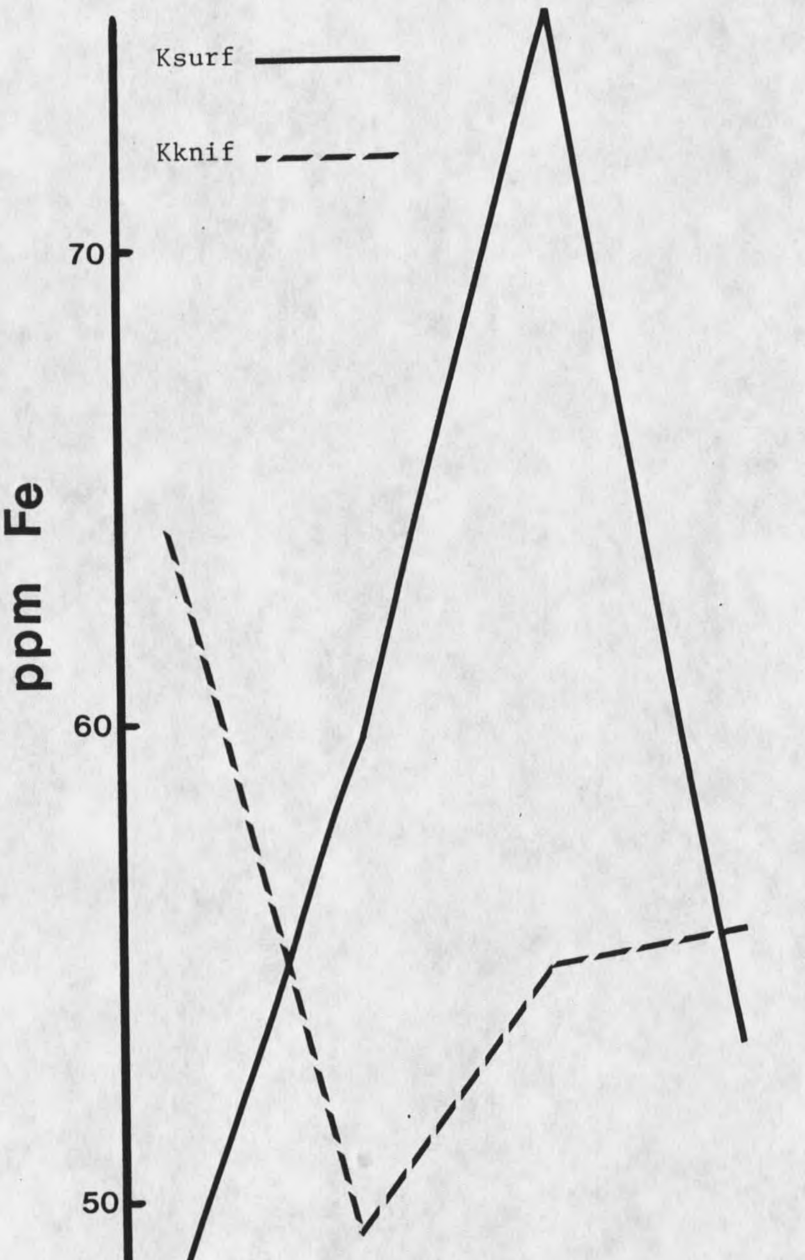

Figure 33. Interaction on ppm Fe at PN82 between placement and rate of K treatments.

Winter Wheat

Soil Test Results and Climatic Data

Soil test results and climatic data for the 1983 Lake (VV83) and Flathead (WG83) County sites are presented in Table 33. The levels of N and P fertilizers applied were based in part on soil test results. Both of these sites had good soil nutrient status. For both sites, the rates of application were 100 kg N/ha and 30 kg P/ha. The liquid ammonium nitrate solution was banded on the surface.

The amount and distribution of rainfall at these sites was much better than other 1983 sites previously discussed. Soil moisture at seeding was high and winter moisture storage was good. As a result of these excellent moisture conditions and good fertility, highest yields for these sites were very good.

Yield, Test Weight and Protein

Form of nitrogen. Yield and test weight at the WG83 site were greater when ammonium nitrate was the form of N, while grain protein was lower (Table 34). These variables did not respond to rate of K. Yields of winter wheat, as with spring wheat, trended higher with ammonium nitrate, although not all responses were significant.

Placement of phosphorus. Yield responded significantly at the VV83 site to rate of K, although there was no response to placement of P (Table 35). However, at the WG83 site, test weight was greater when P was knifed as compared to banded and there were no responses to rate of K.

Table 33. Soil test results and climatic data for winter wheat sites.

		Location	
		VV83	WG83
(a)	Soil Test Results		
	NO_3-N = 0-15cm	55	33
	ppm = 15-30	10	13
	P = 0-15cm	12.3	18.2
	ppm = 15-30	2.4	3.1
	K = 0-15cm	478	374
	ppm = 15-30	432	238
	pH = 0-15cm	5.8	6.6
	15-30	7.0	7.9
	EC = 0-15cm	0.9	0.8
	mmhos = 15-30	0.6	0.9
	OM = 0-15cm	5.1	5.3
	% = 15-30	2.8	3.4
(b)	Growing Season Precipitation (cm)		
	April	2.36	5.54
	May	4.70	1.98
	June	8.48	7.85
	July	5.73	5.23
	Total	21.27	20.60
(c)	Monthly Average Temperature (F)		
	April (max)	57.2	55.9
	(min)	34.7	28.6
	May (max)	68.4	66.3
	(min)	42.7	36.6
	June (max)	73.1	69.8
	(min)	48.0	44.7
	July (max)	76.0	73.8
	(min)	50.3	48.5

Table 34. Grain yield, test weight, and protein for winter wheat sites as affected by form of N and rate of K.

