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THE EFFECT OF NITROGEN SUPPLY ON THE PROTEIN CONTENT OF NEEPAWA WHEAT

by

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ABSTRACT

The effect of foliar and soil applied nitrogen and soil nitrate nitrogen content on the protein content of Neepawa wheat was studied. Results from field and greenhouse studies showed that yield and protein content of wheat were higher on fallow than on nonfallow land. Protein content of wheat usually increased with increases in the amounts of nitrate nitrogen present in the soil. Significant yield increases were obtained when 30 or 60 lb N/acre was applied broadcast to nonfallow land at time of seeding. Protein content of wheat at the above rates of added nitrogen decreased or increased only slightly; protein content increased substantially when 90 to 180 lb N/acre was applied. Protein content of wheat increased markedly with increasing amounts of added nitrogen only when yields remained relatively constant. Protein content of wheat grown on fallow land increased with increased amounts of added nitrogen up to about 120 lb N/acre, but yields did not increase greatly with added nitrogen. Addition of nitrogen with the seed as urea or ammonium nitrate did not usually increase yields or protein contents above that obtained with equivalent rates of nitrogen as ammonium nitrate applied broadcast at time of seeding. Wheat protein content was found to be related to nitrogen supply (soil nitrate nitrogen or soil nitrate nitrogen and nitrogen applied at time of seeding). An R^2 value of 0.73 was obtained when wheat protein content was related to soil nitrate nitrogen measured to a depth of two feet and nitrogen applied broadcast at time of seeding.

Soil and foliar applied post emergent nitrogen applications increased the protein content more than equivalent rates of nitrogen applied broadcast at time of seeding in field studies conducted in 1971, but not in 1970. A greenhouse experiment showed that usually less than one

percent of the nitrogen from ammonium nitrate, urea or ammonium sulfate was absorbed into the grain when applied to the foliar surfaces of wheat; usually greater than 30 percent of the nitrogen from these fertilizers was absorbed when soil applied.

Wheat quality was found to be related to protein content and independent of nitrogen source.

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I INTRODUCTION

The proposed establishment of a protein subgrading system for wheat grown in Canada, in lieu of the existing system, could result in a diminution in wheat production for milling purposes in parts of Manitoba, particularly the Manitoba Lowlands. Areas such as this, which lie outside of the so called "Paliser Triangle" have, characteristically grown high yields of low protein content wheat.

Several factors can influence wheat protein content. Climatic factors such as water supply, air temperature and light conditions acting directly or indirectly upon the plant can influence the protein content of grains. Soil properties such as moisture holding capacity and availability of plant nutrients also affect protein content of grains. The availability of nitrogen or soil nitrogen supply would be of extreme importance as nitrogen is a constituent of plant protein. Manitoba soils usually contain less nitrate nitrogen than soils located in the more arid regions of the Prairie Provinces. Also, wheat is more frequently grown on nonfallow land in Manitoba than in the other Prairie Provinces. Nonfallow land usually contains less available nitrogen than does fallow land. It would therefore appear that the low protein content of wheat grown in Manitoba may be due to low or insufficient available nitrogen.

The purpose of this investigation was to study the relationship between the protein content of wheat and nitrogen supply. The objectives of the study were as follows:

a) to study the influence of soil nitrate nitrogen content on the protein content of wheat;

b) to study the influence of nitrogen fertilizers applied at time of seeding on the protein content of wheat;

c) to study the effect of time of application of urea, ammonium sulfate and ammonium nitrate foliar sprays and broadcast ammonium nitrate on the protein content of wheat.

II LITERATURE REVIEW

A. Effect of Temperature on Yield and Protein Content

It has been shown (3, 32) that increases in air temperature result in increases in the protein content of wheat. Campbell and Read (3) grew Chinook wheat in a growth chamber and found that increasing the night temperature from $13^{o}C$ to $27^{o}C$ increased the protein content and decreased the yield.

The effect of temperature on yield and protein content has been explained by the effect of temperature on respiration and amino acid synthesis. Devlin (6) and Salisbury and Ross (38) reported that respiration increased with increasing temperature. Consequently, an increase in temperature will cause carbohydrate depletion. Amino acid synthesis is enhanced by increasing temperature due to the direct dependence of the enzymes involved in amino acid synthesis on temperature. Partridge (32) conducted a series of greenhouse experiments and reported that increases in protein content of wheat with increasing temperature was mainly due to an indirect effect through reductions in yield. A smaller, but significant effect, was attributed directly to increases in temperature. This effect was probably due to increased amino acid synthesis with increased temperature.

B. The Effect of Water Supply on Yield and Protein Content

Many authors (22, 15, 33, 43) have reported that increases in soil moisture stress increases the protein content of wheat. Sosulski *et al.* (42) found that variations in soil moisture stress influenced protein content of the grain more than nitrogen fertilization or variations in temperature.

Paul and Anderson (33) conducted a regression analysis on wheat protein content and precipitation data collected over 14 years from seven stations located in the dry belts of Southwestern Saskatchewan. They found that 34% of the residual variance in wheat protein content could be explained by variations in precipitation. The most critical periods during which high rainfall reduced protein content were April, early May and late July. The occurrence of lower protein content with increased rainfall early in the growing season, according to Hopkins (15), is due to increased proliferation of tillers which would have a dilution effect on available nitrogen. The stimulatory effect of precipitation on tillering would be greatest in areas of low rainfall. Russel and Bishop (36) suggested that high precipitation during the early part of the growing season could increase leaching of available nitrates from the soil root zone. Paul and Anderson (33) suggested that high precipitation in April resulted in increased germination causing a thicker stand, and therefore, less available nitrogen per plant. It seems probable that a combination of the above factors could result in decreased protein with above normal spring precipitation.

Paul and Anderson (33) suggested that decreased protein content due to above normal precipitation in late July may be the result of the ratio of carbohydrates translocated to the kernel and carbohydrates respired. Under dry conditions, translocation of nitrogeneous compounds and carbohydrates becomes lower than normal while respiration of carbohydrates remains normal. This indirectly increases the protein content, which would not happen under conditions of adequate soil moisture.

Lehane and Staple (22) found that on medium textured soils, a soil moisture stress late in the growing season tended to reduce the yield of wheat.

This observation coincides with the findings of Paul and Anderson.

Several researchers (7, 16, 17, 18, 34, 42) have studied the interaction of soil moisture stress and nutrient availability and its effects on protein content and yield of wheat. Dubetz (7) found that Lethbridge loam soil, when dried from field capacity to ¼ field capacity responded with greater increases in protein content with added ammonium nitrate than when the soil was dried from field capacity to ½ or 3/4 field capacity with the same amount of fertilizer. The opposite effects were noted for yield. Similarily, Sosulski et al. (42) found that varying the soil moisture content between field capacity (27%) and permanent wilting percentage (9%), with 40 lb N/acre added as ammonium nitrate, yielded wheat with 20.8% protein in the grain. When 200 lb N/ acre was added to the same loam soil and the moisture stress varied between 27-17%, only 12.7% protein in the grain was achieved. The greatest protein response to added nitrogen was obtained at medium moisture stress.

Hutcheon and Paul (17) using a Melfort clay soil, with a high nitrogen supplying power and a high inorganic nitrogen content, produced wheat with 16% protein in the grain at almost all nitrogen levels and at optimum moisture content. Only when a moisture stress was placed on the plants, did protein contents increase. They reasoned that a moisture stress reduced the absolute levels of carbohydrates more than the absolute levels of protein, thereby increasing the percentage protein. Both Hutcheon and Paul (17) and Hutcheon and Rennie (16) reported no protein response to nitrogen fertilization at very high moisture stresses. In view of these findings, it is not surprising that the 40 year average protein content of wheat grown in Manitoba with an average annual precipitation of 18-20 inches (5) is 13.2% (25). In contrast, Saskatchewan, with a mean annual precipitation of 14-16 inches during the same period (5), produced wheat with an average of 13.9% (25) protein content.

Lehane and Staple (22, 23) have found that yield losses due to soil moisture stress over a growing season are less severe on clay textured soils than in coarser textured soils. Since a clay soil has a low hydraulic conductivity available moisture in the soil is distributed over the growing season such that moisture is available during the filling and maturing stages of the grain. As explained previously, protein content is proportional to moisture stress and yield is inversely proportional to moisture stress. This may explain why wheat produced on the clay soils in the Morris, Manitoba area averaged 12.98% protein during the years 1947 to 1967 (25).

C. Effect of Soil Type on Yield and Protein Content

Rennie (35) and McKercher (27) have reported differences in wheat protein content due to soil type. McKercher (27) studied wheat protein variations in Saskatchewan during 1956 to 1962. He found that on any given year wheat protein variations between different soil zones (e.g. Black vs Dark Grey) were usually smaller than variations within a soil zone. He attributed the differences in wheat protein content within a soil zone to changes in profile type. The profile type is a reflection of drainage and micro-climate. Rego and calcareous soils produced wheat with high protein contents in comparison to those of solonetz and gleysolic soils. Orthic soils generally produced wheat with a slightly lower protein content than the rego and calcareous soils.

Solod and solonetz soils are analogous to the Luvisolic soil order since all have rather impervious B horizons and all have undergone some degree of leaching. Poor root penetration into the B horizon would cause lower nutrient uptake. The protein content of the grain from the Luvisolic soils was lower than from the drier Dark Brown and Black soils.

Rennie (35) attributed significant differences in protein content to variations in climate and soil profile type. Areas of low precipitation produced higher protein wheat than did areas of high precipitation. He attributed this to conditions being more conducive to free nitrogen fixation and biological release of organic nitrogen in the low precipitation areas. Thus the more arid Brown and Dark Brown soils should contain greater amounts of available nitrogen than Black and Grey Wooded soils. Although Rennie's observations are shown to be accurate in that the protein content of wheat in Western Canada generally follows the soil order boundaries (25), the effect of increased protein contents of wheat in in areas of lower rainfall, and consequently different soil types, may also be due to the indirect effect of lower yields as well as nitrogen supply.

D. The Effect of Agronomic Practices on Yield and Protein Content

Hill (14) studied the effects of commonly accepted agronomic practices on yield and protein content of wheat. He found that the yield and protein content of wheat grown on summerfallow fields were greater than that of wheat grown on nonfallow fields. No differences in yield or protein content were found when wheat was grown on fields previously black summerfallowed or trash summerfallowed. Thus, trash summerfallow can be used to prevent soil erosion without affecting protein levels. Spraying the crop with 2-4 dichlorophenoxyacetic acid ester at six ounces acid equivalent per acre when the wheat was six inches in height had no significant effect on protein content over that of the handweeded or weed infested checks.

Ellis (9) and Hedlin *et al.* (13) have studied the effects of crop residues on the protein content of wheat. They found that wheat had the highest protein content when grown after a legume crop and had the lowest when grown after a grass crop. Hedlin _et al._ state that "residues which nitrify rapidly and release greater amounts of available nitrogen during the growing season resulted in higher yields and protein content of wheat than those residues which nitrify slowly and release smaller amounts of available nitrogen."

E. The Effect of Fertilization on Yield and Protein Content

1) Soil applied fertilizers

The effect of soil applied fertilizers on plant growth and protein content has been studied by many researchers. Phosphorous fertilization has been found to increase yields and reduce the protein content of wheat (37, 8). Hill (14) reported that the addition of phosphorous at a rate of 40 pounds P_2O_5 per acre lowered the protein content of wheat below that of a check not treated with fertilizer. The protein content of wheat treated with 80 pounds of nitrogen per acre and 40 pounds P_2O_5 per acre was lower than that of wheat treated with nitrogen alone. Eck (8) suggested that increasing grain yields without additional nitrogen dilutes the available nitrogen supply giving higher yields without proportionately higher nitrogen uptake. In work done at Billings Oklahoma in 1953 (8), unfertilized plots yielded 19.3 bushels of wheat per acre with 11.8% protein content. Phosphorous fertilized plots yielded 24.8 bushels of wheat per acre with 10.2% protein content. Eck (8) found that within the genetic capabilities of any one variety, grain protein was mainly a function of soil nitrogen levels.

Much of the early work conducted shows little or no effect of nitrogen fertilizers on grain protein levels. Hedlin _et al._ (13) reported no effect of fertilizer on grain protein in field studies conducted during 1949 to 1953. They did, however, obtain a yield increase from the addition of the 108 pounds per acre of 16-20-0. Rennie (35) found no increase in protein content of wheat when rates of nitrogen up to 40 pounds per acre were added to nonfallow fields.

Rates of nitrogen fertilizer required to obtain increases in yield are not necessarily sufficient for increases in protein content. Ridley* found that when seven pounds of nitrogen and 40 pounds of P_2O_5 per acre were added to four experiments conducted on nonfallow land, the yield of wheat was 19.7 bushels per acre. The yield increased to 31.0 bushels per acre, when 40 pounds of nitrogen plus 40 pounds P_2O_5 per acre was added to the same soil, but the protein content remained the same (12.9%). The protein content increased to 14.9% and the yield to 38.8 bushels per acre when 80 pounds of nitrogen and 40 pounds of P_2O_5 per acre were applied. On soil low in available nitrogen, small amounts of applied nitrogen (0-40 lb N/acre) can result in such a large yield increase, that the protein content of the grain is lowered due to dilution (32).

