Nitrogen and Phosphorus Fertilization in the Production of Winter Wheat under Zero Tillage Management

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Cynthia Ann Grant
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NITROGEN AND PHOSPHORUS FERTILIZATION IN THE PRODUCTION OF WINTER WHEAT UNDER ZERO TILLAGE MANAGEMENT

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ABSTRACT

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Dr. E.H. Stobbe

The effects of rate and timing of broadcast ammonium nitrate fertilizer and of combinations of fall applied broadcast ammonium nitrate and monoammonium phosphate applied with the seed on winter survival and growth parameters of zero tillage winter wheat were examined.

Fall applied nitrogen fertilizer was found to decrease winter survival, when applied at high rates. Application of phosphorus fertilizer was found to counteract the negative effect of the nitrogen and maintain winter survival at levels comparable to the unfertilized check.

Grain yield was increased by additions of nitrogen fertilizer. The level of fertilization where yield ceased to increase with further additions of nitrogen depended to a great extent on climatic conditions, particularly rainfall. Percentage grain protein increased with high rates of nitrogen fertilization, however low rates tended to decrease percentage protein if the grain yield response was great.

Timing of low rates of nitrogen fertilizer influenced grain yield obtained, with spring application producing the greatest yield response. Application of nitrogen on the snow was least efficient in increasing grain yield.

Percentage grain protein was influenced by timing of nitrogen application only at low fertilizer rates. With low fertilizer rates, application timings which resulted in the greatest grain yield increase produced the lowest percentage grain protein.

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INTRODUCTION

Winter wheat production on the Canadian prairie provinces has traditionally been limited to an area in the south western corner of Alberta and in a triangular area of Saskatchewan between Shaunavon, Val Marie and Govenlock. In other areas of the prairies, including Manitoba, winter wheat production has proven uneconomical due to the frequent occurrence of excessive winter kill (Grant et al., 1976). With the advent of zero tillage, as an alternate management system, the potential has developed for the expansion of winter wheat production to areas beyond these traditional limits. Under zero tillage, an insulating blanket of snow is retained over the winter wheat stand, which serves to increase the temperature at the crown and so reduce winter mortality (Aase & Siddoway, 1980).

Production of winter wheat has demonstrated a number of advantages to the grower. Compared to spring wheat, winter wheat has produced higher yields, superior competition with weeds, and improved utilization of available moisture in the fall and early spring. Fall seeding and early maturity combine to spread the workload for men and machinery over a longer period of time. As well, early maturity tends to allow the crop to escape damage from disease, midsummer drought and insect attacks in many cases.

Problems still exist in winter wheat production. Excessive winter kill may limit the profitability of the crop. Marketing of winter wheat poses problems, largely due to the inherently lower protein content of winter wheat as compared to hard red spring wheat. Alterations in the management practices used for winter wheat production are needed to cope with these problems.

Studies conducted on conventionally tilled winter wheat have shown large increases in winter hardiness, yield and grain protein in response to proper nitrogen and phosphorus fertilization. However, data on the effects of these fertilizers on winter wheat production under zero tillage are lacking. This study was initiated to examine the influence of phosphorus and nitrogen fertilizer management on the winter hardiness, yield and protein content of winter wheat grown under zero tillage conditions.

LITERATURE REVIEW

Introduction

A number of reviews have been written, dealing with zero tillage agriculture (Phillips _et al._, 1980; Baeuman and Bakermans, 1973) and with winter hardiness of plants (Single 1971, Alden and Herman 1971, Gusta and Fowler 1979). These reviews provide an informative overview of these subjects on a general basis.

I. Changes in Soil Properties Under Zero Tillage

Soil Temperature

The existence of a surface trash mulch and lack of soil disturbance as found under zero tillage has tended to produce modifications in soil temperature relations. Smika et al. (1971) working with mulch effects on soil temperatures at North Platte, found that the mulch acted as an insulating layer, moderating the extent of temperature fluctuations. The surface mulch led to slow warming of the soil in the spring and lower soil temperatures throughout the growing season. A similar moderating effect also occurred during cooling phases, leading to slower temperature decreases during the fall and winter and the maintenance of higher soil temperatures throughout the winter months (Gauer et al., 1980).

Soil Moisture

Under zero tillage, soil moisture levels have been shown to increase (Gauer _et al._, 1980; Aase & Siddoway, 1980; Blevins _et al._, 1971; Smika _et al._, 1969; Willes _et al._, 1969). Water loss from the soil was decreased due to reduced evaporation from the soil prior to the stage when the crop canopy fully covered the soil surface (Blevins et al., 1971). Reduction of soil crusting and surface runoff (Aase &

Siddoway, 1980) and increased snow trapping over the winter due to the maintenance of standing stubble served to increase water retained in the field (Willis et al., 1969). These factors combined to increase the level of soil water available to the crop.

Soil Aeration

Decreased soil aeration has occurred under zero tillage management in a number of experiments (Diebert et al., 1980). The decreased soil aeration has been attributed to compaction of the soil, which increased bulk density while it decreased porosity. As well, increased soil moisture has led to a decrease in air filled porosity.