Fertilizer	VV83 Yield (kg/ha)	VV83 Grain Prot (%)	VV83 Test Wt (lb/bu)	WG83 Yield (kg/ha)	WG83 Grain Prot (%)	WG83 Test Wt (lb/bu)
none (+)	4321	8.90	61.00	5150	7.70	58.80
AN (#)	5457	9.27	60.40	6657	8.10	57.90
NH_3 (@)	5423	9.75	60.42	6423	8.75	55.10
LSD	ns	ns	ns	232**	0.61**	1.50**
0 kg K	5119	9.55	60.60	6460	8.80	55.60
25	5629	10.05	60.65	6477	8.30	57.05
50	5671	9.30	60.35	6558	8.35	57.25
100	5340	9.15	60.05	6666	8.25	56.10
LSD	ns	ns	ns	ns	ns	ns

* = significant at $P < 0.10$; ** = significant at $P < 0.05$; ns = not significant

\+ = check plots with no fertilization

\# = ammonium nitrate (AN)

@ = anhydrous ammonia (NH_3)

Table 35. Grain yield, test weight, and protein for winter wheat sites as affected by placement of P and rate of K.

	VV83			WG83		
Fertilizer	Yield (kg/ha)	Grain Prot (%)	Test Wt (lb/bu)	Yield (kg/ha)	Grain Prot (%)	Test Wt (lb/bu)
none(+)	4321	8.90	61.00	5150	7.70	58.80
Pband(#)	5432	9.75	60.42	6423	8.75	55.10
Pknif(@)	5716	10.25	60.65	6693	9.17	56.70
LSD	ns	ns	ns	ns	ns	1.56**
0 kg K	5236a	10.05	60.65	6426	8.95	55.10
25	5349ab	10.40	60.70	6324	9.30	55.45
50	6015 b	10.00	60.30	6565	8.75	56.45
100	5678ab	9.55	60.50	6917	8.85	56.60
LSD	698**	ns	ns	ns	ns	ns

* = significant at P < 0.10; ** = significant at P < 0.05; ns = not significant

\+ = check plots with no fertilization

\# = banded with the seed

@ = knifed at 15 cm depth

Placement of potassium. At the VV83 site, grain protein was greater when K was surface applied, as compared to knifed (Table 36). Both yield and test weight responded to rate of K at this site, but these responses were not consistent. The data suggest that yields are greater and test weights lower when K is knifed, although all of the differences are not significant. The differences were not large enough to conclude an advantage for yield of knifed K.

Seedling Vigor

Form of nitrogen. Speed of emergence index at the VV83 site responded significantly to rate of K, with increased speed of emergence at 50 kg K/ha (Table 37), although there were no responses to form of N. At the WG83 site, both variables responded to rate of K, but the responses were not consistent. Form of N did not produce any effect.

Placement of phosphorus. Speed of emergence index responded significantly to rate of K at the 1983 Lake County site (VV83) (Table 38). There were no other significant responses.

Placement of potassium. Dry weight per plant at the VV83 site was greater when K was knifed as compared to surface application (Table 39), while at the WG83 site there were no responses to placement of K. Dry weight per plant responded significantly to rate of K application at the WG83 site.

Table 36. Grain yield, test weight, and protein for winter wheat sites as affected by placement and rate of K.

Fertilizer	VV83			WG83		
	Yield (kg/ha)	Grain Prot (%)	Test Wt (lb/bu)	Yield (kg/ha)	Grain Prot (%)	Test Wt (lb/bu)
none(+)	4321	8.90	61.00	5150	7.70	58.80
Ksurf(#)	5716	10.25	60.65	6693	9.17	56.70
Kknif(@)	5866	9.97	60.58	7364	8.97	56.73
LSD	ns	0.22*	ns	ns	ns	ns
0 kg K	5652ab	10.15	60.85 c	6643	9.25	56.40
25	5652ab	10.10	60.50ab	6536	9.30	56.35
50	6465 b	10.00	60.35a	8112	8.70	56.90
100	5393a	10.20	60.75 bc	6822	9.05	57.20
LSD	876*	ns	0.32**	ns	ns	ns

* = significant at P < 0.10; ** = significant at P < 0.05; ns = not significant

\+ = check plots with no fertilization

\# = applied in a band on the soil surface

@ = knifed at 15 cm depth

Table 37. Seed vigor variables for winter wheat sites as affected by form of N and rate of K.

	VV83		WG83	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
AN(+)	23.37	0.28	18.71	0.22
NH_3(#)	21.06	0.25	18.29	0.21
LSD	ns	ns	ns	ns
0 kg K	21.03a	0.26	19.19ab	0.24 b
25	20.55a	0.27	16.33a	0.22ab
50	26.90 b	0.29	17.53a	0.21ab
100	20.38a	0.25	20.96 b	0.20a
LSD	5.81*	ns	3.33**	0.0273*

* = significant at $P < 0.10$
ns = not significant
\# = anhydrous ammonia (NH_3)
** = significant at $P < 0.05$
\+ = ammonium nitrate (AN)

Table 38. Seed vigor variables for winter wheat sites as affected by placement of P and rate of K.

	VV83		WG83	
Fertilizer	SEI	D Wt/ Plant (mg)	SEI	D Wt/ Plant (mg)
Pband(+)	21.06	0.25	18.23	0.21
Pknif(#)	19.96	0.25	18.56	0.22
LSD	ns	ns	ns	ns
0 kg K	21.14ab	0.27	19.83	0.21
25	16.66a	0.24	17.61	0.23
50	24.85 b	0.26	16.84	0.21
100	19.39ab	0.26	19.31	0.21
LSD	6.01**	ns	ns	ns

* = significant at $P < 0.10$
ns = not significant
\# = knifed at 15 cm depth
** = significant at $P < 0.05$
\+ = banded with the seed

Table 39. Seed vigor variables for winter wheat sites as affected by placement and rate of K.

Fertilizer	VV83 SEI	VV83 D Wt/ Plant (mg)	WG83 SEI	WG83 D Wt/ Plant (mg)
Ksurf(+)	19.96	0.26	18.56	0.22
Kknif(#)	23.76	0.30	20.23	0.23
LSD	ns	0.0349*	ns	ns
0 kg K	24.80	0.28	20.59	0.22ab
25	20.98	0.26	17.87	0.24 b
50	21.89	0.27	19.67	0.20a
100	19.77	0.29	19.44	0.24 b
LSD	ns	ns	ns	0.0328**

* = significant at $P < 0.10$ ** = significant at $P < 0.05$
ns = not significant
\+ = applied in a band on the soil surface
\# = knifed at 15 cm depth

Mineral Composition

Form of nitrogen.