Eck (8) states that nitrogen in excess of that required for yield is reflected in increases in protein content. Hutcheon and Rennie (16) found that added nitrogen at rates up to about 125 pounds nitrogen per acre increased grain yield greatly and protein contents only slightly. Added nitrogen above about 125 pounds of nitrogen per acre did not increase yields, but increased the general level of protein in the grain. Ridley* showed that increasing added nitrogen levels above 80 pounds per acre on summerfallow land decreased yields, although protein content continued to increase. The yield decrease was probably due to either lodging and/or

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* Unpublished data. A.O. Ridley. University of Manitoba. 1968.

a nutrient deficiency of an element other than nitrogen.

It is generally agreed (37, 39, 50) that nitrogen fertilizer can increase both the yield and protein content of wheat when soil available nitrogen levels are low. However, as previously stated, nitrogen fertilization does not always increase both yield and protein content. Several researchers (8, 24, 26, 28) have explained the discrepancies observed. When small amounts of nitrogen are added in the spring to soil originally low in available nitrogen, most of the nitrogen is utilized early in the growing season and very little of the applied nitrogen remains for the latter part of the growing season. As a result, the nitrogen is utilized in the enhancement of early vegetative growth and yield, and little of the applied nitrogen remains in the soil for plant utilization during grain formation. This would explain the good yield response and poor protein response to small amounts of applied nitrogen.

McNeal and Davis (28) studied differences in protein content within a head of wheat. They found that the earlier maturing kernels in the middle of the head were higher in protein content than the later maturing kernels on the top of the head. This points out the need for adequate available nitrogen later in the growing season for maximum protein content.

McBeath and Toogood (26) conducted a series of barley field trials during 1957 and 1958. They found that early nitrogen top-dressing nearly always increased yield as well as protein content, but later nitrogen application did not always increase yield. Long and Sherbakoff (24) found similar results using late applications of granular nitrogenous fertilizer on winter wheat.

2) Foliar applied fertilizers

The effect of post emergent nitrogeneous spray applications on the protein content and yield of wheat has been studied by several researchers. Finney et al. (11) sprayed 10, 30 and 50 pounds of nitrogen per acre as urea at concentrations of 0.25, 0.75 and 1.25 pounds of urea per gallon of solution, respectively, on Pawnee winter wheat. They found that responses in yield and protein content increased with increased amounts of nitrogen sprayed. One to fifteen spray applications per treatment were conducted at various times during the growing season. Fifty pounds of nitrogen per acre as urea spray at 35 days before flowering resulted in a 13.4 bushel per acre yield increase over the unfertilized check. The same rate at flowering produced the highest protein increases over the check for any single spray application. Multiple spray applications resulted in the highest protein contents. Increases in protein content were greatest when the sprays were applied at the flowering stage. Wheat in one treatment that was sprayed with 50 pounds of nitrogen per acre fifteen times during the growing season contained 21% protein, but yielded only 22.4 bushels per acre. The low yield was attributed to leaf burn. They also found that yield and protein response to 50 pounds of nitrogen per acre was not affected by the concentration of the urea solution. The concentrations used were 1.25, 2.94 and 4.68 pounds of urea per gallon of solution.

At Lethbridge Alberta* in 1952, urea and ammonium nitrate solutions were sprayed on the foliar surfaces of Kharkov winter wheat. Two application times were compared: one at the three leaf stage and one at mid-heading stage. One hundred pounds of nitrogen per acre applied as urea spray at mid-heading stage was more effective in increasing the protein content than ammonium nitrate spray at either time or urea spray at the

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* Unpublished data. Dominion Experimental Station, Lethbridge, Alberta.

three leaf stage. The protein content of wheat grown on the unfertilized check was 13.91%, whereas; that for wheat sprayed with urea at mid-heading stage was 16.2%. Yield of grain was unaffected by nitrogen sprays. Field trials conducted at Lethbridge* in 1953 and 1954 using spring wheat showed no significant increase in yield or protein content where rates of nitrogen up to 200 pounds per acre as urea and 264 pounds per acre as ammonium nitrate were sprayed ten days prior to flowering. Addition of a small portion of 10^{-9} molal indol aceticacid to the nitrogen sprays gave no added response.

In many of the previous studies the efficacy of foliar applied nitrogen was measured by comparing foliar applied nitrogen to unfertilized checks. A comparison of nitrogeneous sprays to similar amounts of nitrogen applied as a granular top dressing, however, is a more realistic evaluation of the effectiveness of foliar sprays as the amounts of nitrogen added are the same. Hanley et al. (21) applied ammonium sulfate, sodium nitrate and urea in granular form and as liquid sprays to winter wheat early in the spring. They found the granular top dressings more effective in increasing yields than the liquid sprays.

Thorne (45), in a review of British work on foliar application of nitrogen to wheat, reported that studies conducted at Jealot's Hill (1953) showed no advantage of adding urea as a foliar spray over urea as a granular soil top dressing applied when the winter wheat was six inches in height. Similarily, at Rothamstad, Thorne and Watson (47, 48) sprayed ammonium nitrate on the foliar surfaces of winter wheat as well as to the soil surface at eight different times throughout the growing season. These

* Unpublished data. Dominion Experimental Station, Lethbridge, Alberta.

treatments, when compared to a single granular nitrogen top-dressing at seeding, showed no advantage in yield or protein content.

The simultaneous application of 2,4 dichlorophenoxyacetic acid (2,4-D) and nitrogen spray has been studied. Thorne (46) found that separate granular nitrogen top-dressing and 2,4-D spray would increase yields and control weeds more effectively than simultaneous liquid spray applications. At Lethbridge* (1952), yields of winter wheat were found not to vary significantly with simultaneous spraying of nitrogen solutions and 2,4-D at rates of 265 pounds nitrogen per acre, but the protein content increased to 15.7% from 14.0%. However, the increase in protein content was greater when nitrogen was sprayed alone. Also, weed control in the simultaneously sprayed trial was poor. The poor weed control was attributed to the small amounts of 2,4-D applied.

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* Unpublished data. Dominion Experimental Station, Lethbridge, Alberta.

III METHODS AND MATERIALS

The study conducted consisted of field and greenhouse experiments. The field experiments were conducted during 1970 and 1971. The greenhouse experiment was conducted during the winter and early spring of 1971. Neepawa wheat was used in all studies. The legal description and seeding and harvest dates for the field experiment sites are listed in Table 1.

A. Description of Soils

Several soil samples were taken at all field sites prior to seeding. Table 2 lists some physical and chemical properties of the soils selected for the ten field experiments conducted. The sites were selected on the basis of cropping history and available nitrogen content.

All soils, except the Wellwood sites, were located in the Manitoba Lowlands. The Red River soils belong to the gleyed rego black soil subgroup while the other soils belong to the orthic black subgroup. Soil textures varied from clay to loamy fine sand. A wide range of soil nitrogen content was found; the largest amount (165 lb/acre to a depth of 4 ft) was present in the Wellwood fallow site in 1970 and the smallest amount (9 lb/acre to a depth of 4 ft) was present in the Red River nonfallow site in 1971.

Some physical and chemical properties of the soil used in the greenhouse experiment is shown in Table 3. The soil was obtained in the fall of 1970 from the Ah horizon of an Altona soil located near the 1970 Altona fallow site. Barley was previously grown on the field from which the soil was obtained.

B. Description of Field Experiments

1) Seeding and harvest procedure.

Triticum aestivum L.cv. Neepawa was seeded in 1970 and 1971 with

TABLE 1

NAME, LEGAL DESCRIPTION AND SEEDING AND HARVEST DATES FOR THE FIELD EXPERIMENTAL SITES

Site Name	Legal Description	Seeding Date	Harvest Date
Altona fallow-1970	N.E. 5-4-4 W	June 1	August 31
Altona nonfallow-1970	S.E. 5-4-4 W	June 2	September 1
Almasippi fallow-1970	N.E. 19-7-4 W	June 3	August 28
Almasippi nonfallow-1970	S.W. 19-7-4 W	June 3	August 27
Wellwood fallow-1970	N.W. 30-11-14 W	June 8	September 4
Wellwood nonfallow-1970	S.E. 31-11-14 W	June 9	September 3
Altona fallow-1971	N.W. 5-4-4 W	May 11	August 27
Altona nonfallow-1971	N.W. 5-4-4 W	May 11	August 24
Red River fallow 1971	S.E. 14-5-1 W	May 19	August 31
Red River nonfallow 1971	S.W. 14-5-1 W	May 12	August 30

TABLE 2

CHARACTERISTICS OF THE SOILS ON THE FIELD EXPERIMENTAL SITES

Site name	Soil subgroup	Soil texture	NO_3-N (lb/acre) (to depth of 2 ft)	NO_3-N (lb/acre) (to depth of 4 ft)	$NaHCO_3$ Ext. P (ppm)	NH_4OAc Ext. K (ppm)	pH	Cond. (mmhos/cm)	Organic matter (%)	Carbonate content (% $CaCO_3$)
Altona fallow 1970	Orthic Black	VFSCL	69	92	13.6	555	6.8	0.73	4.70	0.48
Altona nonfallow 1970	Orthic Black	VFSCL	18	30	9.9	429	6.1	0.25	4.88	0.09
Almasippi fallow 1970	Orthic Black	LFS	83	136	7.2	75	8.0	0.81	3.02	1.11
Almasippi nonfallow 1970	Orthic Black	LFS	38	60	4.2	62	8.0	0.43	2.83	1.36
Wellwood fallow 1970	Orthic Black	CL	131	165	20.2	638	6.2	0.67	8.11	0.07
Wellwood nonfallow 1970	Orthic Black	CL	13	16	22.2	238	6.2	0.30	7.21	0.71
Altona fallow 1971	Orthic Black	VFSL	67	86[1]	8.1	91	7.9	0.75	2.40	1.00
Altona nonfallow 1971	Orthic Black	VFSL	7	10	9.4	195	7.6	0.28	2.47	0.66
Red River fallow 1971	Gleyed Rego Black	C	64	70	7.5	704	7.7	0.62	5.56	1.12
Red River nonfallow 1971	Gleyed Rego Black	C	6	9	12.0	653	7.7	0.32	4.70	1.59

[1] Measured to a depth of three feet.

TABLE 3

CHARACTERISTICS OF SOIL USED IN GREENHOUSE EXPERIMENT

Soil name	Soil subgroup	Soil texture	NO_3-N (ppm)	$NaHCO_3$ Ext. P (ppm)	NH_4OAc Ext. K (ppm)	pH	Cond. (mmhos/cm)	Carbonate content (% $CaCO_3$)
Altona Ah	Orthic black	VFSCL	4.8	15	444	7.2	0.3	None detected

a specially constructed six row double disc seeder. The experimental design was a randomized block with six replicates. Each treatment consisted of six rows of wheat, twenty feet long and spaced seven inches apart. All sites were sprayed with a 2,4-D ester plus bromoxynil mixture ("Buctril M") at a rate of eight ounces of active ingredient per acre when the wheat was at the three and one-half to four leaf stage. Good weed control was obtained on all plots except on the 1970 Almasippi sites which contained an abundance of green foxtail.

At maturity two 10-foot sections of wheat were cut from the two centre rows of each treatment and every replicate. The samples from each treatment were placed in cotton bags, dried at approximately 80°F, and threshed. The weights of grain were obtained for each treatment and replicate, and composite samples were then made from the various replicates for each treatment. The composite samples were analyzed for nitrogen content by the Kjeldahl procedure. The samples obtained from the Wellwood experiments in 1970 and from the Red River experiments in 1971 were also analyzed for grain, dough and bread quality. These quality tests were also conducted on the wheat obtained from the control treatment (no nitrogen fertilizer added) for all experimental sites except the Almasippi fallow and Altona nonfallow 1970 sites.

2) Fertilizers applied at seeding time

Thirty pounds of P_2O_5 per acre as 11-55-0 was applied with the seed for all treatments and all experimental sites. The phosphorous fertilizer was applied from a standard fertilizer attachment on the seeder. Twenty, 30 40 or 60 lb N/acre as ammonium nitrate (34-0-0) or 20, 30, or 40 lb N/acre as urea (46-0-0) was also applied with the seed in 1970 and 1971. The ammonium nitrate and urea fertilizers were preweighed and placed with the seed by means of a rotating rubber V-belt on the seeder which dropped the fertilizer with the seed as the seeder was moved forward.

Varying amounts of nitrogen were also broadcasted at seeding time. Nitrogen at rates of 30, 60, 90, 120, 180, 240 or 360 lb N/acre as ammonium nitrate (34-0-0) was broadcasted by hand immediately after seeding.

3) Post emergent fertilization

Nitrogen solutions were sprayed onto the wheat plants at various times during the growing season in 1970 and 1971. The equipment used to spray the nitrogen solution was as follows: A pair of steel tracks twenty-two feet long were held above the plant surfaces by four steel stands. The height of the tracks above the plants could be adjusted to any desired height. A spray boom three feet in width was attached to small rollers and pulled along the tracks by a rope and pulley system. The spray boom had three no. 85.067 nozzles which covered a width of three and one-half feet. The height of the track was adjusted so that the nitrogen spray covered the foliar surfaces of the plants. The nitrogen spray solution was supplied to the boom by a trailing rubber hose connected to a fluid tank. Constant pressure was maintained by a portable pressure tank and regulator valves. The amount of spray solution applied was regulated by timing the movement of the boom over the treatment area with a stop watch.