Organic Matter

Zero tillage has been observed to retain significantly higher levels of organic matter in the surface levels of the soil than normally occur under conventional tillage treatments (Blevins et al., 1977; Engle et al., 1980). The increase in organic matter has been attributed to the maintenance of the raw organic matter at the soil surface. Residues retained at the soil surface decayed more slowly than residues incorporated into the soil, since temperature and moisture conditions at the soil surface varied widely, producing a hostile environment for microorganisms decaying the material. The rate of decomposition of unincorporated residue has been observed at rates as low as one-third as quickly as decay of incorporated material, over a 26 month period (Engle et al., 1980). The lack of soil mixing also increased the amount of organic matter initially deposited in the surface soil horizons by restricting distribution of organic matter in the lower levels of the soil profile.

II. Effects of Changes in Soil Properties on Nutrient Availability

By alteration of the physical characteristics of the soil, zero tillage has been shown to alter nutrient cycling and availability.

Nitrogen

Soil nitrogen has been shown to be involved in a cycle in which the total nitrogen available in the soil solution is determined by the relative rates of reactions contributing nitrogen to and removing nitrogen from the system. Major pathways contributing available nitrogen to the soil system have been shown to include nitrification and mineralization, while leaching and denitrification have been shown to remove available nitrogen from the system (Buckman and Brady, 1972).

Mineralization, the conversion of organic nitrogen to mineral nitrogen forms has been observed to be affected by temperature and aeration. Total mineralization of nitrogenous compounds has been seen to decrease as the soil temperature falls (Milthorpe & Mooreby, 1974) and as soil aeration decreases (Buckman & Brady, 1972). Therefore, under zero tillage, nitrogen tended to be tied up in an unavailable form as organic matter to a greater extent than under conventional (Baeumer and Baremans, 1973) tillage systems.

Nitrification rate also has been observed to decrease as soil temperature decreases and as aeration in the soil decreases (Buckman and Brady, 1972). Therefore, under zero tillage, nitrification would tend to be restricted.

On the other side of the cycle, immobilization, denitrification and leaching have been shown to decrease the amount of available nitrogen in the soil system. Denitrification has been observed to increase under situations of decreased aeration and excess moisture (Buckman and Brady, 1972), while immobilization may tend to decrease. Leaching of nitrate also increased as moisture levels increased. Increased levels of denitrification and leaching tended to produce higher losses of nitrogen under zero tillage management in studies conducted in Northern Idaho (Harder et al., 1980). Nitrogen reactions would vary depending on the precipitation levels experienced. The distribution of nitrogen throughout the soil profile has been observed to alter under zero tillage. Although inputs of nitrogen are primarily at the soil surface, from decaying organic matter and chemical fertilizer application, nitrogen, a mobile nutrient, appeared to move freely through the soil profile (Triplett and Van Doren, 1969). Downward displacement of nitrogen has been observed to increase, due to high moisture levels associated with zero tillage. High moisture levels resulted in increased nitrogen leaching and lower concentrations of nitrate remaining in the upper soil layers under zero tillage. Movement of nitrogen beyond the rooting zone appeared to result in lower efficiency of nitrate utilization under zero tillage (Baermer and Bakermans, 1973).

The net result of zero tillage effects on inputs and outflows in the nitrogen cycle has been shown to be a decrease in the amount of nitrogen available to the plant. In the short term, decreased nitrogen availability led to recommendations for increased rates of nitrogen fertilizer applications under zero tillage management, in order to retain yields at levels comparable to conventionally tilled crops (Engle et al., 1980).

Phosphorus

Phosphorus, as well as nitrogen, has been observed to bind in organic matter. The same factors, decreased aeration and decreased temperature, which tended to decrease nitrogen release, also tended to reduce the rate of phosphorus release through organic matter breakdown (Harder et al., 1980; Engle et al., 1980).

Reduced soil mixing drastically altered the distribution pattern of phosphorus in the soil (Drew and Saker, 1978; Triplett and Van Doren, 1969; Drew and Saker, 1980). Since organic matter and fertilizers have been applied to the soil surface, concentrations of phosphorus in the top layers have proved to be higher in zero tillage than in conventional tillage, while in deeper soil layers, concentrations of phosphorus and of organic matter have proven to be lower under zero tillage (Drew and Saker, 1978, 1980; Triplett and Van Doren, 1969). Triplett and Van Doren, working with maize, found that phosphorus applied to zero tilled crops tended to remain in the top 2.5cm of the soil, while Drew and Saker (1978 and 1980) using spring barley and winter wheat, showed high concentrations of phosphorus in the top 5cm. Differences in depth of phosphorus penetration may have been caused by differences in precipitation levels between Ohio, where Triplett and Van Doren worked and England, where Drew and Saker conducted their research. The relative immobility of phosphorus in the soil would have prevented penetration to greater depths.

Higher concentration of phosphorus in the upper soil profile appeared to promote root proliferation in the surface 5cm., leading to enhanced phosphorus availability under zero tillage, in years when this layer remained moist (Drew and Saker, 1978, 1980). In dry years, there did not appear to be any detrimental effect due to localization of phosphorus or of rooting (Drew and Saker, 1978, 1980). Therefore, zero tillage appeared to promote more efficient utilization of phosphorus fertilizer than did conventional tillage (Drew and Saker, 1978, 1980; Triplett and Van Doren, 1969).