(1) VV83 site: Zinc was the only variable which responded to form of N (Table 40). The level of Zn in the grain was higher when anhydrous ammonia as the form of N, as compared to ammonium nitrate. None of the minerals responded to rate of K at this site.

(2) WG83 site: Calcium, Zn, Mn, and Fe were higher when anhydrous ammonia was the form of N, which is in agreement with the result from the VV83 site. These same nutrients responded to rate of K, although the responses were not as consistent. Significant interaction occurred for Fe between form of N and rate of K (Figure 34).

Table 40. Mineral composition of winter wheat as affected by form of N and rate of K.

	VV83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
AN(+)	0.157	0.012	0.062	0.275	23.1	3.2	31.7	46.9
NH_3(#)	0.152	0.012	0.061	0.271	25.5	3.1	33.3	50.6
LSD	ns	ns	ns	ns	2.04**	ns	ns	ns
0 kg K	0.158	0.013	0.065	0.281	25.5	2.9	32.3	48.6
25	0.154	0.012	0.061	0.267	24.6	3.2	33.3	47.9
50	0.154	0.012	0.061	0.269	23.8	3.3	32.5	49.2
100	0.152	0.011	0.059	0.275	23.1	3.1	31.8	49.3
LSD	ns	ns	ns	ns	ns	ns	ns	ns

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = ammonium nitrate (AN)

\# = anhydrous ammonia (NH_3)

Table 40--Continued

	WG83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
AN(+)	0.192	0.018	0.047	0.320	13.7	1.9	27.9	38.5
NH_3(#)	0.1905	0.020	0.047	0.324	16.9	2.1	31.8	50.0
LSD	ns	0.0012*	ns	ns	2.90**	ns	2.67**	6.90**
0 kg K	0.192	0.021 b	0.049	0.331	18.3 b	2.1	30.1ab	41.4a
25	0.194	0.020ab	0.049	0.326	14.4ab	2.2	30.2ab	38.5a
50	0.186	0.018a	0.046	0.315	14.1a	1.8	27.8a	40.9a
100	0.191	0.019ab	0.045	0.316	14.5ab	1.9	31.2 b	56.0 b
LSD	ns	0.0020**	ns	ns	4.10**	ns	3.12*	9.76**

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = ammonium nitrate (AN)

\# = anhydrous ammonia (NH_3)

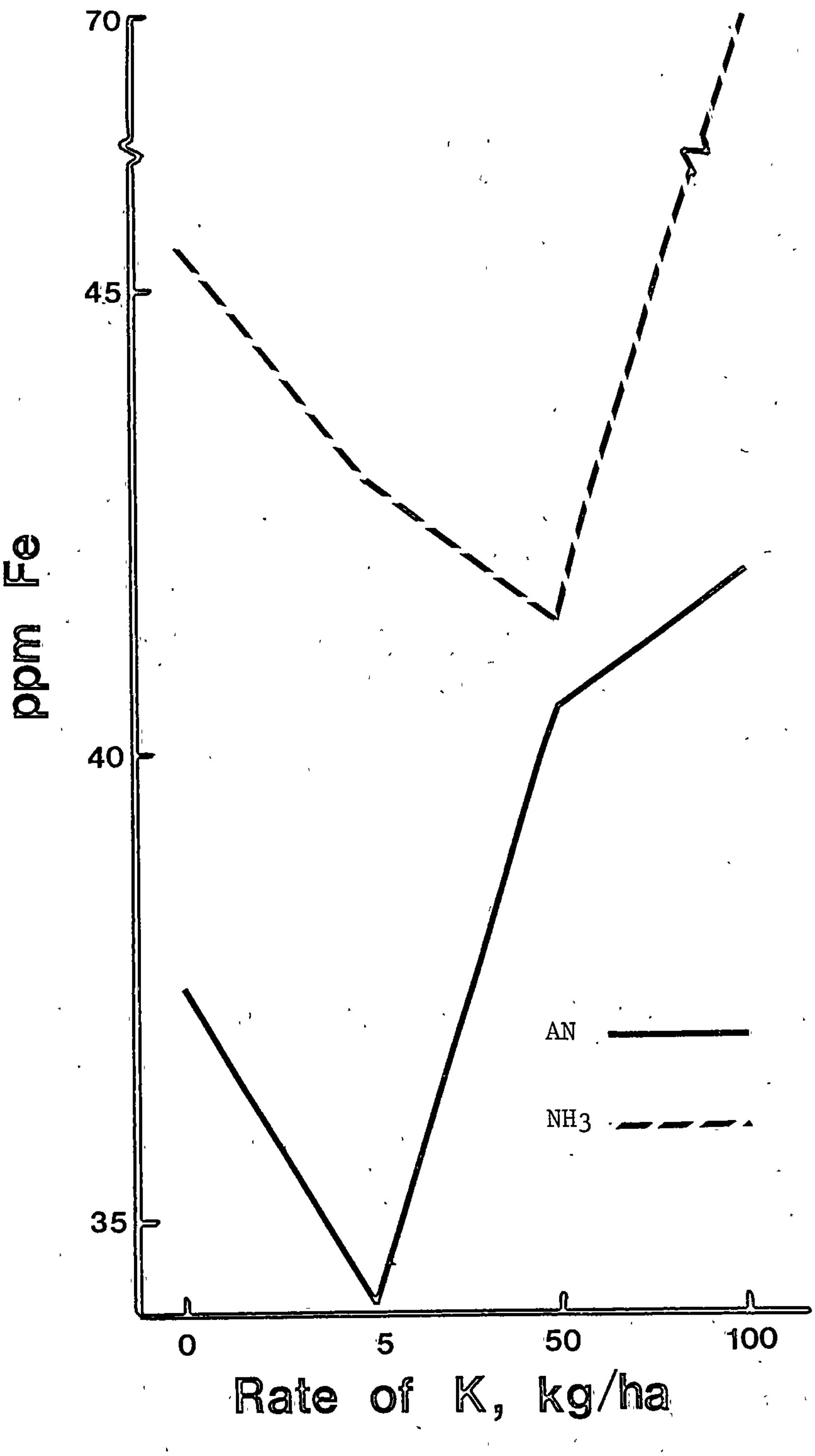

Figure 34. Interaction on ppm Fe at WG83 between form of N and rate of K treatments.