All the nitrogen solutions used in the field experiments contained 10.948 grams of nitrogen in 100 milliliters of water. In 1970, 30 lb N/acre as urea spray or 30 lb N/acre as granular ammonium nitrate was applied at three, five, seven, nine or eleven weeks after seeding to plots treated with 60 lb N/acre as ammonium nitrate at seeding time. At seven and nine weeks after seeding, 15 or 45 lb N/acre as urea solution was also applied to wheat treated with 60 lb N/acre at the time of seeding. Thirty pounds of nitrogen per acre as urea spray was also applied at seven and nine weeks to wheat treated with zero or 120 lb N/acre at time of seeding.

In 1971, 30 lb N/acre as urea, ammonium nitrate or ammonium sulfate spray or 30 lb N/acre as granular ammonium nitrate was applied seven and ten weeks after seeding. At seven weeks after seeding, 30 lb N/acre as urea spray mixed with a wetting agent (0.25% "Tween 20' (polyoxyethlene (20) sorbitan monolaurate) on a volume basis) was also applied. The effects of the wetting agent applied alone were also studied.

C. Description of the Greenhouse Experiment

The greenhouse experiment conducted during the winter of 1971 consisted of 32 treatments replicated three times. A randomized block design was used. Two kilograms of Altona soil (Table 3), previously sieved through a 0.25 inch screen, was placed into one-half gallon glazed pots.

Forty ppm P as KH_2PO_4 and 100 ppm K as KH_2PO_4 and K_2SO_4 were added to all pots at time of seeding. Ammonium nitrate at rates of 25, 50, 75, 100, 125, 200 or 400 ppm N was also added. The fertilizers were dissolved in water and the appropriate amounts added to 2000 g samples of soil. The fertilizer was thoroughly mixed with the soil and the fertilized soil placed into the pots. Eight seeds of Neepawa wheat were placed one-half inch below the soil surface in each pot and the soil was wetted to field capacity. Upon emergence, the seedlings were thinned to five plants per pot. Adequate moisture was maintained throughout the growth period by the daily addition of water. The pots were rotated weekly on the greenhouse bench to minimize error due to variations in light intensity. Additional lighting was provided for a duration of 16 hours each day.

Five and eight weeks after seeding, 25 ppm N as urea, ammonium nitrate or ammonium sulfate solutions, labelled with ^{15}N, were applied to the soil surface or sprayed on the foliar surfaces of the wheat plants treated with 50 ppm of unlabelled nitrogen at time of seeding. Eight weeks after seeding, ^{15}N labelled urea, ammonium nitrate and ammonium sulfate solutions were also applied as sprays or on the soil surfaces to wheat treated with 0 or 100 ppm unlabelled nitrogen at time of seeding. The post emergent ^{15}N labelled nitrogen solutions contained 0.05 g nitrogen per 5 ml of water. The post emergent soil applied ^{15}N was evenly distributed on the soil surface using a pipette. The foliar applied ^{15}N was sprayed onto the foliar surfaces of the wheat plants using a glass atomizer attached to an air hose.

The soil surfaces of all pots were covered with plastic. This prevented excess loss of soil water and prevented the foliar applied fertilizers from falling on the soil surfaces. Thus the foliar applied fertilizers could enter the plant only by foliar absorption. The plants protruded through holes cut in the plastic. To prevent foliar applied ^{15}N from leaking through the holes in the plastic, absorbent cotton and paper towelling were placed on the plastic at time of spraying.

Ninety-eight days after seeding, the plants reached maturity and were harvested. The wheat heads were cut off and threshed by hand. The grain and the straw obtained from each treatment for each replicate were weighed. Composite samples from the various replicates were made for each treatment prior to analysis. All grain samples were washed several times with distilled water to remove nitrogen from the sprays which may have adhered to the external surfaces of the kernels. The samples were then dried at 110°C and finely ground. The total nitrogen content of all samples was then determined. Analysis for ^{15}N content was conducted on all samples of wheat treated with ^{15}N labelled nitrogen fertilizers.

D. Analytical Procedures

1) Soil analysis

a) Field capacity moisture content.

The field capacity moisture content of the soil used in the greenhouse experiment was determined by placing the soil into a 400 ml beaker and adding sufficient water to wet the top one-half of the soil. The beaker was sealed with plastic and allowed to equilibrate for 48 hours. Soil samples were taken above the wetting front and the moisture content of the samples determined.

b) Chemical analysis.

The NO_3-N content of the soils was determined colorimetrically using the phenoldisulphonic acid method described by Black (2). The available phosphorous content of the soils was determined using 0.5 M sodium bicarbonate as the extractant (30). Exchangeable potassium was extracted with 1.0 N ammonium acetate solution adjusted to pH 7 and containing 250 ppm lithium. The potassium content of the extracts were determined on a Baird Atomic Flame Photometer Model KY2. Carbonate content of the soils was determined by gravimetric measurement of CO_2 liberated on digestion of the soil with HCl (2). Conductivity of the soils was measured on a soil/water suspension (1:1 w/w) using a Radiometer type CDM 104 conductivity cell. Organic matter content was determined by chromic acid digestion as described by Walkley and Black (49). pH was measured on a saturated soil water paste using a Universal pH meter equipped with glass and calomel electrodes.

2) Plant analysis

a) Determination of the protein content of the grain.

Finely ground one gram samples of grain were dried in an oven at

$110^{\circ}C$ for 12 hours. Nitrogen content of the samples was determined by the Kjeldahl-Gunning method as described by Jackson (20). The factor used in converting percent nitrogen to percent protein was 5.7. All values for percent protein were expressed on a 13.5% moisture basis.

b) ^{15}N Analysis

The grain samples from the treatments which had been treated with ^{15}N labelled nitrogen fertilizer were analyzed for total nitrogen as described above with the following modifications. Ammonia was distilled into excess 0.1N H_2SO_4 containing methyl red as an indicator. The total nitrogen content of the samples was determined by titrating the excess acid with 0.1N NaOH. The solution was then acidified with a drop of concentrated H_2SO_4 in order to prevent NH_3 volatilization and the total volume reduced to approximately 10 ml by heating on a hotplate. The ammonium was converted to N_2 by hypobromite oxidation in a vacuum system described by Fehr (10) and Pang (3). The isotopic composition of the N_2 was determined by using a MATGD 1500 mass spectrometer.

The atom percent ^{15}N was calculated (2). The following equations were used in calculating the total labelled compound absorbed and percent uptake of ^{15}N labelled fertilizer.

$$\%^{15}N - 0.366 = \%^{15}N \text{ excess in sample} \qquad (1)$$

$$\frac{\text{total N in plant (mg/g)} \times \%^{15}N \text{ excess in sample}}{\%^{15}N \text{ excess in fertilizer}} = \text{total labelled compound absorbed (mg/g of grain)} \qquad (2)$$

$$\frac{\text{yield(g)} \times \text{total labelled compound absorbed}}{\text{total N added (mg/pot)}} \times 100 = \%\text{ uptake of } ^{15}N \text{ labelled fertilizer} \qquad (3)$$

The value 0.366 indicates the natural abundance of ^{15}N in the atmosphere. The % ^{15}N excess in the fertilizer was given by the manufacturer.

c) Wheat quality tests.

Standard AACC (1) quality tests on wheat, flour, dough and bread were conducted on the grain from selected field experiments. All the determinations were conducted according to methods approved by the AACC (1) with the exception of loaf volume (19) and ash content (22).

IV. RESULTS AND DISCUSSION

A. Field Experiments

1) The effect of time and method of application, and amount and source of nitrogen on the yield of wheat.

a) The effect of soil nitrate nitrogen content on yield.

Wheat yields, when no nitrogen fertilizer was added, were greater on the fallow sites than on the nonfallow sites (Tables 4 and 5). The fallow sites contained greater amounts of nitrate nitrogen than the nonfallow sites. Thus, the yield of wheat without added nitrogen was related to the nitrate nitrogen content of the soil. Field experiments conducted by Soper et al. (41) showed that nitrogen uptake by barley was related to soil nitrate nitrogen content. They also found a very good relationship between nitrogen uptake and yield. Therefore, the relationship obtained between yield of wheat and soil nitrate nitrogen content was expected.

The yields obtained in 1971 were generally greater than those obtained in 1970 (Tables 4 and 5). This was particularly evident for the fallow control treatments (only 11-55-0 added) and the nonfallow treatments which had been treated with high rates of applied nitrogen. In 1971, wheat yield on the Altona fallow control treatment was over 15 bu/acre higher than on the 1970 Altona fallow, even though the soil nitrate nitrogen contents were similar.

b) The effect of nitrogen broadcasted at time of seeding on yield.

Yields obtained on the Altona fallow site in 1970 were not significantly affected when ammonium nitrate at rates of 30 to 360 lb N/acre were broadcasted at time of seeding (Table 4). The absence of a yield response was probably due to the high nitrate nitrogen content of the soil (40). Addition of 30, 90 or 180 lb N/acre at the Altona nonfallow

TABLE 4

THE EFFECT OF ADDED NITROGEN ON THE YIELD OF WHEAT (1970)

Source, Rate and Method of Application[1]	Yield (bu/acre)					
	Altona fallow 1970	Altona nonfallow 1970	Almasippi fallow 1970	Almasippi nonfallow 1970	Wellwood fallow 1970	Wellwood nonfallow 1970
0	42.6_{a-c}[5]	26.3_{a}	32.3_{e-g}	20.3_{c-f}	39.8_{g-i}	14.6_{a}
NH_4NO_3 20D[2]	43.2_{a-c}	30.3_{ab}	28.6_{c-f}	23.8_{d-f}	37.2_{c-i}	20.8_{c}
NH_4NO_3 30D	45.6_{bc}	33.7_{a-f}	30.9_{d-g}	21.9_{c-f}	37.5_{c-i}	22.9_{c-e}
NH_4NO_3 40D	39.5_{a}	39.0_{c-i}	29.6_{c-f}	22.3_{d-f}	36.0_{b-h}	26.5_{d-f}
NH_4NO_3 60D	39.1_{a}	35.4_{b-g}	25.1_{a-c}	25.0_{f}	36.5_{b-h}	30.8_{f-k}
Urea 20D	40.7_{a}	32.6_{a-e}	28.7_{c-f}	18.6_{b-e}	37.0_{c-i}	20.6_{c}
Urea 30D	40.9_{ab}	32.4_{a-e}	22.9_{ab}	16.1_{a-c}	38.7_{e-i}	22.1_{cd}
Urea 40D	39.7_{a}	35.7_{b-g}	21.6_{a}	12.4_{a}	39.1_{f-i}	22.5_{c-e}
NH_4NO_3 30B[3]	43.4_{a-c}	32.3_{a-e}	29.9_{c-f}	24.8_{e-f}	40.7_{i}	23.9_{c-e}
NH_4NO_3 60B	40.4_{a}	36.9_{b-i}	27.9_{b-e}	22.5_{d-f}	35.5_{f}	29.5_{f-k}
NH_4NO_3 90B	40.2_{a}	33.8_{a-f}	30.2_{c-f}	24.3_{ef}	33.6_{a-c}	34.6_{k-o}
NH_4NO_3 120B	42.7_{a-c}	37.3_{b-i}	31.8_{d-g}	25.3_{f}	35.5_{a-f}	37.2_{no}
NH_4NO_3 180B	39.1_{a}	31.8_{a-c}	36.0_{g}	24.1_{ef}	34.1_{a-d}	38.8_{no}
NH_4NO_3 240B	41.0_{ab}	35.2_{b-g}	30.1_{c-f}	23.1_{d-f}	32.5_{ab}	36.2_{l-o}
NH_4NO_3 360B	42.1_{a-c}	35.7_{b-g}	31.1_{d-g}	24.3_{ef}	31.7_{a}	37.7_{no}
60B 30S @ 3 wks[4]	40.9_{ab}	33.9_{a-f}	30.4_{c-f}	22.7_{d-f}	35.9_{b-g}	34.5_{j-o}
60B 30S @ 5 wks	42.6_{a-c}	32.2_{a-d}	30.4_{c-f}	23.4_{d-f}	34.4_{a-d}	31.0_{f-k}
60B 30S @ 7 wks	41.4_{a-c}	39.1_{c-i}	32.6_{fg}	19.8_{c-f}	35.5_{a-f}	34.1_{i-n}
60B 30S @ 9 wks	41.0_{ab}	37.2_{b-i}	33.2_{fg}	24.5_{ef}	37.7_{c-i}	28.9_{f-i}
60B 30S @ 11 wks	44.8_{a-c}	36.4_{b-h}	30.8_{d-g}	24.6_{ef}	36.7_{c-i}	31.9_{g-l}
60B 30B @ 3 wks	42.9_{a-c}	42.0_{f-i}	31.4_{d-g}	23.3_{d-f}	34.6_{a-e}	32.6_{h-m}
60B 30B @ 5 wks	40.1_{a-c}	44.5_{h-i}	32.9_{fg}	22.6_{d-f}	37.1_{c-i}	30.8_{f-k}
60B 30B @ 7 wks	39.6_{a}	42.6_{g-i}	28.1_{c-f}	21.7_{c-f}	37.9_{d-i}	33.3_{i-m}
60B 30B @ 9 wks	40.7_{a}	39.9_{c-i}	29.7_{c-f}	21.0_{c-f}	34.0_{a-d}	26.2_{d-f}
60B 30B @ 11 wks	39.2_{a}	40.0_{c-i}	28.9_{c-f}	23.5_{d-f}	33.7_{a-c}	26.6_{d-g}
0B 30S @ 7 wks	42.9_{a-c}	39.9_{a-f}	27.2_{b-d}	17.7_{a-d}	38.7_{e-i}	18.6_{bc}
0B 30S @ 9 wks	46.3_{c}	33.1_{a-e}	28.1_{c-f}	13.3_{ab}	40.1_{hi}	15.4_{ab}
120B30S @ 7 wks	39.5_{a}	40.2_{d-i}	30.2_{c-f}	21.3_{c-f}	36.3_{b-h}	39.9_{o}
120B30S @ 9 wks	40.2_{a}	40.6_{e-i}	33.3_{fg}	22.9_{d-f}	37.0_{c-i}	36.7_{m-o}
60B 15S @ 7 wks	42.2_{a-c}	33.6_{a-e}	30.9_{d-g}	23.7_{d-f}	35.6_{a-f}	29.0_{f-j}
60B 45S @ 7 wks	41.1_{ab}	40.1_{c-i}	30.0_{c-f}	20.9_{c-f}	35.4_{a-f}	33.5_{i-n}
60B 15S @ 9 wks	43.8_{a-c}	44.9_{i}	30.8_{d-g}	21.7_{c-f}	35.4_{a-f}	29.6_{f-k}
60B 45S @ 9 wks	41.7_{a-c}	32.7_{a-e}	31.1_{d-g}	22.4_{d-f}	37.3_{c-i}	27.6_{e-h}