Experiments dealing with fertility relations under zero tillage, have indicated that phosphorus fertilization needs under zero tillage were apt to change little. Bound phosphorus in organic matter may have resulted in slightly higher phosphorus requirements, but increased efficiency of phosphorus uptake due to its concentration in the surface layers may have tended to balance this loss. Under zero tillage, nitrogen recommendations are increased and phosphorus recommendations are similar to or only slightly higher as compared to conventional tillage.

III. Zero Tillage Effects on Overwintering of Winter Wheat

Aase and Siddoway (1980) reported that maintenance of stubble under zero tillage led to increased snow trapping, which resulted in significantly higher soil temperatures in the zero tillage treatments as compared to the bare soil trials. Gauer, Shaykewich and Stobbe (1980) reported similar results in experiments conducted in southern Manitoba. Higher minimum soil temperatures and reduced temperature fluctuation throughout the winter months as produced under zero tillage resulted in an environment conducive to successful overwintering of a winter wheat stand.

IV. Physiological Factors Promoting Overwintering of Winter Wheat

Although modification of the field environment has been shown to promote winter wheat survival, the importance of maintaining the stand in a state of optimal cold hardiness has also been noted (Gusta and Fowler, 1977). A number of physiological factors associated with increasing cold tolerance have been determined.

Carbohydrate Content

A number of studies have shown a positive correlation between soluble carbohydrate content and frost hardiness (Green and Ratzlaff, 1975;

Paulsen, 1968; Freyman, 1978; Newton and Anderson, 1932; Steponkus, 1979). Steponkus (1979) proposed that sugars protect cell membranes by colligatively reducing the salt concentration of the cell. In their review of the hardiness mechanisms of plants, Alden and Herman (1971) cited a suggestion by Lusena (1955) that substances like sucrose may serve to retard the growth of ice crystals and alter their pattern, decreasing their potential for cellular damage, and protecting the proteins from sudden water loss with freezing. Alden and Herman (1971) also cited a suggestion by Ullrich and Heber (1957) that the sugars could protect proteins by replacing their water of hydration or by holding the water of hydration more firmly. Heber and Santarius (1964) showed that sugars can protect ATP synthesis against frost damage in winter wheat plants and proposed that the sugars bound to the functional water or sensitive sites of membrane systems to protect them from the effects of freeze dehydration. Sugars have also been seen to be important in contributing to the long term energy reserves required by the plant for survival beneath the snow over the winter months (Pyiklik, 1963, as cited by Alden and Herman, 1971) and in providing energy for recovery from winter damage (Smith and Olien, 1981).

Cell wall polysaccharides have been implicated in a cold tolerance system differing distinctly from the role of the simple sugars. Cell wall polysaccharides have been shown to alter the freezing process. In experiments conducted by Olien (1967a, 1967b) and by Shearman et al. (1973) using winter cereals, cell wall polymers were seen to interfere with the structure of ice crystals by competing with water for sites on the crystal lattice. The interference resulted in an ice mass consisting of small or imperfect crystals. These crystals were considered less harmful to the plant than normal ice crystal lattices.

Lipids and Lipoproteins

A number of studies have illustrated an increase in the phospholipid composition of the plant during the hardening process (Steponkus, 1979; De la Roche et al., 1972; Ashworth et al., 1981; and Willemot, 1975).

Studies have also shown an increase in the degree of unsaturation of lipids (Ashworth et al., 1981) particularily in the ratio of linolenic to linoleic acid (De la Roche et al., 1972; Ashworth et al., 1981). Increasing the unsaturation of cell membrance lipids served to increase membrane fluidity and permeability. But, studies conducted with BASF 13338, a pyridazinone derivative which was used to inhibit photosynthesis and destroy the ability of the plant to synthesize linolenic acid, indicated that linolenic acid production is not a prerequisite to frost hardening (Ashworth et al., 1981; De la Roche, 1971; Willemot et al., 1979). Willemot (1975) postulated that phospholipid biosynthesis could be required for the maintenance of frost resistance over an extended period of time. Steponkus (1979) and Willemot (1975) postulated that maintenance of frost hardiness could be due to repair of membranes damaged by freezing or thawing, incorporation of less saturated fatty acids into the membranes to maintain membrane function at lower temperatures, multiplication of existing membranes or increases in the proportion of phospholipids to other membrane components, processes that led to increased lipid and phospholiped synthesis.

Growth Rate and Development Status

Hardiness has been shown to be related to the growth rate and developmental status of the plant. Environmental factors that depress growth have been linked with increased hardiness (Levitt, 1972).

Roberts (1971) showed that additions of CCC, a growth depressant, tended to increase winter hardiness in wheat, while added gibberellins tended to decrease hardiness. It has been suggested that high growth rates deplete the carbohydrate reserves required for successful overwintering or lead to decreased secondary wall development, increasing the cells' sensitivity to freezing (Levitt, 1972).

Related to the growth rate, decreased developmental status of the plant tended to increase susceptibility of the plant to winter injury. The deleterious effect of decreased developmental status has been linked to the decreased secondary cell wall development, depleted carbohydrate reserves and to the decreased percentage dry matter associated with a physiologically more youthful plant (Levitt, 1972).