Placement of phosphorus.

(1) VV83 site: Manganese was higher when P was knifed (Table 41) as compared to banded with the seed. The other nutrients tended to follow this trend, although the differences were not significant. Percentage Mg and ppm Zn responded significantly to rate of K.

(2) WG83 site: Banded application of P produced a significantly higher level of Fe in the grain than did knifed application. Concentrations of P, Zn, and Fe responded significantly to rate of K. Significant interaction occurred between placement of P and rate of K for Fe (Figure 35).

Placement of potassium.

(1) VV83 site: Concentration of Cu in the grain was greater when K was surface applied (Table 42). Magnesium and Cu levels were affected significantly by rate of K.

(2) WG83 site: Mineral composition was not affected at this site due to placement of K. Rate of K significantly increased Cu in the grain. Figure 36 presents the significant interaction observed for ppm Zn between placement of K and rate of K.

Table 41. Mineral composition of winter wheat as affected by placement of P and rate of K.

	VV83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Pband(+)	0.152	0.012	0.061	0.271	25.4	3.1	33.3	50.6
Pknif(#)	0.158	0.012	0.063	0.288	27.1	3.2	36.4	54.7
LSD	ns	ns	ns	ns	ns	ns	2.55**	ns
0 kg K	0.160	0.013	0.066 b	0.288	28.4 b	3.0	34.1	53.9
25	0.150	0.011	0.060a	0.262	26.1ab	3.1	34.9	52.2
50	0.158	0.013	0.061ab	0.281	25.9ab	3.3	35.7	54.9
100	0.153	0.012	0.061ab	0.287	24.7a	3.2	34.5	49.7
LSD	ns	ns	0.0053*	ns	3.05*	ns	ns	ns

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = banded with the seed

\# = knifed at 15 cm depth

Table 41--Continued

	WG83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Pband(+)	0.190	0.020	0.047	0.324	16.9	2.1	31.8	50.0
Pknif(#)	0.190	0.023	0.053	0.318	15.2	1.8	31.1	40.8
LSD	ns	ns	ns	ns	ns	ns	ns	6.23**
0 kg K	0.191	0.022	0.052	0.326ab	19.1 b	1.8	32.2	45.7a
25	0.189	0.024	0.053	0.310a	14.6a	2.2	31.3	39.3a
50	0.190	0.019	0.049	0.328 b	15.1a	1.7	29.6	41.6a
100	0.191	0.020	0.046	0.320ab	15.5ab	2.0	32.6	54.8 b
LSD	ns	ns	ns	0.0175*	3.98**	ns	ns	08.82**

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = banded with the seed

\# = knifed at 15 cm depth

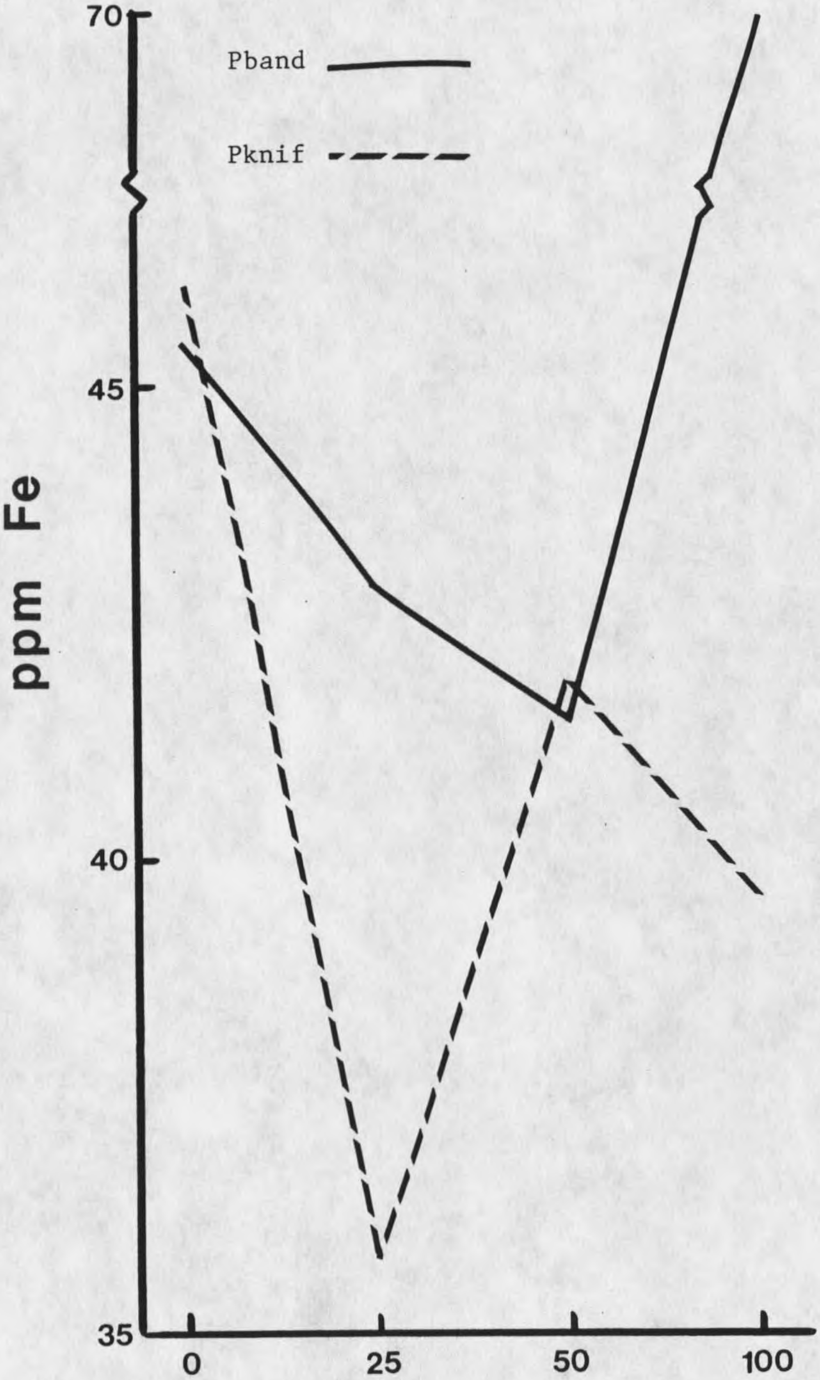

Figure 35. Interaction on ppm Fe at WG83 between placement of P and rate of K treatments.