1 All treatments were treated with 30 lb P_2O_5/acre with the seed as 11-55-0. All rates are given in lb N/acre.

2 D = drilled with the seed.

3 Broadcast at time of seeding.

4 First figure indicates rate of NH_4NO_3 broadcast at seeding time and second figure indicates rate of post emergent urea spray(S) or NH_4NO_3 (B) broadcast.

5 Duncan's multiple range test. Yields followed by the same letter are not significantly different at the 5% P level.

TABLE 5

THE EFFECT OF ADDED NITROGEN ON THE YIELD OF WHEAT (1971)

Source, rate and method of N application[1]	Yield (bus/acre) Altona fallow 1971	Altona nonfallow 1971	Red River fallow 1971	Red River nonfallow 1971
0	57.8_{c-e}[6]	21.1_{a}	46.3_{bc}	21.9_{a}
NH_4NO_3 20D[2]	57.7_{c-e}	29.8_{b}	47.5_{b-d}	32.2_{bc}
NH_4NO_3 30D	56.6_{c-e}	36.2_{b-d}	50.0_{b-g}	39.2_{d}
NH_4NO_3 40D	58.5_{c-e}	43.0_{e-h}	55.6_{gh}	43.5_{d-f}
NH_4NO_3 60D	58.9_{de}	46.5_{g-i}	54.3_{e-h}	48.2_{f-h}
Urea 20D	57.3_{c-e}	29.8_{b}	50.7_{b-h}	29.3_{b}
Urea 30D	53.9_{b-d}	35.4_{b-d}	49.9_{b-f}	37.5_{cd}
Urea 40D	57.1_{c-e}	38.5_{c-e}	52.1_{c-h}	37.5_{cd}
NH_4NO_3 30B[3]	62.3_{e}	33.2_{bc}	52.2_{c-h}	37.2_{cd}
NH_4NO_3 60B	58.8_{de}	39.4_{c-f}	53.7_{d-h}	42.2_{d-f}
NH_4NO_3 90B	57.4_{c-e}	47.7_{hi}	55.3_{f-h}	50.4_{g-i}
NH_4NO_3 120B	59.6_{de}	52.9_{ij}	56.6_{h}	51.4_{g-i}
NH_4NO_3 180B	57.7_{c-e}	57.6_{j}	55.8_{gh}	50.6_{g-i}
NH_4NO_3 240B	57.0_{c-e}	51.8_{ij}	56.1_{gh}	55.1_{i}
NH_4NO_3 360B	55.3_{b-d}	58.2_{j}	51.1_{b-h}	51.7_{g-i}
60B 30S urea @ 7 wks[4]	58.3_{c-e}	52.3_{ij}	56.2_{gh}	46.7_{e-h}
60B 30S NH_4NO_3 @ 7 wks	56.5_{c-e}	44.2_{e-h}	48.5_{b-e}	41.3_{de}
60B 30S $(NH_4)_2SO_4$ @ 7 wks	43.4_{a}	44.4_{e-h}	45.6_{b}	42.9_{d-f}
60B 30B NH_4NO_3 @ 7 wks	58.7_{de}	52.8_{ij}	54.9_{e-h}	52.2_{h-i}
60B 30S Urea @ 10 wks	54.9_{bd}	47.2_{hi}	54.1_{e-h}	48.0_{f-h}
60B 30S NH_4NO_3 @ 10 wks	49.7_{b}	40.3_{d-g}	46.4_{bc}	43.2_{d-f}
60B 30S $(NH_4)_2SO_4$ @ 10 wks	38.5_{a}	24.2_{a}	29.1_{a}	31.5_{b}
60B 30B NH_4NO_3 @ 10 wks	56.7_{c-e}	47.5_{h-i}	51.8_{b-h}	48.4_{f-h}
60B 30S Urea & W.A.[5] @ 7 wks	52.4_{bc}	49.8_{hi}	52.9_{d-h}	52.4_{hi}
60B with W.A. @ 7 wks	59.1_{de}	45.9_{f-i}	54.8_{e-h}	45.8_{e-g}

1 All treatments were treated with 30 lb P_2O_5/acre with the seed as 11-55-0. All rates are given in lb N/acre.

2 D = drilled with the seed.

3 Broadcast at time of seeding.

4 First figure indicates rate of NH_4NO_3 broadcast at time of seeding and second figure indicates rate of post emergent spray(S) broadcast (B).

5 Wetting agent ("Tween 20" - polyoxyethlene (20) sorbitan monolaurate).

6 Duncan's multiple range test. Yields followed by the same letter are not significantly different at the 5% P level.

site did not significantly increase yields above that of the control treatment. Yields were significantly increased above that of the control treatment when 60, 120, 240 or 360 lb N/acre were added. Both of the Almasippi sites produced poor yields in 1970 and did not respond significantly to additions of broadcast nitrogen, although the nonfallow site contained small amounts of nitrate nitrogen. The absence of a response to additional nitrogen was probably due to a heavy infestation of green foxtail. Nitrogen, at rates greater than 30 lb N/acre significantly decreased yields on the Wellwood fallow site in 1970. The yield decrease with large amounts of applied nitrogen was probably due to lodging of the grain which was particularly evident on the plots treated with large amounts of fertilizer nitrogen. The lodging probably occurred as a result of a combination of high soil nitrate nitrogen content (131 lb NO_3-N to a depth of 2 ft) and applied nitrogen. In 1970, significant and consistent yield responses were obtained only on the Wellwood nonfallow site. Yield was increased from 14.6 bushels per acre (control treatment) to 34.6 bushels per acre when 90 lb N/acre was added. However, yields obtained with 60, 90, 120, 180, 240 or 360 lb N/acre were not significantly different.

Yield increases with added nitrogen were usually greater in 1971 than in 1970. This was probably due to the higher yields obtained in 1971. Yields obtained in 1971 at the Altona fallow site were not significantly increased when ammonium nitrate fertilizer was applied broadcast (Table 5). The yield of wheat on the Altona nonfallow site was significantly lower without, than with applied fertilizer. The yields obtained when 120 lb N/acre or more were applied were not significantly different. The yield of wheat increased with increases in added nitrogen up to 90 lb N/acre. On the Red River fallow site, wheat yields obtained with 60 lb N/acre or more were significantly higher than when no nitrogen was applied, but were not significantly greater than the yield obtained with 30 lb N/acre broadcast at seeding time. Yields on the Red River nonfallow site were significantly increased by addition of nitrogen fertilizer. Yield of wheat increased with increases in the amount of nitrogen added when 90 lb N/acre or less was added. The yields obtained when 90 lb N/acre or more were applied were not significantly different.

c) The effect of nitrogen applied with the seed on yield.

The yield on the Altona fallow site in 1970 was not significantly higher or lower than the control treatment when urea or ammonium nitrate was drilled with the seed (Table 4). Yields were similar when nitrogen at equivalent rates were broadcasted or drilled in with the seed. Since little or no response to nitrogen fertilization occurred at this site, no difference between nitrogen source or methods of fertilizer application would be expected. On the Altona nonfallow site in 1970, 40 and 60 lb N/acre as ammonium nitrate and 40 lb N/acre as urea drilled with the seed produced yields significantly greater than the control treatment. The yield increases were about nine to thirteen bushels per acre. However, none of the yields obtained with the drilled treatments were significantly different from yields obtained with 30 lb N/acre as ammonium nitrate broadcast. Yields on the Almasippi fallow site in 1970 were significantly lower than that obtained on the control treatment when 60 lb N/acre as ammonium nitrate or 30 or 40 lb N/acre as urea were drilled in with the seed. Carefoot (4) and Toews (44) also found that urea at rates greater than 20 lb N/acre reduced yields of cereal crops particularly on coarse textured soils and when the soil moisture content was low. Carefoot (4) reported that the reduction in yield in barley due to urea fertilizer was caused by reduced germination resulting from the accumulation of ammonia in the soil solution. To a lesser extent, Carefoot (4) attributed yield reductions to: (1) accumulation of nitrite in the soils; (2) entry of urea into the seed followed by enzymatic hydrolysis of urea in the seed and subsequent accumulation of ammonia; (3) high osmotic potentials in the soil solution caused by urea and its reaction products. High rates of ammonium nitrate fertilizer with the seed were found to reduce barley yields by a toxic and osmotic effect on the seed. Since, Toews (44) and Carefoot (4) found that seed damage from urea or ammonium nitrate fertlizer was greatest in coarse textured soils of a high pH, it is not surprising that the yields on the Almasippi fallow site were reduced when more than 20 lb N/acre as urea or more than 40 lb N/acre as ammonium nitrate was drilled with the seed. Similar yield reductions occurred on the Almasippi nonfallow site when more than 20 lb N/acre as urea was drilled with the seed. The addition of ammonium nitrate or 20 lb N/acre as urea with the seed did not produce yields significantly different from that of the control treatment or from that produced with 30 lb N/acre as ammonium nitrate broadcast on the Altona nonfallow site. Yields obtained when nitrogen was applied with the seed on the Wellwood fallow site in 1970 were usually lower than that of the control treatment. However, these yield differences were not significant. All treatments with seed applied nitrogen fertilizer on the Wellwood nonfallow site produced yields significantly greater than the control treatment. Yields were similar when nitrogen at similar rates was broadcasted or drilled in with the seed.

Yields on the Altona fallow site in 1971 followed the trends noted for the 1970 Altona fallow site (Table 5). No significant yield increases were found when urea or ammonium nitrate was applied with the seed. Yields when ammonium nitrate at 40 or 60 lb N/acre were applied with the seed on the Red River fallow site were significantly greater than the yield of the control treatment. No significant differences were noted between seed applied and broadcast nitrogen. In 1971 both the Altona and Red River nonfallow sites responded similarily to nitrogen applied with the seed. All yields with seed applied nitrogen were significantly greater than the yield of the control treatment. Yields increased with increased amounts of nitrogen applied with the seed. Although yields with ammonium nitrate were generally greater than with urea, these differences were not significant. Yields with broadcast and seed applied nitrogen at equivalent rates were similar.

d) The effect of post emergent nitrogen fertilizer on the yield of wheat.

The wheat yields obtained in 1970 for the post emergent nitrogen applications are shown in Table 4. The yields obtained with 90 lb N/acre applied in the spring were usually not significantly different from the yields obtained when 60 lb N/acre was applied at seeding time followed by the addition of 30 lb N/acre as a post emergent foliar spray or soil application. Only in four instances were significant differences in the above treatments noted. These were as follows: The yields on the Altona nonfallow site with ammonium nitrate broadcast five and seven weeks after seeding and the yield on the Wellwood nonfallow site with urea sprayed at nine weeks. These differences in yield, although statistically significant, may be due to experimental error as the yields for these treatments are higher or lower than those obtained for similar treatments. The other yield differences occurred on the Wellwood nonfallow site. The yields when ammonium nitrate was broadcast at nine and eleven weeks after seeding were significantly lower than when 90 lb N/acre was applied at seeding time. These post emergent soil nitrogen fertilizer applications were probably made too late in the growing season to be utilized by the plants since neither of the yields differ from that obtained with 60 lb N/acre at seeding time.

