MONTANA STATE UNIVERSITY

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

by Sandra Le Anne Schwarzin

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University
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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, 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.

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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:

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

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					
NO_3-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

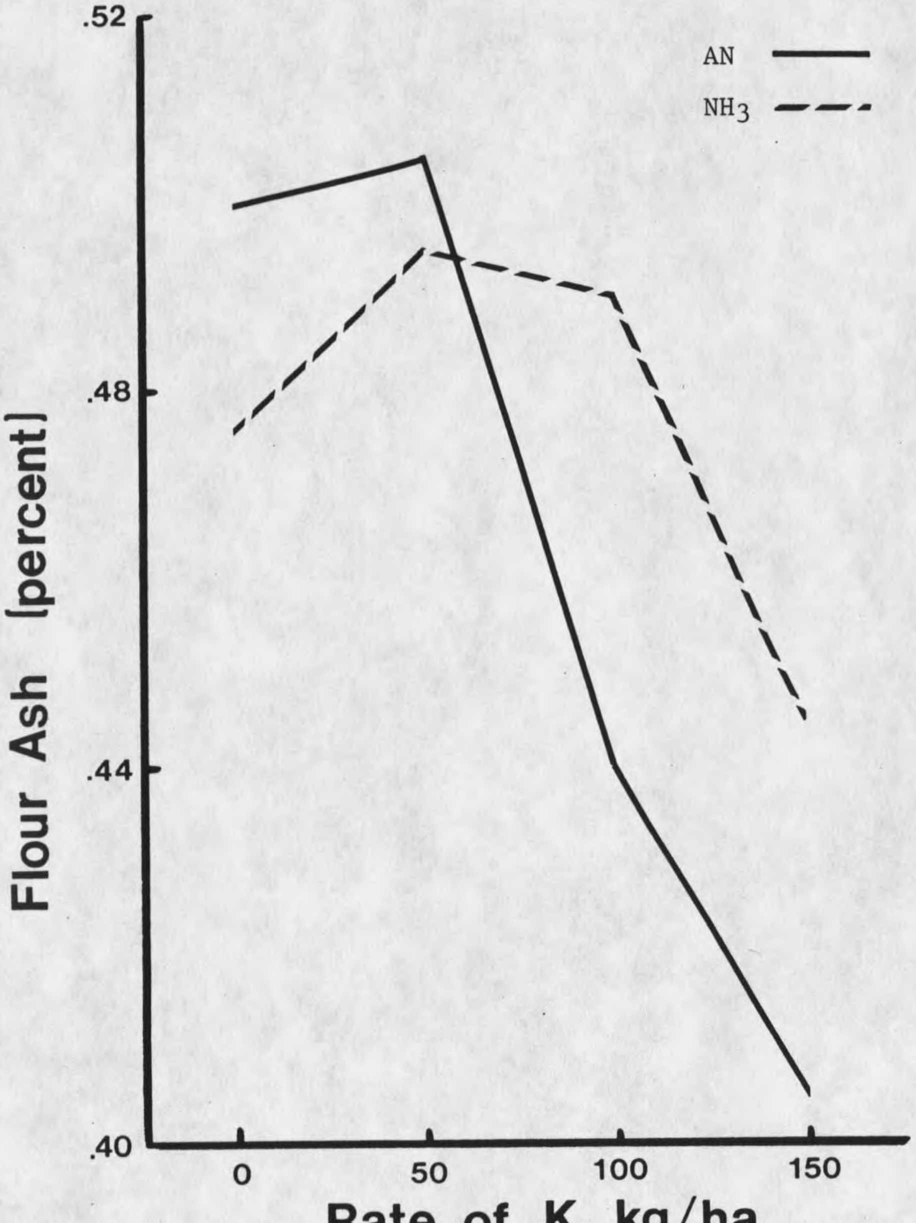

Figure 1. Interaction on percent ash in flour at R082 between form of N and rate of K treatments.