Tissue Hydration and Dry Matter Accumulation

Numerous studies have shown a relationship between tissue hydration and freezing tolerance (Freyman, 1978; Freyman and Kaldy, 1979; Metcalfe et al., 1970; Fowler and Carles, 1979; Gusta and Fowler, 1976). These researchers found increased hardiness with decreased tissue hydration, with an optimum of near 65% moisture. Total dry matter accumulation has been correlated with hardiness, as well. In studies conducted by Gusta and Fowler (1979), Paulsen (1968), Freyman (1978) and Fowler and Carles (1979) increasing dry matter content of the plant was correlated with an increase in cold tolerance. In fertilizer trials conducted by Freyman and Kaldy (1979), no significant correlation between dry matter and hardiness was found. When nitrogen fertilizer was applied, crowns tended to be heavier, yet less hardy than crowns from the unfertilized treatment.

V. Effects of Fertility Treatments on Overwintering

Alteration of soil fertility levels has been proposed as a method of influencing winter hardiness, by affecting the physiological status of the plant. Nitrogen and phosphorus have been shown to influence the physiological status of winter wheat plants (Freyman and Kaldy, 1979; Single, 1971; Alden and Herman, 1979).

Nitrogen

Freyman and Kaldy (1979), in a number of growth chamber studies conducted on nitrogen and phosphorus deficient soils, found that high application rates of nitrogen fertilizer tended to reduce winter hardening in winter wheat, unless balanced with adequate phosphorus fertilization. Pyiklik (1963), found the fall nitrogen applications tended to increase cold resistance in nitrogen deficient soils and decreased resistance in soils with ample nitrogen.

Moderate nitrogen levels increased accumulations of free sugars in winter wheat plants if soils were very deficient in nitrogen, but decreased free sugar and percent dry weight if soil nitrogen levels were adequate (Pyiklik, 1963). Excessive fall nitrogen application encouraged lush fall growth. Plants with lush fall growth were low in carbohydrate reserves, and possibly possessed insufficient carbohydrate for maintenance of winter hardiness (Gusta and Fowler, 1979). The rapid growth encouraged by the additional nitrogen utilized photosynthate which could otherwise be available for storage or for differentiation (Levitt, 1972). The lack of differentiation was reflected in decreased secondary wall development, which increased susceptibility both to frost and to certain pathogens (Stakman and Harran, 1957). Nitrogen also served to increase the crown water content of winter wheat (Freyman and Kaldy, 1979) which was associated with decreased cold tolerance.

Excessive nitrogen fertilization without adequate phosphorus fertilization, appeared to produce a less hardy plant.

Phosphorus

Applications of phosphorus fertilizer in deficient soils have tended to produce increased winter hardiness, particularly where nitrogen levels were high (Freyman and Kaldy, 1979; Gusta and Fowler, 1979). Phosphorus tended to cause the plant to respire less CO_2 at low temperatures, so increasing carbohydrate accumulation (Dorokhov et al., 1966). Dry matter accumulation has been observed to increase with phosphorus fertilization (Freyman and Kaldy, 1979; and Gusta and Fowler, 1979) counteracting the lush growth encouraged by nitrogen fertilization and allowing the plant to preserve more of its carbohydrate reserves and increase secondary wall development in the cells.

Willemot (1975) speculated that adequate phosphorus supplies may be required to allow synthesis of phospholipid membrane components. He found that the rate of phosphorus uptake by winter wheat plants did not correlate directly with frost resistance, but ^{33}phosphorus was taken up and incorporated into lipids during the hardening process. Phosphorus uptake and phosphorus incorporation did not necessarily have to occur simultaneously for phosphorus to be required for phospholipid synthesis.

Although the precise roles of nitrogen and phosphorus in winter hardiness have not been determined, studies indicate a low nitrogen/phosphorus ratio is desirable in the fall to ensure adequate survival over the winter months. Fall nitrogen application has been practiced without serious decline in cold tolerance, as long as it was balanced by adequate phosphorus levels (Freyman and Kaldy, 1979).

VI. Influence of Nitrogen and Phosphorus on Yield

Almost invariably, moderate levels of nitrogen fertilization have been shown to increase winter wheat yields, if moisture levels were adequate for sustained crop production (Black and Siddoway, 1977; Boswell et al., 1976; Cochran et al., 1978; Daegger and Sander, 1976; Eck and Tucker, 1968; Finney et al., 1957; Hucklesby et al., 1971; Hunter and Stanford, 1973; Jackson and Sims, 1977; Johnson et al., 1973; Laopirojana et al., 1972; Nelson et al., 1978; Olson et al., 1976; Pendleton and Dungein, 1960; Terman et al., 1969). Phosphorus fertilization often increased yield, but results were not as large or as reliable as with nitrogen (Eck and Stewart, 1959; Karanthanasis et al., 1980; Peterson et al., 1981; Prummel, 1957; Singh, 1962).

Optimum rate of fertilization has been seen to relate to the "first limiting factor" effect. Yield increased with increasing fertilization until some factor becomes limiting. In the prairies, if fertility is adequate, moisture generally has been the limiting factor. So fertilizer rates have produced the greatest yields when moisture supply is adequate. Application of high rates of fertilizer, particularly nitrogen, with limited moisture has produced little yield increase, and in some cases, an actual yield decrease (Laspirojana et al., 1972; Johnson et al., 1973). Exceptionally high fertility rates have produced yield reductions due to toxicity (Buckman and Brady, 1972).