The yields on all experimental sites, when no nitrogen was applied at seeding time followed by post emergent spray application were usually not significantly different than the yields of the control treatments or the yields obtained with 30 lb N/acre broadcasted at seeding time. Only on the Almasippi nonfallow site was the yield for the post emergent spray, applied nine weeks after seeding, significantly lower than that for the control treatment. This may have been due to leaf burn which resulted from the application of the sprays. However, in 1970, leaf burn on the the wheat treated with urea spray, was generally not very pronounced. Similarily, no consistent yield differences were found between 120 lb N/acre applied at time of seeding and 120 lb N/acre applied at time of seeding followed by post emergent nitrogen spray applications. Also no consistent yield differences were found between 90 lb N/acre applied at time of seeding followed by the application of 15 or 45 lb N/acre as urea spray at seven or nine weeks after seeding.

In 1971, visual inspection of the plots, one day after spraying, showed that the extent of leaf burn was related to the form of nitrogen solution used. Crop damage from sprays decreased in the order: $(NH_4)_2SO_4 > NH_4NO_3 >$ urea with wetting agent $>$ urea. As found in 1970, the urea foliar spray resulted in a very small amount of leaf burn. The ammonium sulfate caused extensive crop damage, turning the foliar surfaces grey to brown in color. Treatments sprayed with ammonium sulfate were readily descernible at a distance from the experimental site. Yields when ammonium sulfate was sprayed were usually lower than when ammonium nitrate or urea was used (Table 5). These yield differences were more pronounced when ammonium sulfate was applied ten weeks after seeding than when applied at seven weeks after seeding. Yields of wheat sprayed with ammonium nitrate were also reduced, however, usually not as much as those sprayed with ammonium sulfate. Yields of wheat sprayed with urea or treated with granular ammonium nitrate at seven or ten weeks after seeding were not significantly different from the yields obtained with 90 lb N/acre applied at time of seeding. The addition of wetting agent did not influence yields.

2) The effect of time and method of application and amount and source of nitrogen on the protein content of wheat.

a) The effect of soil nitrate nitrogen content on the protein content of wheat.

The protein contents of grain from the control treatments of the 1971 field experiments were lower than that from the 1970 field experiments at comparable soil nitrate nitrogen contents (Table 6). This was probably due to the higher yields obtained in 1971. Protein contents of wheat grown on fallow sites were higher than for wheat grown on nonfallow sites and was related to the nitrate nitrogen content of the soil. Regardless of the yearly variation in protein contents, a good agreement between soil nitrate nitrogen content and protein content of wheat was obtained (Table 7). The r^2 values for the logarithmic, linear and exponential regression equations were 0.57, 0.66 and 0.66, respectively, when soil nitrate nitrogen content was measured to a depth of two feet. The r^2 values increased as depth of sampling was increased. In a similar study, Nuttall (29) found an r^2 value of 0.702 when soil nitrate nitrogen content

TABLE 6

EFFECT OF SOIL NITRATE NITROGEN CONTENT ON THE PROTEIN CONTENT OF WHEAT

Location and year	Soil NO_3-N content (lb/acre)		Protein[1] content (%)
	0 - 24"	0 - 48"	
Wellwood 1970 fallow	131	165	15.5
Almasippi 1970 fallow	83	136	14.2
Altona 1970 fallow	69	92	14.8
Altona 1971 fallow	67	86	12.9
Red River 1971 fallow	64	70	11.6
Almasippi 1970 nonfallow	38	60	13.7
Altona 1970 nonfallow	18	30	12.1
Wellwood 1970 nonfallow	13	16	11.4
Altona 1971 nonfallow	7	10	11.3
Red River 1971 nonfallow	6	9	12.1

1 Protein content of wheat treated with 30 lb P_2O_5/acre as 11-55-0.

TABLE 7

COEFFICIENTS OF DETERMINATION BETWEEN WHEAT PROTEIN CONTENT AND NITRATE NITROGEN IN THE SOIL

Depth of sampling (inches)	Regression equation	Coefficient of determination (r^2)
0 - 24	$\%P = 9.36 + 2.38 \text{ Log}_{10} X$	0.57*
0 - 48	$\%P = 8.71 + 2.57 \text{ Log}_{10} X$	0.62**
0 - 24	$\%P = 11.54 + 0.0302 X$	0.66**
0 - 48	$\%P = 11.3 + 0.0241 X$	0.74**
0 - 24	$\%P = 11.5 + 0.0275 X + 0.0000221 X^2$	0.66*
0 - 48	$\%P = 11.4 + 0.0223 X + 0.0000109 X^2$	0.74**

%P = percent protein in grain

X = soil nitrate nitrogen content (lb/acre)

* significant at the 5% P level

** significant at the 1% P level

measured to a depth of two feet and the protein content of Conquest barley were related using an exponential regression equation.

b) The effect of nitrogen broadcast at time of seeding on the protein content of wheat.

Protein content of wheat increased with the addition of small amounts of broadcast nitrogen on the fallow sites (Table 8). Usually maximum protein contents of wheat grown on the fallow sites were obtained without the addition of extremely large amounts of nitrogen. The amount of added nitrogen required to achieve maximum protein contents of wheat on the fallow sites varied with the soil nitrate nitrogen content and the year. Substantial increases in protein content did not occur on the Wellwood and Almasippi fallow sites in 1970 when rates of nitrogen above 90 lb N/acre were added and when rates of nitrogen above 120 lb N/acre were added to the Altona fallow site in 1970 and 1971. Maximum protein content was achieved on the Red River fallow site in 1971 only when 240 or 360 lb N/acre was added, although substantial increases in protein content with added nitrogen did not occur when more than 240 lb N/acre was added.

The protein content of wheat grown on the nonfallow sites usually increased with increased amounts of nitrogen added when more than 30 lb N/acre was added. The protein content of wheat obtained from the control treatments of the Red River and Altona nonfallow sites in 1971 and the Wellwood nonfallow site in 1970 was greater than that obtained with 30 lb N/acre. This was due to the large yield increases obtained. Protein contents decreased or increased only slightly when large yield increases were obtained for each increment of added nitrogen. Application of low rates of added nitrogen (30 or 60 lb N/acre) was utilized by the plant for the

TABLE 8

THE EFFECT OF NITROGEN APPLIED BROADCAST AT TIME OF SEEDING ON THE PROTEIN CONTENT OF WHEAT

	Protein Content (%)									
Nitrogen added[1] (lb/acre)	Altona fallow 1970	Altona nonfallow 1970	Almasippi fallow 1970	Almasippi nonfallow 1970	Wellwood fallow 1970	Wellwood nonfallow 1970	Altona fallow 1971	Altona nonfallow 1971	Red River fallow 1971	Red River nonfallow 1971
0	14.8	12.1	14.2	13.7	15.5	11.4	12.9	11.3	11.6	12.1
30	15.7	12.3	14.7	14.0	15.3	10.8	14.1	11.0	12.1	10.5
60	16.6	13.6	14.9	14.2	16.3	11.1	14.9	10.9	13.2	10.9
90	16.7	15.0	15.4	15.1	16.5	13.1	15.3	11.5	14.4	12.4
120	17.2	15.7	14.9	15.4	16.6	15.0	15.6	13.1	14.8	14.0
180	17.5	17.1	15.4	15.5	16.8	15.5	16.0	15.2	14.8	15.0
240	17.6	17.1	14.9	16.0	17.0	15.9	15.9	15.8	15.6	15.3
360	17.3	17.6	15.2	16.3	17.0	16.3	15.7	16.3	15.7	15.5

1 All treatments were treated with 30 lb P_2O_5 /acre as 11-55-0.

enhancement of vegetative growth, and hence, yield was increased rather than grain protein content. Protein content of wheat on the nonfallow sites greatly increased with increased amounts of added nitrogen when yields remained relatively constant. This rapid increase in protein content with added nitrogen usually occurred when 90 to 180 lb N/acre was added. Protein contents, when greater than 180 lb N/acre was added to the nonfallow sites, increased only moderately with increasing amounts of added nitrogen.

The protein content of wheat as a function of soil nitrate nitrogen content and fertilizer nitrogen applied broadcast at time of seeding is shown in Table 9. A good agreement between percent protein and nitrogen supply (nitrogen from the soil and added nitrogen) was obtained. The R^2 values obtained for the above relationship for the linear and exponential regression equations were 0.53 and 0.73, respectively, when measurements for soil nitrate nitrogen were made to a depth of two feet. The values were slightly greater when nitrate nitrogen was measured to a depth of four feet.

c) The effect of nitrogen added with the seed on the protein content of wheat.

Equivalent rates of ammonium nitrate or urea applied with the seed and ammonium nitrate broadcast at time of seeding produced wheat with about the same protein content (Table 10). Only in 1971, did 60 lb N/acre as ammonium nitrate drilled with the seed consistently produce wheat with a higher protein content than 60 lb N/acre as ammonium nitrate applied broadcast. Protein contents of wheat on the fallow sites in 1970 were usually only slightly increased by urea and ammonium nitrate applied with the seed. However, in 1971, protein contents on the fallow sites increased

TABLE 9

COEFFICIENTS OF DETERMINATION BETWEEN WHEAT PROTEIN CONTENT, SOIL NITRATE NITROGEN AND NITROGEN APPLIED BROADCAST AT TIME OF SEEDING

Depth of sampling (inches)	Regression equation	Coefficient of determination (R^2)
0 - 24	$\%P = 12.4 + 0.0215\ X_1 + 0.000966\ X_2$	0.53**
0 - 24	$\%P = 9.86+0.0586X_1-0.000128X_1^2+0.0357X_2-0.0000495X_2^2-0.000138X_1X_2$	0.73**
0 - 48	$\%P = 12.4 + 0.0163\ X_1 + 0.00966\ X_2$	0.54**
0 - 48	$\%P = 9.53+0.0542X_1-0.000129X_1^2+0.0363X_2-0.0000495X_2^2-0.000110X_1X_2$	0.76**

%P = percent protein in grain

X_1 = soil nitrate nitrogen content (lb/acre)

X_2 = fertilizer nitrogen added (lb/acre)

** significant at the 1% P level

TABLE 10

THE EFFECT OF AMMONIUM NITRATE AND UREA APPLIED WITH THE SEED ON THE PROTEIN CONTENT OF WHEAT

Protein Content (%)

Fertilizer source and method of application	Altona fallow 1970	Altona nonfallow 1970	Almasippi fallow 1970	Almasippi nonfallow 1970	Wellwood fallow 1970	Wellwood nonfallow 1970	Altona fallow 1971	Altona nonfallow 1971	Red River fallow 1971	Red River nonfallow 1971
0[1]	14.8	12.1	14.2	13.7	15.5	11.4	12.9	11.3	11.6	12.1
NH_4NO_3 20 lb N/acre D[2]	15.2	11.7	14.7	13.0	15.7	10.6	14.1	10.6	11.7	10.7
NH_4NO_3 30 lb N/acre D	15.2	12.5	14.8	13.6	16.2	10.6	14.2	10.7	12.1	10.4
NH_4NO_3 40 lb N/acre D	16.5	13.3	14.4	13.9	16.0	11.0	15.1	10.4	13.0	10.7
NH_4NO_3 60 lb N/acre D	16.3	12.8	14.7	14.2	16.0	11.2	15.6	11.2	14.0	11.1
Urea 20 lb N/acre D	16.1	12.4	14.5	13.2	15.7	10.8	13.7	10.6	11.6	10.5
Urea 30 lb N/acre D	15.7	12.8	14.6	13.6	15.5	10.8	14.2	10.6	12.4	10.6
Urea 40 lb N/acre D	16.2	12.4	14.3	14.4	15.9	10.8	15.0	10.3	12.9	10.7
30 lb N/acre B[3]	15.7	12.3	14.7	14.0	15.3	10.8	14.2	11.0	12.1	10.5
60 lb N/acre B	16.6	13.6	14.9	14.2	16.3	11.1	14.9	10.9	13.2	10.9

1 All treatments treated with 30 lb P_2O_5/acre as 11-55-0.

2 Drilled at time of seeding.

3 NH_4NO_3 broadcast at time of seeding.

quite markedly with increased rates of seed applied nitrogen. This difference in protein response to added nitrogen was probably due to higher yields and the lower protein contents encountered in 1971. Due to the exponential relationship between wheat protein content, soil nitrate nitrogen and nitrogen applied with the seed, (Table 11), low values of wheat protein content will increase more markedly than will high values of wheat protein content with applied nitrogen provided a large yield increase is not obtained. This is evident for the data obtained for the 1971 fallow sites.

Protein contents of wheat grown on the nonfallow sites were only slightly increased or decreased with increased amounts of nitrogen applied with the seed. As previously discussed, the additon of low rates of nitrogen to nonfallow sites is manifested in yield increases rather than in increases in protein content. However, protein content on the Almasippi nonfallow sites which had yield decreases when urea was applied with the seed, did not change substantially from that of the control treatment. The added nitrogen, in this case, appears not to have been utilized by the plant.