Table 42. Mineral composition of winter wheat as affected by placement and rate of K.

	VV83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Ksurf(+)	0.158	0.012	0.063	0.288	27.1	3.2	36.4	54.7
Kknif(#)	0.155	0.013	0.062	0.277	26.2	2.9	35.9	56.1
LSD	ns	ns	ns	ns	ns	0.228**	ns	ns
0 kg K	0.156	0.012	0.065 b	0.283	28.0	3.0ab	36.0	53.5
25	0.157	0.012	0.062ab	0.273	26.7	3.2 b	36.1	55.8
50	0.158	0.012	0.061a	0.291	25.4	3.1 b	36.2	57.4
100	0.155	0.014	0.063ab	0.283	26.6	2.8a	36.3	54.8
LSD	ns	ns	0.0037**	ns	ns	0.322**	ns	ns

* = significant at P < 0.10

** = significant at P < 0.05

ns = not significant

\+ = applied in a band on the soil surface

\# = knifed at 15 cm depth

Table 42--Continued

	WG83							
	%				ppm			
Fertilizer	K	Ca	Mg	P	Zn	Cu	Mn	Fe
Ksurf(+)	0.190	0.023	0.052	0.318	15.2	1.8	31.1	40.8
Kknif(#)	0.188	0.020	0.049	0.309	14.7	2.1	29.6	39.6
LSD	ns	ns	ns	ns	ns	ns	ns	ns
0 kg K	0.192	0.022	0.053	0.320	15.4	1.8ab	31.4	42.6
25	0.188	0.024	0.053	0.307	14.8	1.7a	29.9	38.2
50	0.186	0.020	0.049	0.308	14.4	1.9ab	29.3	40.1
100	0.190	0.019	0.049	0.317	15.3	2.2 b	30.8	39.9
LSD	ns	ns	ns	ns	ns	0.422*	ns	ns

* = significant at $P < 0.10$

** = significant at $P < 0.05$

ns = not significant

\+ = applied in a band on the soil surface

\# = knifed at 15 cm depth

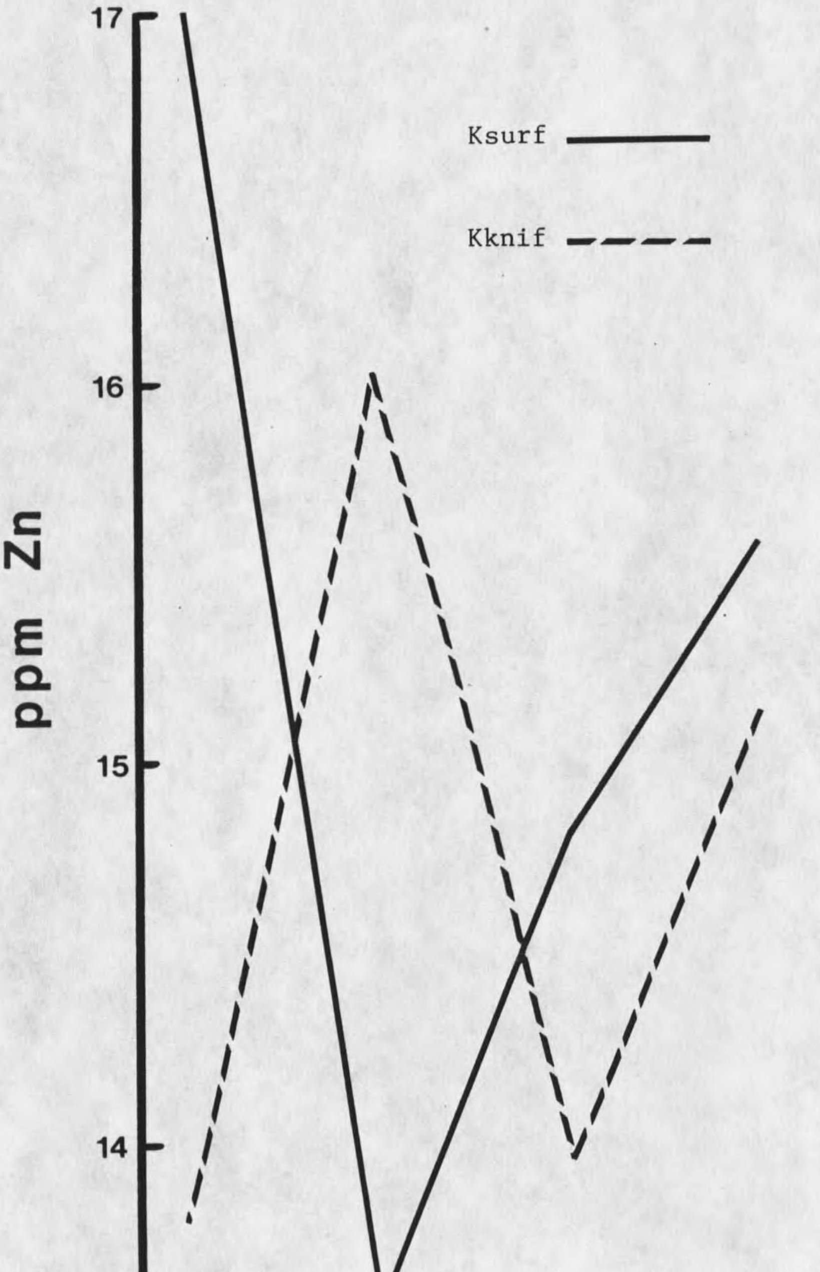

Figure 36. Interaction on ppm Zn at WG83 between placement and rate of K treatments.