Timing of fertilizer application has been shown to be important in determining the response of the stand to added nutrients. Spring applied nitrogen produced a greater yield response than an equal amount of fall applied nitrogen in studies conducted by Welch et al. (1966) and by Boswell et al. (1976). Delaying nitrogen application until after the resumption of spring growth tended to decrease efficiency of nitrogen use by the plant (Finney et al., 1957; Hucklesby et al., 1971; Terman et al., 1969). Split applications of nitrogen, with a small portion applied in the fall and the remainder applied early in the spring proved more efficient than fall nitrogen applications (Boswell et al., 1976 and Ellen and Spiertz, 1980) and more efficient than spring applications if native soil fertility was exceptionally low, except in instances where fertilizer applications were light (Ellen and Spiertz, 1980).

These results have been attributed to the nitrogen uptake and growth patterns of the wheat plant. Yield potential of wheat has been shown to be determined by the grain volume available for dry matter storage, which was in turn influenced by the spikes produced, which depended on the tillering of the plant. Nitrogen affected grain number by promoting tillering in the autumn and early spring and by increasing heading ability and grain number per ear (Ellen and Spiertz, 1980). Therefore, for nitrogen fertilizer to have had a great influence on yield, it must have been available to the stand early in the growth cycle, prior to the time when these factors are determined. It has also been shown that nutrients accumulated by the plant were utilized to produce growth in the following stage. If nutrient uptake was delayed in the life cycle, the concentration of nutrients in the plant tissue may have increased after the nutrients were added to the system, but did not bring about a proportionate increase in growth or yield (Singh, 1962). However, total nitrogen uptake in the fall period of the winter wheat growth cycle was low in studies conducted by Smika and Grib (1973). Approximately 1/3 of the total nitrogen uptake by the plant occurred prior to the winter period. Therefore, only a small portion of the total nitrogen fertilizer would have been utilized during the fall period, with the bulk of fertilizer uptake being delayed to spring. Over the winter period, it has been shown that nitrogen present in the soil is subject to losses by denitrification, leaching, erosion, volatalization and utilization by soil microorganisms (Buckman and Brady, 1972). Extended exposure to these factors has led to high losses of fall applied nitrogen (Boswell et al., 1976; Ellen and Spiertz, 1980; Welch et al., 1966). Since winter wheat has been shown to absorb most of its nutrients between the period when growth resumes in the spring and the heading stage, most efficient use of nitrogen occurred when application is made early in this period (Welch et al., 1966). Earlier applications had led to excessive nitrogen losses, while delayed applications have led to nutrient deficiencies and subsequent yield declines (Ellen and Spiertz, 1980).

Phosphorus fertilizer timing was also shown to be important in winter wheat production. Phosphorus has been shown to be less subject to overwinter losses than nitrogen, since readily soluble forms of phosphorus tended to enter into an equilibrium relationship with the less soluble forms in the soil, protected from erosion, yet still available to the plants (Buckman and Brady, 1972). In studies conducted by Boatwright and Haas (1961) on spring wheat, the bulk of phosphorus uptake occurred early in plant development, with insignificant amounts being absorbed after heading. Singh (1962) attained comparable results working with winter wheat. Boatwright and Viets (1966) stated that with spring wheat, a supply of phosphorus for the first five weeks of growth was sufficient to produce maximum yield. If phosphorus was withheld for the first two weeks of growth, tillering and secondary root development was retarded. Phosphorus appeared essential for development of tillers and an adequate secondary root system. Salisbury and Ross (1978) stated that phosphorus is important in promoting root growth. Since a well established root system has been seen to be important in allowing adequate overwintering and rapid resumption of growth in the spring by the winter wheat stand, phosphorus fertilization of the crop in the fall has been viewed as desirable (Gusta and Fowler, 1979). Phosphorus also tended to increase seedling dry matter, which encouraged overwintering (Gusta and Fowler, 1979; Freyman and Kaldy, 1979).

Efficiency of phosphorus fertilization was observed to increase if the fertilizer was placed in the row or in bands as opposed to a broadcast application (Peterson et al., 1981; Prummel, 1957). Placement of phosphorus fertilizer with or below the seed at the time of seeding therefore has been viewed as the most efficient method of application (Grant et al., 1976).

VII. Influence of Nitrogen on Grain Protein

The goals of optimum yield and high percentage protein have appeared to be in conflict, since an inverse relationship between yield and percent protein has been domonstrated in a number of studies (Hunter and Stanford, 1973; Johnson and Mattern, 1979; Miezan et al., 1977; Pushman and Bingham, 1976; Terman et al., 1969). The decrease in percent protein with increasing yield was a dilution effect. As yield increased, the dry matter among which the limited nitrogen supply of the plant was to be distributed increased, decreasing the protein nitrogen per unit dry matter. Factors which tended to increase yield would simultaneously tend to decrease percentage nitrogen. Available nitrogen was first directed to promoting a yield increase. Only when yield potential was satisfied within the environmental conditions present was additional nitrogen directed towards increasing percentage protein (Terman et al., 1969; Miezan et al., 1977). Increasing nitrogen fertilization to higher levels tended to produce simultaneous increases in yield and percent protein (Terman et al., 1969; Pushman and Bingham, 1976; Nelson et al., 1978, Olson et al., 1976; Johnson et al., 1973 and Cochran et al., 1978). Additions of nitrogen above rates where yield response ceased to occur continued to increase percent protein to a higher plateau. Since high grain protein has been correlated with improved baking quality of flour (Bushuk, 1977; Orth and Bushuk, 1972; Pushman and Bingham, 1976; Miezan et al., 1977) increasing grain protein to high levels by application of high nitrogen rates has been seen as a viable practice. Since no price advantage for high protein wheat has been paid to individual producers, incentive for this practice on the farm level has not materialized.