Regression analysis conducted between protein content, soil nitrate nitrogen and nitrogen applied with the seed are shown in Table 11. The R^2 values obtained when ammonium nitrate was applied with the seed were higher than when urea was applied with the seed. However, in both cases, good agreement between protein content and nitrogen supply (soil nitrate nitrogen and nitrogen applied with seed) was obtained, particularly with the exponential regression equations and when soil nitrate nitrogen was measured to a depth of four feet. The R^2 value for the exponential regression equation was 0.87 when ammonium nitrate was applied with the seed and

TABLE 11

COEFFICIENTS OF DETERMINATION BETWEEN PROTEIN CONTENT OF WHEAT, SOIL NITRATE NITROGEN AND NITROGEN APPLIED WITH THE SEED

Treatment	Depth of sampling (inches)	Regression equation	Coefficient of determination (R^2)
NH_4NO_3 Drilled	0 - 24	$\%P = 10.2 + 0.0444\ X_1 + 0.0232\ X_2$	0.76**
NH_4NO_3 Drilled	0 - 24	$\%P = 8.99+0.0836X_1-0.000310X_1{}^2+0.0508X_2-0.000320X_2{}^2-0.0000296X_1X_2$	0.82**
NH_4NO_3 Drilled	0 - 48	$\%P = 10.1 + 0.0342\ X_1 + 0.0232\ X_2$	0.79**
NH_4NO_3 Drilled	0 - 48	$\%P = 8.61+0.073X_1-0.000226X_1{}^2+0.0534X_2-0.000320X_2{}^2-0.0000612X_1X_2$	0.87**
Urea Drilled	0 - 24	$\%P = 10.7 + 0.0423\ X_1 + 0.00900\ X_2$	0.66**
Urea Drilled	0 - 24	$\%P = 9.47+0.0747X_1-0.000275X_1{}^2+0.0546X_2-0.000799X_2{}^2-0.0000480X_1X_2$	0.70**
Urea Drilled	0 - 48	$\%P = 10.5 + 0.0334\ X_1 + 0.00900\ X_2$	0.71**
Urea Drilled	0 - 48	$\%P = 9.18+0.0647X_1-0.000204X_1{}^2+0.0534X_2-0.000799X_2{}^2-0.0000525X_1X_3$	0.77**

%P = percent protein

X_1 = soil nitrate nitrogen content (lb N/acre)

X_2 = N added (lb N/acre)

** significant at the 1% P level

soil sampling was conducted to a depth of four feet. The R^2 values obtained using a linear regression equation were lower than when an exponential regression equation was used.

d) The effect of post emergent nitrogen applications on the protein content of wheat.

The protein content of wheat grown on the nonfallow sites was usually increased above that obtained with 60 lb N/acre applied at time of seeding when urea foliar spray or ammonium nitrate was broadcasted at various times during the growing season on wheat previously treated with 60 lb N/acre at time of seeding (Table 12). However, in most instances, the addition of 90 lb N/acre at time of seeding to the nonfallow sites resulted in protein contents equal to or exceeding those obtained from the above mentioned split applications. The post emergent fertilizers' effectiveness in increasing protein contents on the nonfallow sites decreased as time of application after seeding increased. Post emergent broadcast nitrogen was generally more effective in increasing the protein content of wheat on the nonfallow sites than the spray treatments, except at the nine and eleven week application times, when it was usually less effective. The protein content of wheat grown on the fallow sites was not greatly influenced by the post emergent urea fertilizer spray or the 30 lb N/acre broadcast treatment.

Protein contents were consistently increased in only two instances when 30 lb N/acre as urea spray was applied at seven and nine weeks after seeding to wheat not previously treated with broadcast nitrogen. The protein contents of wheat treated with the urea spray on the Altona and Wellwood nonfallow sites were considerably higher than that obtained when 30 lb N/acre was applied broadcast at time of seeding. Protein content

TABLE 12

THE EFFECT OF POST EMERGENT NITROGEN FERTILIZERS
ON THE PROTEIN CONTENT OF WHEAT
(Field experiments 1970)

Source, rate and[1] method of N application	Protein content (%)					
	Altona fallow 1970	Altona nonfallow 1970	Almasippi fallow 1970	Almasippi nonfallow 1970	Wellwood fallow 1970	Wellwood nonfallow 1970
0	14.8	12.1	14.2	13.7	15.5	11.4
30 B[2]	15.7	12.3	14.7	14.0	15.3	10.8
60 B	16.6	13.6	14.9	14.2	16.3	11.1
90 B	16.7	15.0	15.4	15.1	16.5	13.1
120 B	17.2	15.7	14.9	15.4	16.6	15.0
60B 30S @ 3 wks[3]	16.6	14.9	14.8	15.3	16.0	12.1
60B 30S @ 5 wks	16.4	14.2	14.6	15.0	16.2	12.3
60B 30S @ 7 wks	16.8	14.7	14.9	14.9	16.2	12.3
60B 30S @ 9 wks	17.1	14.3	15.6	14.8	16.8	12.5
60B 30S @ 11 wks	16.6	13.8	15.3	14.6	16.8	12.1
60B 30B @ 3 wks	16.8	15.4	15.0	14.9	16.3	13.1
60B 30B @ 5 wks	17.2	15.1	14.5	14.7	16.2	12.8
60B 30B @ 7 wks	17.2	15.8	15.2	15.1	15.9	12.3
60B 30B @ 9 wks	16.5	13.2	14.9	14.4	16.0	11.4
60B 30B @ 11 wks	16.9	14.1	15.0	13.8	15.8	11.5
0B 30S @ 7 wks	15.7	13.8	14.5	14.1	16.0	12.0
0B 30S @ 9 wks	15.9	13.3	15.1	13.8	15.6	12.3
120B 30S @ 7 wks	17.4	16.6	15.4	15.5	17.0	14.5
120B 30S @ 9 wks	17.8	16.6	14.9	15.8	16.6	15.0
60B 15S @ 7 wks	16.8	14.6	15.6	14.5	16.1	12.2
60B 45S @ 7 wks	16.7	14.7	15.8	14.9	16.1	12.7
60B 15S @ 9 wks	16.8	14.1	15.1	14.4	16.9	12.3
60B 45S @ 9 wks	17.3	14.5	15.7	15.4	17.0	13.0

1 All treatments were treated with 30 lb P_2O_5/acre as 11-55-0.

2 Nitrogen broadcast at time of seeding as NH_4NO_3 in lb N/acre.

3 First figure indicates NH_4NO_3 broadcast (B) in lb N/acre at time of seeding. Second figure indicates urea spray (S) or NH_4NO_3 broadcast (B) in lb N/acre.

of wheat treated with 120 lb N/acre at time of seeding was not increased by urea spray applied at seven and nine weeks after seeding except on the Altona fallow site. Protein content of wheat when 45 lb N/acre urea spray was applied was only slightly higher than when 15 lb N.acre was applied.

Table 13 shows the effect of adding ammonium nitrate, urea and ammonium sulfate foliar sprays and broadcast ammonium nitrate at various times after seeding on the protein content of wheat in 1971. The protein content of wheat grown on both fallow and nonfallow sites was increased above that obtained with 60 lb N/acre at time of seeding when additional nitrogen was applied at seven or ten weeks after seeding. In many instances, the protein contents obtained with the split application were greater than with 90 lb N/acre applied at time of seeding. This was probably due to the slightly lower yields obtained with the split application. There appeared to be no consistent difference in the effectiveness of the various forms of nitrogen fertilizer sprays in increasing protein content; nor did the post emergent broadcast applications appear to be less effective than the sprays. Protein contents of wheat on the nonfallow sites were generally higher when treated with post emergent nitrogen at ten weeks after seeding (mid-flowering stage) than when treated at seven weeks after seeding (boot stage). Similar results were obtained by Finney _et al_. (11). Protein contents on the fallow sites did not differ consistently when post emergent nitrogen was applied at either time. Wetting agent had no effect on the protein content.

3) The effect of nitrogen on wheat quality.

A summary, in tabular form, of the wheat quality tests conducted on wheat from selected sites in 1970 and 1971 is shown in the Appendix (Tables 1A to 8A). Wheat quality as reflected by farinograms, sedimentation

TABLE 13

THE EFFECT OF POST EMERGENT NITROGEN FERTILIZERS ON THE PROTEIN CONTENT OF WHEAT (1971)

Source, rate and method of N application[1]	Protein contents (%)			
	Altona fallow 1971	Altona nonfallow 1971	Red River fallow 1971	Red River nonfallow 1971
0	12.9	11.3	11.6	12.1
60 B[2]	14.9	10.9	13.2	10.9
90 B	15.3	11.5	14.4	12.4
60B 30S Urea @ 7 wks[3]	15.7	12.7	15.3	13.8
60B 30S NH_4NO_3 @ 7 wks	15.8	12.3	15.0	13.7
60B 30S $(NH_4)_2SO_4$ @ 7 wks	15.9	12.0	15.3	12.5
60B 30B NH_4NO_3 @ 7 wks	15.2	12.4	14.4	12.7
60B 30S Urea @ 10 wks	16.2	13.1	15.5	14.0
60B 30S NH_4NO_3 @ 10 wks	15.2	14.9	14.9	14.8
60B 30S $(NH_4)_2SO_4$ @ 10 wks	15.3	14.2	14.7	13.6
60B 30B NH_4NO_3 @ 10 wks	16.1	13.6	14.5	13.3
60B 30S Urea + W.A. @ 7 wks	15.8	12.3	15.1	13.7
60B W.A. @ 7 wks	15.3	11.0	13.1	11.1

1 All treatments treated with 30 lb P_2O_5/acre as 11-55-0. All rates in lb N/acre.

2 B = nitrogen broadcast at time of seeding as NH_4NO_3.

3 First figure indicates NH_4NO_3 broadcast at time of seeding (B). Second figure indicates nitrogen spray (S) in lb N/acre.

4 Wetting agent ("Tween 20" - polyexyethlene (20) sorbitan monolaurate).

values and loaf volumes was lower in 1970 than in 1971 at equal protein contents. This discrepancy may be the result of yearly climatic variations or some other unknown factor(s). Wheat protein content and quality increased with increasing amounts of soil nitrate nitrogen. This is shown by the wheat quality tests conducted on the wheat obtained from the control treatments. In both 1970 and 1971, loaf volumes increased almost linearily with increases in protein content. Wheat which maintained equal protein contents, whether grown on a control plot or a nitrogen fertilized plot during the same year, was also of similar quality. Thus, wheat quality was reflected mainly by protein content. Also, wheat quality was not dependent upon nitrogen source (soil or fertilizer). Wheat quality for the post emergent nitrogen applications also closely followed protein content.

B. Greenhouse Experiment

1) The effect of nitrogen applied at time of seeding on the yield and protein content of wheat.

Yields were increased when nitrogen fertilizer was added (Table 14). However, the yields obtained when rates of 50 ppm N or more were added were not significantly different. Protein content of wheat treated with 25 or 50 ppm N was lower than that of wheat not treated with nitrogen. This was due to the large yield increases obtained. Wheat protein contents when 75 ppm N or more was applied were considerably greater than for wheat not treated with nitrogen. A similar protein response to added nitrogen occurred on some of the nonfallow field sites in 1970 and 1971. A slight decrease followed by a large increase in protein content with increasing amounts of nitrogen added was also noted by Partridge (32).

TABLE 14

THE EFFECT OF NITROGEN APPLIED AT TIME OF SEEDING ON THE YIELD AND PROTEIN CONTENT OF WHEAT

N added (ppm)	Yield (g)	Protein content (%)
0	1.74_{ab}[2]	16.4
25	2.57_{c}	15.5
50	2.96_{c-g}	16.2
75	2.95_{c-g}	17.7
100	3.13_{e-g}	17.7
125	2.64_{cd}	18.4
200	2.81_{c-f}	17.6
400	3.01_{c-g}	18.8

2 Duncan's multiple range test - yields followed by same letter(s) are not significantly different at the 5% P level.

2) The effect of post emergent nitrogen application on the yield, protein content and nitrogen uptake of wheat.

Yields of wheat, within any particular level of nitrogen applied at time of seeding, were not significantly different when treated with urea, ammonium sulfate or ammonium nitrate post emergent nitrogen applications (Table 15). Yields obtained with broadcast post emergent nitrogen applications were not significantly different from those obtained with sprayed post emergent treatments within any given level of nitrogen applied at time of seeding. The only exception occurred when ammonium nitrate was added at eight weeks after seeding to wheat treated with 100 ppm N at time of seeding. Wheat yields were usually not significantly different when nitrogen was applied at five or eight weeks after seeding to wheat treated with 50 ppm N at time of seeding. Only the application of ammonium sulfate to the soil at five weeks after seeding resulted in a significantly higher yield than when applied at eight weeks after seeding.