SUMMARY AND CONCLUSIONS

Improved production levels and grain quality are two avenues open to farmers for increased income. While there is a wealth of research information dealing with the relationship between fertilizer management and production levels, this is not the case for grain quality. The relationship between fertilizer management and grain quality is important not only for producers, but also for consumers, especially professionals such as millers and dietitians. The objective of this work was to investigate and identify relationships of grain baking quality, seedling vigor, and mineral composition to form of N, placement of P, placement of K, and rate of K fertilizers.

A series of eight field experiments was conducted during which the grain for the "quality" determinations was produced. Fertilizers were applied so that the desired comparisons could be tested: anhydrous ammonia was compared to liquid ammonium nitrate solution; commercial grade phosphoric acid was applied, at one rate, either knifed through the anhydrous shanks or banded with the seed; liquid suspension KCl, at various rates, was either knifed or applied in a band on the surface.

Shortly after harvest, the grain produced in the series of field trials was weighed, and test weight and protein were determined. After a period of storage, greenhouse experiments were conducted using the harvested grain from the various fertilizer treatments to determine seedling vigor, the grain was analyzed for mineral contents, and hard red spring wheat from four of the field trials was analyzed for milling and baking quality. A summary of the number of sites where increases in response variables were recorded due to the main fertilizer treatments is presented in Table 43. Large differences did not occur at every site for every variable. The responses which were observed were not overwhelming. Therefore, in discussing and summarizing these results, trends which were consistent but not significant are considered.

Yields were generally higher for the winter and spring wheats when ammonium nitrate was the form of N. All three grain types trended toward higher protein contents with anhydrous ammonia. For the wheats, knifing P tended to produce both higher yields and greater protein contents, supporting the theory that this nutrient should be placed so that it is "positionally available." For winter wheat in this study, knifing K tended to produce higher yield and lower protein levels. Rate of K produced few effects on yields, protein contents, or test weights.

Fertilizer treatments produced several responses in the milling and baking quality variables observed in this work. Protein in the flour and the wheat was consistently greater with anhydrous ammonia, while test weight was lower. Longer farinograph times were realized with grain from the anhydrous ammonia treatments, indicating greater dough strength. Surface application of K tended to produce greater protein in the flour and wheat, although not all differences were significant. Test weights were generally higher with knifed K. Strength of dough was improved through knifed application of K as evidenced by longer farinograph times, especially under drought conditions. Flour ash appeared to be consistently lower when rates of K were high. Loaf volumes were

Table 43. Summary of statistically significant results, by site. (Total number of sites was eight except where noted.)

Variable	Number of Sites Which Showed Significant Increase Due to					
	AN	NH_3	Pband	Pknif	Ksurf	Kknif
Yield	3	1	1	4	-	1
Grain Protein	-	5	1	-	2	1
Test Weight	5	-	1	3	-	1
Flour Yield*	-	-	1	2	-	1
Flour Ash*	1	1	2	-	1	-
Flour Protein*	-	3	1	1	1	1
Farin Peak*	-	2	-	-	1	1
Farin Stability*	-	1	1	-	-	1
Loaf Volume*	-	1	1	3	-	1
SEI	-	1	-	-	-	-
Dry Wt per Plant	1	-	-	1	-	1
Phosphorus	2	-	-	1	-	1
Calcium	-	4	-	1	1	1
Magnesium	-	1	1	1	1	1
Potassium	1	-	1	-	-	1
Iron	-	2	1	1	-	-
Zinc	1	3	-	2	-	-
Copper	-	1	2	1	2	-
Manganese	-	2	-	2	1	1

*These variables were determined at only four sites.

greater when rates of K were high. However, most often, when rate of K influenced yield and/or quality, the largest influence occurred at the first or second increment of K addition, with reversal of the effect at higher rates of K.

The three main fertilizer management variables generally produced no effects on seedling vigor. However, for all three grain types, rate of K had significant effects on seedling vigor. Seedling vigor of barley was high with no added K or 50 kg/ha, with low values at the 25 kg/ha addition, and often at the 100 kg/ha addition.

Mineral composition was generally not affected by the main fertilizer management comparisons, for the two types of wheat. However, for barley, generally higher mineral contents were associated with knifed application of P and surface application of K. Calcium levels in the grains were significantly higher at four of the eight locations when anhydrous ammonia was the form of N. Mineral composition of all three grain types were affected by rates of K. Iron concentrations were often affected by K rates. In addition, 10 of 21 significant interactions on mineral content between rate of K and a main comparison were for Fe concentration.

Based on these results, a relationship exists between fertilizer management practices (N source, P placement, and K placement) and yields of small grains in Montana, although for these sites a relationship was not consistently detected between rate of K application and yields. Nitrogen source, K placement, and K rate affect hard red wheat baking quality, and more research is warranted, especially for the effects of K, and the importance of fertilizer "balance" when K is added, as indicated by the observed reversals of the effects of K at higher rates of addition. Rates of K application appear to have a strong relationship with the vigor of subsequent seeds. More research will be necessary for full understanding of this relationship, as well as for the relationship between rate of K and mineral contents. Relationships occurred for barley between mineral content and placement of P and K fertilizers. Although these relationships may not be economically important for malting purposes, they are worthy of more research in connection with feed barley.

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APPENDICES

APPENDIX A

COMPLETE ORIGINAL FIELD EXPERIMENT TREATMENTS

Table 44. Original field experiment treatment combinations.