Timing of nitrogen fertilization to increase efficiency of stand utilization of added nutrients has been viewed as a method to increase protein percentage. Spring applied nitrogen was more efficient in increasing protein than a similar amount of nitrogen applied as a fall or split treatment (Welch et al., 1966; Boswell et al., 1976). Delaying nitrogen application until after the resumption of spring growth increased percent grain protein, but was inefficient in increasing grain yield (Hucklesby et al., 1971; Finney et al., 1957; Johnson et al., 1973; Terman et al., 1969). Late applications of nitrogen were unavailable during the periods of wheat growth when yield factors such as tillering and spike production were determined, but were taken up and stored in the plant during grain filling, increasing percent protein in the limited dry matter produced. If nitrogen was available for uptake throughout filling, over one-half of the grain protein was derived from nitrogen taken up during this period (Evans et al., 1978). The nitrogen may be supplied during this period by high rates of fertilization or by providing nitrogen increments late in the growing season.

MATERIALS AND METHODS

Field experiments were conducted near Minnedosa, Manitoba in 1979-80 and 1980-81. Trials in 1979-80 were located on a clay loam soil on SW 22-14-18. In 1980-81, trials were shifted to a clay soil on NW 20-15-18. Both sites were within the Newdale Clay Loam soil region.

In both years, winter wheat was sown into barley stubble cut at a height of fifteen centimeters. A Melroe 701 zero till drill was used for all seeding operations and set to sow to a depth of approximately six centimeters. With the exception of two experiments in 1980-81 sown to Winalta, all trials were seeded to Norstar winter wheat.

Yield was determined by hand harvesting four, one-half square meter areas selected at random in each plot. Samples were dried, then threshed with a Vogel thrasher. Protein determination of the grain was conducted by the protein analysis laboratory at the University of Manitoba, using a Kjeldhal method. Percent nitrogen recovery in the grain was determined using the formulae:

1. $$\text{N uptake} = \frac{\%\ \text{grain protein}}{100} - 5.7 \times \text{Yield (kg/ha)}$$
2. % N efficiency =

$$100 \times \left[\frac{\text{N uptake i} - \text{N uptake check} - \left(\frac{\text{N applied with phosphate}}{2}\right)}{(\text{N applied with phosphate} + \text{N applied as treatment})} \right]$$

All qualitative assessments were statistically analyzed and treatment means compared using Least Significant Differences or Duncan's Multiple Range Test. Only differences at the five percent level were considered meaningful.

Trials Conducted in 1979-80.

Barley from the previous crop was harvested by a straight cut combine and the straw was chopped and spread. Rate of seeding was eighty-five kilograms per hectare. Phosphorus fertilizer was applied as 11-51-0 with the seed. Nitrogen was applied as 34-0-0, broadcast.

As assessment of plant growth stage was made on November 1, 1979 and plants were found to be commencing tillering (Feekes' scale stage 2). Soil tests were taken in April of 1980, at the 0-15 cm and 15-60 cm depth (Table 1).