The yields obtained with nitrogen applied at time of seeding (Table 14) can be compared to those of the post emergent spray and broadcast treatments since the statistical comparison using the Duncan's multiple range test was conducted on all the data obtained from the greenhouse experiment. Yields with no nitrogen added at time of seeding and 25 ppm N applied eight weeks after seeding were significantly lower than when 25 ppm N was applied at time of seeding. Yields obtained with the other post emergent nitrogen applications did not vary significantly from those obtained with equivalent amounts of nitrogen applied at time of seeding except when 25 ppm N as ammonium nitrate was applied broadcast to wheat treated with 100 ppm N at time of seeding. In this case, however,

TABLE 15

THE EFFECT OF POST EMERGENT NITROGEN APPLICATION ON THE YIELD AND PROTEIN CONTENT OF WHEAT

N applied[1]	Post emergent N source	Time of post emergent treatment (wks)	Yield (g)	Protein content (%)	Uptake of ^{15}N labelled fertilizer(%)
50/25 S	Urea	5	2.78_{c-f}[2]	16.2	.967
50/25 S	$(NH_4)_2SO_4$	5	3.05_{d-g}	16.0	.748
50/25 S	NH_4NO_3	5	2.86_{c-f}	16.5	1.82
50/25 B	Urea	5	2.69_{c-e}	17.3	40.3
50/25 B	$(NH_4)_2SO_4$	5	3.38_{g}	16.9	29.2
50/25 B	NH_4NO_3	5	3.02_{c-g}	16.5	47.5
0/25 S	Urea	8	1.89_{ab}	16.1	.627
0/25 S	$(NH_4)_2SO_4$	8	1.69_{ab}	16.0	.155
0/25 S	NH_4NO_3	8	1.48_{a}	16.1	.420
0/25 B	Urea	8	1.92_{b}	18.4	37.6
0/25 B	$(NH_4)_2SO_4$	8	1.76_{ab}	19.0	29.3
0/25 B	NH_4NO_3	8	1.68_{ab}	19.5	30.6
50/25 S	Urea	8	2.98_{c-g}	16.0	1.23
50/25 S	$(NH_4)_2SO_4$	8	2.65_{cd}	16.6	.371
50/25 S	NH_4NO_3	8	2.74_{c-e}	17.1	.685
50/25 B	Urea	8	2.97_{c-g}	17.9	51.7
50/25 B	$(NH_4)_2SO_4$	8	2.90_{c-f}	18.0	55.9
50/25 B	NH_4NO_3	8	2.63_{cd}	17.7	41.0
100/25 S	Urea	8	2.70_{c-e}	18.4	.799
100/25 S	$(NH_4)_2SO_4$	8	2.71_{c-e}	18.2	10.7
100/25 S	NH_4NO_3	8	2.78_{c-f}	17.8	.734
100/25 B	Urea	8	3.02_{c-g}	18.4	29.9
100/25 B	$(NH_4)_2SO_4$	8	3.07_{d-g}	18.1	16.1
100/25 B	NH_4NO_3	8	3.23_{g}	18.5	52.5

1 First figure indicates ppm of nitrogen applied at time of seeding; second figure indicates ppm of post emergent nitrogen spray (S) or broadcast (B).

2 Duncan's multiple range test, yields followed by the same letter(s) are not significantly different at the 5% P level.

the yield did not differ significantly from that obtained when 100 ppm N was applied at time of seeding.

Protein content of wheat did not vary consistently with source of post emergent nitrogen (Table 15). Protein contents were usually higher when nitrogen was broadcasted than when sprayed except for urea and ammonium sulfate applied at eight weeks after seeding to wheat treated with 100 ppm N at time of seeding. The protein content of wheat obtained when 25 ppm N was sprayed or applied broadcast at eight weeks (early flowering) after seeding was usually higher than that of wheat treated at five weeks after seeding (four to five leaf stage). A similar trend was noted in the field trials. Protein content of wheat not treated with nitrogen at time of seeding increased substantially when nitrogen was applied broadcast eight weeks after seeding (Tables 14 and 15). However, the protein contents of wheat treated with spray applications were similar to that of the control treatments. Protein content of wheat treated with 50 ppm N at seeding time and 25 ppm N broadcast eight weeks after seeding was greater than that of wheat treated with 50 ppm N at time of seeding, but did not differ substantially from that obtained when 75 ppm N was added at time of seeding. Wheat protein content obtained with 50 ppm N added at time of seeding and post emergent spray or broadcast applications at five weeks and spray treatments at eight weeks were lower than with 75 ppm N added at time of seeding. Protein contents obtained with 100 ppm N at time of seeding and 25 ppm N broadcasted or sprayed at eight weeks after seeding were not greatly different than with 125 ppm N added at time of seeding, but were higher than with 100 ppm N added at time of seeding.

Uptake of ^{15}N from the various post emergent nitrogen sources was not consistently different. Uptake of nitrogen from the broadcast applications was much greater than that from the spray applications. The percent uptake of the ^{15}N labelled fertilizers from the spray treatments was usually less than one percent and usually greater than 30 percent for the post emergent broadcast treatments. Only in one instance was uptake of foliar applied ^{15}N high. This was probably due to contamination of the sample by ^{15}N. Since the uptake of foliar applied ^{15}N was very low, it would appear that any significant increase in the nitrogen content of plants grown in the field and treated with foliar sprays did not result from foliar absorption. It is most likely, that in the field, rain washed the nitrogen sprays from the surfaces of the plants into the soil where it was absorbed by plant roots.

V. SUMMARY AND CONCLUSIONS

Ten field experiments, five on fallow land and five on nonfallow land, and a greenhouse experiment were conducted in 1970 and 1971 to determine the effects of amount, source, and time and method of application of nitrogenous fertilizers on the protein content of Neepawa wheat.

Yield and protein content of wheat were higher on fallow land than on nonfallow land. Soil nitrate nitrogen contents on the field sites selected in 1970 and 1971 varied from 9 to 165 lb N/acre to a depth of four feet. Yield and protein content of wheat usually increased with increases in soil nitrate nitrogen content. Although higher wheat yields and lower protein contents were obtained in 1971 than in 1970, a good relationship was obtained between soil nitrate nitrogen content and protein content of wheat.

The addition of nitrogen fertilizer at 30, 60, 90, 120, 180, 240 or 360 lb N/acre as ammonium nitrate broadcasted at time of seeding to the fallow sites did not greatly increase the yield of wheat, but increased the protein content. Protein contents on the fallow sites usually did not increase substantially when rates above 120 lb N/acre were applied. The protein content and yield of wheat grown on the nonfallow sites increased when nitrogen was applied broadcast at time of seeding. Significant yield increases were obtained when 30 or 60 lb N/acre was applied. At these rates of added nitrogen, protein content decreased or increased only slightly above that of an unfertilized check. The greatest increases in protein content of wheat with increases in added nitrogen on the nonfallow sites were obtained when rates of 90 to 180 lb N/acre were applied broadcast. This occurred when yields did not increase significantly with added nitrogen. Thus, the addition of lower quantities of nitrogen (30 or 60 lb N/acre) at time of seeding was utilized by the wheat plants for yield increases. Addition of nitrogen at rates above 60 lb N/acre were necessary on nonfallow land in order to increase the wheat protein content. Protein content of wheat was related to the amounts of nitrate nitrogen in the soil and the amount of nitrogen fertilizer applied. The R^2 value obtained for an exponential regression equation relating wheat protein content to nitrogen supply (nitrate nitrogen measured to a depth of four feet and nitrogen broadcasted at time of seeding) was 0.76. The R^2 value was 0.73 when soil nitrate nitrogen content was measured to a depth of two feet.

The addition of nitrogen at rates of 20, 30, 40 or 60 lb N/acre as ammonium nitrate with the seed or 20, 30, or 40 lb N/acre as urea with the seed did not usually produce wheat with yields or protein contents different than when equivalent rates of nitrogen were applied broadcast at time of seeding. Highly significant R^2 values were obtained between wheat protein content and nitrogen supply (soil nitrate nitrogen and nitrogen applied with the seed). The highest R^2 values were obtained with ammonium nitrate drilled with the seed and when soil sampling was conducted to a depth of four feet.

Post emergent nitrogen fertilizers applied to the soil surface in granular form as ammonium nitrate or as nitrogen solutions sprayed on to the foliar surfaces of wheat, did not increase the yield. The protein content of wheat obtained in 1970 with post emergent nitrogen applications were not as high as when equivalent amounts of nitrogen were applied at time of seeding. However, in 1971, the protein content of wheat was higher with the post emergent nitrogen applications than with equivalent amounts added at time of seeding. These nitrogen applications on the nonfallow sites in 1971 were more effective at flowering stage than when applied at the boot stage. No similar trend was noted on the fallow sites. Urea, ammonium nitrate and ammonium sulfate foliar sprays and soil applied granular ammonium nitrate were equally effective in increasing the wheat protein content, but ammonium sulfate foliar spray severely reduced the yield of wheat. Ammonium nitrate foliar sprays reduced yields to a lesser extent, while spray damage from the urea sprays was negligible. Yield reductions appeared to be due to leaf burn induced by the sprays.

Nitrogen applied at time of seeding to wheat grown in the greenhouse resulted in yield and protein responses similar to the field investigations. Increases in protein content of wheat with added nitrogen were not obtained unless large amounts of nitrogen were added ($>$50 ppm N) and when yields did not increase with increased amounts of added nitrogen. Usually less than one percent of the nitrogen applied was absorbed into the grain when ^{15}N labelled nitrogen as urea, ammonium nitrate or ammonium sulfate solutions were sprayed on to the foliar surfaces of wheat. Precautions were taken to prevent contact of the nitrogen solution with the soil. Usually greater than 30 percent of the nitrogen was absorbed into the grain when the same solutions were applied to the soil surface. Increases in wheat protein content were greatest when the nitrogen solution was soil applied, and at the flowering stage. These results would indicate that increases in wheat protein content in the field experiments, which resulted from post emergent nitrogen sprays, were largely due to the nitrogen being washed from the foliar surface into the soil by rain and being absorbed by the wheat plant roots.

Wheat quality tests conducted on wheat from selected field sites in 1970 and 1971, showed that wheat quality was a function of protein content and independent of nitrogen source.

These studies showed that wheat protein content was greatly affected by nitrogen supply. Low protein content of wheat produced in Manitoba, particularly the Manitoba Lowlands, is most likely due to insufficient nitrogen supply. Both high yields and high protein contents were obtained in Manitoba when sufficient nitrogen as soil and/or fertilizer nitrogen was present.

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VII. APPENDIX

TABLE 1 A

THE EFFECT OF SOIL NITRATE NITROGEN CONTENT ON THE GRAIN, FLOUR AND BREAD QUALITY OF WHEAT (1970-71)

	Site and year							
	Wellwood fallow 1970	Altona fallow 1970	Almasippi nonfallow 1970	Wellwood nonfallow 1970	Altona fallow 1971	Red River fallow 1971	Altona nonfallow 1971	Red River nonfallow 1971
NO_3-N content (lb/acre to 2 ft depth)	131	69	38	13	67	64	7	6
WHEAT								
Bushel weight (lb)	60.0	54.0	61.5	62.5	69.3	68.0	68.7	68.8
1000 kernel wt (g)	23.5	26.2	25.0	28.5	33.9	35.4	31.5	33.3
% Moisture	8.5	9.4	8.1	8.5	9.0	10.0	10.2	10.6
% Protein (13.5% m.b.)	15.5	14.8	13.7	11.4	12.9	11.6	11.3	12.1
% Flour yield (Total)	70.0	71.8	72.2	70.6	71.2	70.8	67.9	70.0
FLOUR								
% Protein (14.0 m.b.)	14.3	13.9	13.1	10.6	12.1	11.0	10.8	11.4
% Ash (14.0% m.b.)	0.42	0.38	0.43	0.45	0.34	0.40	0.45	0.44
Color (units)	1.4	0.9	1.0	-	0.1	0.3	0.4	0.6
Falling No. (sec)	206	207	232	254	-	-	-	-
Baking absorption	60.2	58.2	57.2	59.2	62.1	58.6	58.6	58.5
Sedimentation value	52.0	65.0	60.0	44.0	58.0	60.0	50.0	55.0
BREAD								
Loaf volume (c.c.)	805	860	850	575	798	695	715	735
FARINOGRAM								
Absorption (%)	64.2	62.2	61.2	63.2	66.1	62.6	66.6	62.5
Development time (min)	3.5	4.5	4.5	2.0	4.0	3.5	2.5	2.5
M.T.I., B.U.	40	30	40	50	20	40	50	120

TABLE 2 A

THE EFFECT OF ADDED NITROGEN BROADCASTED AT TIME OF SEEDING ON THE GRAIN, FLOUR, AND BREAD MAKING QUALITIES OF WHEAT
(Wellwood fallow 1970)

	N added (lb N/acre)							
	0	30	60	90	120	180	240	360
WHEAT								
Bushel weight (lb)	60.0	60.4	60.0	60.0	60.0	59.5	59.0	59.5
1000 kernel wt (g)	23.5	25.5	23.9	24.5	23.5	23.5	23.0	22.0
% Moisture	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
% Protein (13.5% m.b.)	15.5	15.3	16.3	16.5	16.6	16.8	17.0	17.0
% Flour yield (Total)	70.0	70.0	69.5	68.2	69.0	69.3	65.0	67.7
FLOUR								
% Protein (14.0% m.b.)	14.3	14.4	15.4	15.4	15.7	15.8	15.8	16.1
% Ash (14.0% m.b.)	.42	.40	.45	.42	.43	.42	.43	.49
Color (units)	1.4	1.6	2.1	2.1	2.1	2.1	1.8	-
Falling No. (sec)	206	203	196	200	195	190	185	174
Baking absorption	60.2	61.2	61.1	62.4	62.5	62.4	62.3	62.8
Sedimentation value	52.0	52.5	56.0	58.0	57.0	58.0	55.0	62.5
BREAD								
Loaf volume (c.c.)	805	860	890	920	990	1000	1000	1025
FARINOGRAM								
Absorption (%)	64.2	65.2	65.1	66.4	66.5	66.4	66.3	66.8
Development time (min)	3.5	3.5	4.5	4.5	4.5	4.5	5.0	4.5
M.T.I., B.U.	40	30	20	30	30	30	40	40