Trmt No.	R082 Rate[a] K	R082 Source[b] N	R082 Placement[c] P	R082 Placement[c] K	J082 Rate[d] K	J082 Source N	J082 Placement P	J082 Placement K
1	--	0	0	0	--	0	0	0
2	--	0	Band	0	--	0	Band	0
3	100	0	0	Band	50	0	0	Band
4	100	0	Band	Band	50	0	Band	Band
5	--	AN	0	0	--	AN	0	0
6	100	AN	0	Band	50	AN	0	Band
7	100	AN	Knif	Band	50	AN	Knif	Band
8	K2S04	AN	Band	Band	K2S04	AN	Band	Band
9	0	AN	Band	Band	0	AN	Band	Band
10	50	↓	↓	↓	25	↓	↓	↓
11	100	↓	↓	↓	50	↓	↓	↓
12	150	↓	↓	↓	100	↓	↓	↓
13	0	AN	Band	Surf	0	AN	Band	Surf
14	50	↓	↓	↓	25	↓	↓	↓
15	100	↓	↓	↓	50	↓	↓	↓
16	150	↓	↓	↓	100	↓	↓	↓
17	0	NH_3	Band	Band	0	NH_3	Band	Band
18	50	↓	↓	↓	25	↓	↓	↓
19	100	↓	↓	↓	50	↓	↓	↓
20	150	↓	↓	↓	100	↓	↓	↓
21	0	NH_3	Band	Surf	0	NH_3	Band	Surf
22	50	↓	↓	↓	25	↓	↓	↓
23	100	↓	↓	↓	50	↓	↓	↓
24	150	↓	↓	↓	100	↓	↓	↓
25	0	NH_3	Band	Knif	0	NH_3	Band	Knif
26	50	↓	↓	↓	25	↓	↓	↓
27	100	↓	↓	↓	50	↓	↓	↓
28	150	↓	↓	↓	100	↓	↓	↓
29	0	NH_3	Knif	Band	0	NH_3	Knif	Band
30	50	↓	↓	↓	25	↓	↓	↓
31	100	↓	↓	↓	50	↓	↓	↓
32	150	↓	↓	↓	100	↓	↓	↓
33	0	NH_3	Knif	Surf	0	NH_3	Knif	Surf
34	50	↓	↓	↓	25	↓	↓	↓
35	100	↓	↓	↓	50	↓	↓	↓
36	150	↓	↓	↓	100	↓	↓	↓
37	0	NH_3	Knif	Knif	0	NH_3	Knif	Knif
38	50	↓	↓	↓	25	↓	↓	↓
39	100	↓	↓	↓	50	↓	↓	↓
40	150	↓	↓	↓	100	↓	↓	↓

Table 44--Continued

Trmt No.	R083 Rate[a] K	R083 Source[b] N	R083 Placement[c] P	R083 Placement[c] K	J083 Rate[d] K	J083 Source N	J083 Placement P	J083 Placement K
1	--	0	0	0	--	0	0	0
2	--	NH_3	0	0	--	NH_3	0	0
3	--	0	Knif	0	--	0	Knif	0
4	50	0	0	Knif	25	0	0	Knif
5	50	NH_3	Knif	Knif	25	NH_3	Knif	Knif
6	50	NH_3	0	Knif	25	NH_3	0	Knif
7	50	0	Knif	Knif	25	0	Knif	Knif
8	50	NH_3	Knif	Knif	25	NH_3	Knif	Knif
9	K2S04	NH_3	Knif	Knif	K2S04	NH_3	Knif	Knif
10	50	NH_3	Knif	Knif	25	NH_3	Knif	Knif
11	50	NH_3	Knif	Band	25	NH_3	Knif	Band
12	100	NH_3	Knif	Band	50	NH_3	Knif	Band
13	0	AN	Band	Knif	0	AN	Band	Knif
14	25	↓	↓	↓	25	↓	↓	↓
15	50	↓	↓	↓	50	↓	↓	↓
16	100	↓	↓	↓	100	↓	↓	↓
17	0	AN	Knif	Knif	0	AN	Knif	Knif
18	25	↓	↓	↓	25	↓	↓	↓
19	50	↓	↓	↓	50	↓	↓	↓
20	100	↓	↓	↓	100	↓	↓	↓
21	0	NH_3	Band	Surf	0	NH_3	Band	Surf
22	25	↓	↓	↓	25	↓	↓	↓
23	50	↓	↓	↓	50	↓	↓	↓
24	100	↓	↓	↓	100	↓	↓	↓
25	0	NH_3	Band	Knif	0	NH_3	Band	Knif
26	25	↓	↓	↓	25	↓	↓	↓
27	50	↓	↓	↓	50	↓	↓	↓
28	100	↓	↓	↓	100	↓	↓	↓
29	0	NH_3	Knif	Surf	0	NH_3	Knif	Surf
30	25	↓	↓	↓	25	↓	↓	↓
31	50	↓	↓	↓	50	↓	↓	↓
32	100	↓	↓	↓	100	↓	↓	↓
33	0	NH_3	Knif	Knif	0	NH_3	Knif	Knif
34	25	↓	↓	↓	25	↓	↓	↓
35	50	↓	↓	↓	50	↓	↓	↓
36	100	↓	↓	↓	100	↓	↓	↓

Table 44--Continued

Trmt No.	PN82 Rate[a] K	PN82 Source[b] N	PN82 Placement[c] P	PN82 Placement[c] K	PN83 Rate[d] K	PN83 Source N	PN83 Placement P	PN83 Placement K
1	--	0	0	0	--	0	0	0
2	--	0	Band	0	--	NH_3	0	0
3	50	0	0	Band	--	0	Knif	0
4	50	0	Band	Band	50	0	0	Knif
5	--	AN	0	0	50	NH_3	Knif	Knif
6	50	AN	0	Band	50	NH_3	0	Knif
7	50	AN	Knif	Band	50	0	Knif	Knif
8	K2SO4	AN	Band	Band	50	NH_3	Knif	Knif
9	0	AN	Band	Band	K2SO4	NH_3	Knif	Knif
10	25	↓	↓	↓	50	NH_3	Knif	Knif
11	50	↓	↓	↓	50	NH_3	Knif	Band
12	100	↓	↓	↓	100	NH_3	Knif	Band
13	0	AN	Band	Surf	0	AN	Band	Surf
14	25	↓	↓	↓	25	↓	↓	↓
15	50	↓	↓	↓	50	↓	↓	↓
16	100	↓	↓	↓	100	↓	↓	↓
17	0	NH_3	Band	Band	0	AN	Knif	Surf
18	25	↓	↓	↓	25	↓	↓	↓
19	50	↓	↓	↓	50	↓	↓	↓
20	100	↓	↓	↓	100	↓	↓	↓
21	0	NH_3	Band	Surf	0	NH_3	Band	Surf
22	25	↓	↓	↓	25	↓	↓	↓
23	50	↓	↓	↓	50	↓	↓	↓
24	100	↓	↓	↓	100	↓	↓	↓
25	0	NH_3	Band	Knif	0	NH_3	Band	Knif
26	25	↓	↓	↓	25	↓	↓	↓
27	50	↓	↓	↓	50	↓	↓	↓
28	100	↓	↓	↓	100	↓	↓	↓
29	0	NH_3	Knif	Band	0	NH_3	Knif	Surf
30	25	↓	↓	↓	25	↓	↓	↓
31	50	↓	↓	↓	50	↓	↓	↓
32	100	↓	↓	↓	100	↓	↓	↓
33	0	NH_3	Knif	Surf	0	NH_3	Knif	Knif
34	25	↓	↓	↓	25	↓	↓	↓
35	50	↓	↓	↓	50	↓	↓	↓
36	100	↓	↓	↓	100	↓	↓	↓
37	0	NH_3	Knif	Knif	--	--	--	--
38	25	↓	↓	↓	--	--	--	--
39	50	↓	↓	↓	--	--	--	--
40	100	↓	↓	↓	--	--	--	--