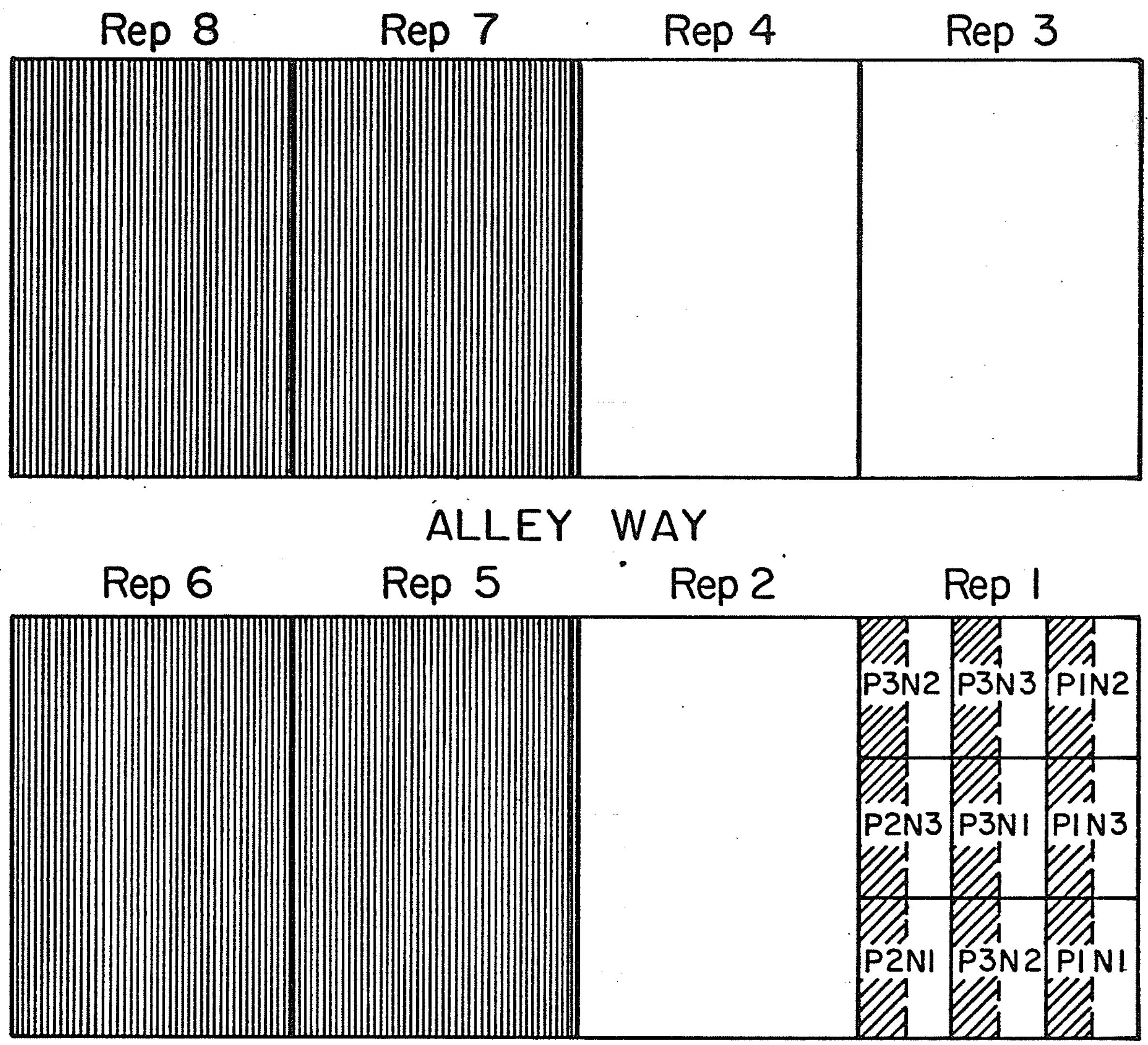
Drought conditions in 1979-80 led to delayed emergence of weeds in the winter wheat stand. Weed populations were not sufficiently high to warrant herbicide applications, until the wheat stand was at a stage too advanced for safe or effective weed control. Therefore, herbicide application in 1979-80 was omitted.

Experiment 1: The effects of nitrogen, phosphorus and sulfur on winter survival and growth of winter wheat.

This experiment was established as a split-split plot split block trial (see Figure 1). Seeding was done on September 8, 1979. Phosphorus was applied with the seed as 11-51-0, at levels of 0, 25, and 50 kilograms P_2O_5 per hectare. Nitrogen was broadcast at levels of 0, 60 and 120 kilograms of actual nitrogen per hectare as 34-0-0 on September 15, 1979. Sulfate sulfur was broadcast on September 15 at a rate of 50 kilograms of sulfur per hectare.

Fall stand counts were taken from six one-meter row lengths in each plot between September 30 and October 7, 1979.

Preliminary estimates of cold tolerance were made in the laboratory using a modification of the technique described by Gusta and Fowler (1976) on plants collected from this trial on November 4, 1979. One hundred plants were collected from the check, the 0 kilogram per hectare



Fall treatments

P1 0 Kg P_2O_5/ha
P2 25 Kg P_2O_5/ha
P3 50 Kg P_2O_5/ha
N1 0 Kg N / ha
N2 60 Kg N / ha
N3 120 Kg N / ha
50 Kg Sulfate / ha

Spring treatment

\- 50 Kg N/ ha

FIG. 1. General plan for experiment 1, with details of a sample rep.

TABLE 1. Soil test results-averaged

Year	Depth (cm.)	Texture	Nitrate-Nitrogen		Available Phosphorous		Available Potassium		Sulphate-Sulphur	
			ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha
1979-80	0-15	SiC	12.2	22.2	10.1	18.2	400.6	721.0	10.4	18.6
	0-60	SiC	8.2	47.8	----	----	-----	-----	20+	116+
1980-81	0-15	C	3.4	6.2	15.0	27.1	271.8	489.4	6.2	11.2
	0-30	C	2.9	18.1	----	----	-----	-----	5.3	32.4

nitrogen plus 50 kilogram per hectare phosphorus treatment, the 120 kilogram per hectare nitrogen plus 0 kilogram per hectare phosphorus treatment and the 0 kilogram per hectare nitrogen, 0 kilogram per hectare phosphorus plus 50 kilogram per hectare sulfur treatment. The plants were dug with a trowel, washed in cold water and sealed in groups of twenty in plastic bags from which the air was evacuated. Samples were refrigerated for twenty-four hours, then placed in a freezing chamber where the temperature was lowered by 2.5° Celsius per hour. One group of plants from each treatment was removed at one hour intervals between negative 10° Celsius and negative 17° Celsius. The plants were refrigerated overnight, and then replanted in vermiculite flats in a greenhouse. An assessment of plant survival was made after twenty-four days. Plants were judged to have survived if regrowth was evident. Lethal temperature (LT_{50}), the temperature at which 50% of the plants failed to survive, was calculated from these measurements.

Spring nitrogen fertilizer was applied as 34-0-0 broadcast on April 28, 1980. A rate of 60 kilograms per hectare was applied.

Spring stand counts were taken from twenty one-meter row lengths in each plot between May 15 and June 5. Percent survival was calculated from these measurements.

Experiment 2: The effects of spring broadcast applications of nitrogen fertilizer on growth parameters of winter wheat.