TABLE 3A

THE EFFECT OF ADDED NITROGEN BROADCASTED AT TIME OF SEEDING ON THE GRAIN, FLOUR, AND BREAD MAKING QUALITIES OF WHEAT
(Wellwood nonfallow 1970)

	N added (lb N/acre)							
	0	30	60	90	120	180	240	360
WHEAT								
Bushel weight (lb)	62.5	65.0	67.0	64.0	65.0	63.5	64.0	63.5
1000 kernel wt (g)	28.5	23.0	30.0	29.0	29.2	28.5	28.0	28.2
% Moisture	8.5	8.2	8.4	8.2	8.2	8.1	8.2	8.1
% Protein (13.5% m.b.)	11.4	10.8	11.1	13.1	15.0	15.5	15.9	16.3
% Flour yield (Total)	70.6	69.8	70.2	71.1	71.6	72.3	72.3	72.0
FLOUR								
% Protein (14.0% m.b.)	10.6	9.9	10.3	12.2	14.2	14.7	15.3	15.7
% Ash (14.0% m.b.)	.45	.41	.40	.41	.38	.38	.39	.37
Color (units)	-	0.4	0.1	-	1.2	1.2	1.4	1.7
Falling No. (sec)	254	245	227	219	206	212	220	220
Baking absorption	59.2	60.2	59.8	59.8	61.9	61.8	61.7	62.0
Sedimentation value	44.0	41.0	41.0	49.0	64.5	66.0	67.5	68.5
BREAD								
Loaf volume (c.c.)	575	450	480	690	830	925	945	1025
FARINOGRAM								
Absorption (%)	63.2	64.2	63.8	63.8	65.9	65.8	65.7	66.0
Development time (min)	2.0	2.0	1.5	3.0	3.5	4.0	4.0	4.5
M.T.I., B.U.	50	80	85	50	35	40	35	30

TABLE 4 A

THE EFFECT OF TIME AND METHOD OF POST EMERGENT NITROGEN APPLICATION ON THE GRAIN, FLOUR AND BREAD MAKING QUALITIES OF WHEAT
(Wellwood nonfallow 1970)

	Urea spray (30 lb N/acre)[2]					Ammonium nitrate broadcast (30 lb N/acre)[2]				
Application time (wks after seeding)	3	5	7	9	11	3	5	7	9	11
WHEAT										
Bushel weight (lb)	66.5	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	64.5
1000 kernel wt. (g)	29.5	28.0	29.5	29.0	29.0	29.0	27.5	29.5	27.5	29.0
% Moisture	8.2	8.2	8.1	8.2	8.2	8.2	8.2	8.2	8.2	8.2
% Protein (13.5% m.b.)	12.1	12.3	12.3	12.5	12.1	13.1	12.8	12.3	11.4	11.5
% Flour yield (Total)	68.3	68.3	69.5	69.0	70.5	71.0	70.2	68.7	69.1	70.1
FLOUR										
% Protein (14.0% m.b.)	11.0	11.2	11.3	11.4	11.0	12.2	11.8	11.2	10.3	10.4
% Ash (14.0% m.b.)	.38	.40	.41	.40	.42	.39	.40	.39	.42	.44
Color(units)	0.3	0.7	0.6	-	0.9	0.6	0.4	0.9	0.2	0.7
Falling no. (sec)	231	236	232	232	246	245	210	221	236	241
Baking absorption	58.7	58.9	59.0	59.1	59.0	58.8	59.1	59.5	58.9	58.4
Sedimentation value	44.0	45.0	44.0	44.0	46.0	46.0	46.0	45.0	41.0	41.0
BREAD										
Loaf volume (c.c.)[1]	615	605	635	610	595	710	670	605	555	550
FARINOGRAM										
Absorption (%)	64.7	64.9	65.0	65.1	65.0	64.8	65.1	65.5	64.9	64.4
Development time (min)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.0	2.0	2.0
M.T.I., B.U.	40	40	40	40	40	40	40	40	50	50

1 Baking done at 6% less moisture content than Farinogram absorption because of dough handling difficulties.

2 All treatments were treated with 60 lb N/acre broadcast at time of seeding as 34-0-0.

TABLE 5 A

THE EFFECT OF ADDED NITROGEN BROADCASTED AT TIME OF SEEDING ON THE GRAIN, FLOUR AND BREAD MAKING QUALITIES OF WHEAT
(Red River fallow 1971)

	N added (lb N/acre)							
	0	30	60	90	120	180	240	360
WHEAT								
Bushel weight (lb)	68.0	68.3	69.5	69.7	69.2	68.7	68.7	68.5
1000 kernel wt (g)	35.4	35.1	35.8	34.3	34.8	35.3	34.8	32.3
% Moisture	10.0	9.8	9.4	9.2	9.4	9.4	9.4	9.2
% Protein (13.5% m.b.)	11.6	12.1	13.2	14.4	14.8	14.8	15.6	15.7
% Flour yield (Total)	70.8	71.5	71.8	72.3	71.8	72.9	72.5	71.6
FLOUR								
% Protein (14.0% m.b.)	11.0	11.6	12.5	13.6	14.3	14.4	14.8	15.1
% Ash (14.0% m.b.)	.40	.39	.37	.36	.36	.35	.35	.34
Color (units)	-0.3	-0.2	-0.2	0.1	0.2	0.2	0.6	0.4
Falling no. (sec)								
Baking absorption	58.6	59.2	59.0	59.2	59.7	59.6	60.7	60.4
Sedimentation value	60.0	64.0	70.0	68.0	73.0	70.0	71.0	71.0
BREAD								
Loaf volume (c.c.)	695	770	835	960	985	1028	1075	1140
FARINOGRAM								
Absorption (%)	62.6	63.2	63.0	63.2	63.7	63.6	64.7	64.4
Development time (min)	3.5	4.0	4.0	5.0	4.5	5.0	4.0	5.0
M.T.I., B.U.	40	40	30	40	40	30	30	25

TABLE 6 A

THE EFFECT OF ADDED NITROGEN BROADCASTED AT TIME OF SEEDING ON THE GRAIN, FLOUR AND BREAD MAKING QUALITIES OF WHEAT
(Red River nonfallow 1971)

	N added (lb N/acre)							
	0	30	60	90	120	180	240	360
WHEAT								
Bushel weight (lb)	68.8	68.6	69.2	69.0	68.3	67.7	68.0	67.4
1000 kernel wt. (g)	33.3	36.2	36.8	36.3	36.2	29.3	35.6	34.0
% Moisture	10.6	10.9	10.9	10.9	11.1	11.7	11.3	11.5
% Protein (13.5% m.b.)	12.1	10.5	10.9	12.4	14.0	15.0	15.3	15.5
% Flour yield (Total)	70.0	67.0	67.6	68.8	70.0	70.5	70.9	71.0
FLOUR								
% Protein (14.0% m.b.)	11.4	9.8	10.4	11.5	13.2	14.0	14.5	14.8
% Ash (14.0% m.b.)	.44	.45	.40	.36	.33	.35	.34	.31
Color (units)	0.6	-0.2	-0.2	0.0	0.2	0.5	0.7	0.6
Falling no. (sec)								
Baking absorption	58.5	58.8	58.5	59.8	60.7	61.6	62.2	61.3
Sedimentation value	55.0	50.0	53.0	58.0	65.0	62.0	64.0	70.0
BREAD								
Loaf volume (c.c.)	735	580	625	700	855	928	975	1015
FARINOGRAM								
Absorption (%)	62.5	66.8	66.5	65.8	64.7	65.6	66.2	65.3
Development time (min)	2.5	2.0	2.5	4.5	5.0	4.0	4.0	5.0
M.T.I., B.U.	120	60	50	40	20	20	20	30

TABLE 7A

THE EFFECT OF TIME AND METHOD OF APPLICATION AND SOURCE OF NITROGEN ON THE GRAIN, FLOUR AND BREAD MAKING QUALITIES OF WHEAT (Red River fallow 1971)

Method and N source	Urea spray		NH_4NO_3 spray		$(NH_4)_2SO_4$ spray		NH_4NO_3 broadcast		Urea spray with W.A.[2]	W.A. spray
N added (lb/acre)[1]	30		30		30		30		30	0
Application time (wks after seeding)	7	10	7	10	7	10	7	10	7	10
WHEAT										
Bushel weight (lb)	68.8	69.3	69.2	68.1	69.6	65.5	69.7	69.4	68.5	69.4
1000 kernel wt. (g)	34.8	32.2	32.2	29.6	33.8	29.6	34.3	35.3	34.3	33.6
% Moisture	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.4	9.2	9.6
% Protein (13.5% m.b.)	15.3	15.5	15.0	14.9	15.3	14.1	14.4	14.5	15.1	13.1
% Flour yield (Total)	72.3	72.9	72.1	71.3	72.2	71.0	72.0	70.6	71.9	71.7
FLOUR										
% Protein (14.0% m.b.)	14.5	15.1	14.0	14.5	14.4	14.0	13.7	14.0	14.4	12.5
% Ash (14.0% m.b.)	.35	.34	.34	.36	.33	.46	.33	.36	.37	.35
Color (units)	0.2	0.5	-0.1	0.4	0.5	0.7	-0.1	0.2	0.2	0.0
Falling no. (sec)										
Baking absorption	60.6	61.4	59.7	61.5	60.2	59.4	59.9	60.6	59.0	59.4
Sedimentation value	70.0	70.0	70.0	70.0	70.0	46.0	70.0	64.0	69.0	67.0
BREAD										
Loaf volume (c.c.)	1040	1060	960	1020	1015	945	965	920	1005	835
FARINOGRAM										
Absorption (%)	64.6	65.4	63.7	65.3	64.2	63.4	63.9	64.6	63.0	63.4
Development time (min)	4.5	5.0	5.0	5.0	5.0	4.0	4.5	5.0	4.5	3.5
M.T.I., B.U.	30	20	20	20	40	45	30	40	40	40

1 All treatments were treated with 60 lb N/acre broadcast at time of seeding as 34-0-0.

2 Wetting agent ("Tween 20").

TABLE 8 A

THE EFFECT OF TIME AND METHOD OF APPLICATION AND SOURCE OF NITROGEN ON THE GRAIN, FLOUR AND BREAD MAKING QUALITIES OF WHEAT (Red River nonfallow 1971)

Method and N source	Urea spray		NH_4NO_3 spray		$(NH_4)_2SO_4$ spray		NH_4NO_3 broadcast		Urea spray + W.A.[2]	W.A. spray
N added (lb/acre)[1]	30		30		30		30		30	0
Application time (wks after seeding)	7	10	7	10	7	10	7	10	7	10
WHEAT										
Bushel weight (lb)	67.9	69.0	68.5	67.7	68.8	65.9	69.5	68.0	68.0	68.5
1000 kernel wt. (g)	34.0	36.8	33.3	34.6	33.8	30.4	35.8	35.1	36.1	35.6
% Moisture	11.5	11.3	10.5	11.3	10.5	11.5	10.7	11.4	11.4	11.3
% Protein (13.5% m.b.)	13.8	14.0	13.7	14.8	12.5	13.6	12.7	13.3	13.7	11.1
% Flour yield (Total)	68.0	69.1	71.6	70.8	69.8	69.4	70.7	69.1	70.4	68.3
FLOUR										
% Protein (14.0% m.b.)	13.0	13.3	12.9	14.2	11.8	12.6	12.0	12.5	13.0	10.3
% Ash (14.0% m.b.)	.39	.35	.40	.44	.35	.47	.39	.36	.37	.35
Color (units)	0.3	0.4	1.1	0.5	0.1	0.3	0.1	0.1	0.2	-0.5
Falling no. (sec)										
Baking absorption	61.6	62.2	61.6	63.2	61.6	61.9	60.7	61.2	62.2	57.5
Sedimentation value	60.0	63.0	57.0	66.0	60.0	42.0	62.0	57.0	57.0	52.0
BREAD										
Loaf volume (c.c.)	835	850	870	945	723	775	743	773	835	630
FARINOGRAM										
Absorption (%)	65.6	66.2	65.6	67.2	65.6	65.9	64.7	65.2	66.2	65.5
Development time (min)	4.0	4.0	3.5	4.0	4.0	3.0	4.0	3.0	4.5	2.5
M.T.I., B.U.	20	30	40	10	30	40	20	40	30	20

1 All treatments were treated with 60 lb N/acre broadcast at time of seeding as 34-0-0.

2 Wetting Agent ("Tween 20").