Table 44--Continued

Trmt No.	WG83 Rate[a] K	WG83 Source[b] N	WG83 Placement[c] P	WG83 Placement[c] K	VV83 Rate[d] K	VV83 Source N	VV83 Placement P	VV83 Placement K
1	--	0	0	0	--	0	0	0
2	--	0	Knif	0	--	0	Knif	0
3	50	0	0	Knif	50	0	0	Knif
4	50	0	Knif	Knif	50	0	Knif	Knif
5	--	AN	0	0	--	AN	0	0
6	50	AN	0	Knif	50	AN	0	Knif
7	50	AN	0	Knif	50	AN	0	Knif
8	K2SO4	AN	Knif	Knif	K2SO4	AN	Knif	Knif
9	0	AN	Band	Band	0	AN	Band	Band
10	25	↓	↓	↓	25	↓	↓	↓
11	50	↓	↓	↓	50	↓	↓	↓
12	100	↓	↓	↓	100	↓	↓	↓
13	0	AN	Band	Surf	0	AN	Band	Surf
14	25	↓	↓	↓	25	↓	↓	↓
15	50	↓	↓	↓	50	↓	↓	↓
16	100	↓	↓	↓	100	↓	↓	↓
17	0	NH_3	Band	Band	0	NH_3	Band	Band
18	25	↓	↓	↓	25	↓	↓	↓
19	50	↓	↓	↓	50	↓	↓	↓
20	100	↓	↓	↓	100	↓	↓	↓
21	0	NH_3	Band	Surf	0	NH_3	Band	Surf
22	25	↓	↓	↓	25	↓	↓	↓
23	50	↓	↓	↓	50	↓	↓	↓
24	100	↓	↓	↓	100	↓	↓	↓
25	0	NH_3	Band	Knif	0	NH_3	Band	Knif
26	25	↓	↓	↓	25	↓	↓	↓
27	50	↓	↓	↓	50	↓	↓	↓
28	100	↓	↓	↓	100	↓	↓	↓
29	0	NH_3	Knif	Band	0	NH_3	Knif	Band
30	25	↓	↓	↓	25	↓	↓	↓
31	50	↓	↓	↓	50	↓	↓	↓
32	100	↓	↓	↓	100	↓	↓	↓
33	0	NH_3	Knif	Surf	0	NH_3	Knif	Surf
34	25	↓	↓	↓	25	↓	↓	↓
35	50	↓	↓	↓	50	↓	↓	↓
36	100	↓	↓	↓	100	↓	↓	↓

[a]Rates of potassium are in kg/ha.

[b]AN = ammonium nitrate; NH3 = anhydrous ammonia.

[c]Band = banded with the seed; Knif = knifed; Surf = applied in a band on the surface.

[d]Rates of K for RO82 were 0, 50, 100, and 150.

APPENDIX B

DISEASE RATINGS

Table 45. Take-All root rot disease ratings for spring wheat from the 1982 and 1983 Teton County sites as influenced by selected fertilizer treatments.

Fertilizer Treatment[b]	Disease Rating[a] R082	Disease Rating[a] R083
0 - 0 - 0	2.26 a[+]	2.41 bcde
NH_3 - 0 - 0	2.41 ab	2.71 e
NH_3 - Pband - 0	----	2.07 abc
0 - Pband - 0	3.00 ab	----
0 - 0 - Kband	2.68 ab	----
NH_3 - Pband - Kknif	----	2.41 bcde
NH_3 - Pband - Ksurf - Ssurf	3.27 b	2.62 de
AN - Pband - 0	2.68 ab	----
AN - Pband - Kband (50)	3.18 ab	----
AN - Pband - Kband (100)	2.82 ab	----
AN - Pband - Kband (150)	2.52 ab	----
NH_3 - Pband - 0	2.98 ab	----
NH_3 - Pband - Kband (50)	2.72 ab	----
NH_3 - Pband - Kband (100)	2.89 ab	----
NH_3 - Pband - Kband (150)	3.02 ab	----
NH_3 - Pknif - Ksurf (25)	----	2.29 abcde
NH_3 - Pknif - Ksurf (50)	----	2.22 abcd
NH_3 - Pknif - Ksurf (100)	----	2.50 cde
NH_3 - Pknif - Kknif (25)	----	2.59 de
NH_3 - Pknif - Kknif (50)	----	2.00 ab
NH_3 - Pknif - Kknif (100)	----	1.91 a

[a]Ratings are made based on degree of discoloration and malformation of subcrown internode, with 1 = no evidence of disease and 5 = completely diseased.

[b]Rates of fertilizer were 80 kg n/ha and 20 kg P/ha in 1982 and 120 kg N/ha and 20 kg P/ha in 1983. Band = banded with the seed; knif = knifed; surf = applied in a band on the surface.

[+]Values followed by the same letter are not significantly different at the 5% level.

DATE	ISSUED TO