This experiment was established as a randomized complete block trial. The wheat was seeded on September 15, 1979 and an overall treatment of 20 kg P_2O_5/ha was applied at the time of seeding. Soil tests were taken on April 27, 1980 at the 0-15 and 15-60 centimeter depths. Fertilizer nitrogen was broadcast as 34-0-0 on April 28, 1980 at levels of 0, 30, 60, 90, 120, 180, and 240 kilograms per hectare actual nitrogen. Yield and percentage grain protein were determined as explained in the general procedures.

Trials Conducted in 1980-81

Barley from the previous crop was swathed and combined. The excess straw was baled and removed. Soil tests were taken at the 0 to 15 and 15 to 60 centimeter depths. Conventionally tilled trials were sown after two cultivations with a light duty cultivator. The rate of seeding was fifty-five kilograms per hectare. Seeding of the Norstar trials was completed on September 12, 1980, while the Winalta seeding was delayed until September 27, due to the late arrival of the seed. An overall treatment of 40 kilograms per hectare P_2O_5 as 11-48-0 was applied with the seed in all experiments not dealing with the effects of phosphorus fertility. Nitrogen was applied as 34-0-0, broadcast.

An overall herbicide treatment of 280 gm/ha Bromoxynil plus 280 gm/ha MCPA, was applied on September 27 for the control of germinating winter annuals. An assessment of stand maturity was made on November 3, 1980 on the Norstar winter wheat and plants were beginning to tiller (Feekes' stage 2).

Spring stand counts were taken from all experiments except the spring nitrogen trial from May 4 to May 16, 1981. Ten one-meter lengths were sampled from the centre ten rows one meter from the front of the plot.

An early spring application of 280 gm/ha bromoxynil + 280 gm/ha MCPA was applied on May 18, 1981 for control of broadleaf weeds.

Dry matter yield of the plots was determined from samples of six one-meter lengths of the rows in all experiments but the spring nitrogen trials. Samples were collected between June 2 and June 29, 1981.

An overall treatment of a diclofop methyl plus bromoxynil tank mixed at a rate of 700 grams diclofop methyl plus 280 grams bromoxynil per hectare was applied on June 11, 1981 for the control of green foxtail, wild oats and the remaining broadleaf weeds.

Straw yield and percent protein were also determined from the harvest samples collected. From these data, total percent nitrogen recovery was determined using the following formulae:

1. $$\%N\ \text{uptake} = \left[\left(\frac{\%\ \text{grain protein}}{100} \div 5.7\right) \times \text{grain yield (kg/ha)}\right] + \left[\left(\frac{\%\ \text{straw protein}}{100} \div 6.25\right) \times \text{straw yield kg/ha}\right]$$

2. $$\%N\ \text{efficiency} = 100 \times \left[\frac{N\ \text{uptake}\ i - \left(N\ \text{uptake check} - \left(\frac{N\ \text{applied with phosphate}}{2}\right)\right)}{N\ \text{applied with phosphate} + N\ \text{applied as treatment}}\right]$$

Harvest was conducted when the individual plot reached the hard dent stage. This ranged from August 15 to August 26, 1981.

Experiment 3: The effects of spring broadcast applications of nitrogen fertilizer on growth parameters of winter wheat.

This experiment was established as a randomized complete block design. Nitrogen fertilizer was broadcast as 34-0-0 on April 26, 1981, at rates of 0, 30, 60, 90, 120, 180, 240, and 300 kilograms per hectare actual nitrogen.

Grain yield and percent protein, straw yield and percent protein and percent nitrogen recovery were determined as described previously.

Experiment 4: The effects of fall applied nitrogen and phosphorus on winter hardiness and growth of zero tilled Norstar winter wheat.

This experiment was laid out as a split plot design. Phosphorus was used as the main treatment, and applied as 11-48-0 at levels of 0, 20 and 50 kilograms per hectare P_2O_5. Nitrogen was broadcast immediately after seeding as 34-0-0 at rates of 0, 60 and 120 kilograms per hectare actual nitrogen.

An assessment of fall cold tolerance was undertaken on all fertility treatments, on plant samples gathered on October 3, October 10, and October 17, 1980. Plant samples were collected from each plot and bagged in groups of ten in the same fashion as described in experiment 1. Then, one group of plants from each treatment was placed in a larger plastic bag, which was then evacuated and sealed. Six of these larger groupings were formed and placed in a styrofoam container filled with two gallons of water and antifreeze mixed in a ratio of one part water to five parts antifreeze. A plywood board weighted with a brick was used to keep the plant samples submerged. The heat sensor of an indoor-outdoor thermometer was placed among the samples and the cooler was covered, then placed in a conventional household freezer precooled to -25 degrees Celsius. The cooling curve of the antifreeze solution is shown in figure 2. Cooling occurred at a rate of approximately 1 degree Celsius per hour until the lower extreme of the cooling curve.

Plant samples were removed at 2 degree intervals between -6 degrees and -16 degrees Celsius the first week, -8 degrees and -18 degrees Celsius the second week and -10 degrees and -20 degrees the third week. After their removal, the plants were placed in a refrigerator set at 3 degrees Celsius. The following day they were transplanted into vermiculite flats. They were kept in a greenhouse and watered periodically with Hoagland's solution for three weeks, when an assessment of LT_{50} was obtained, by noting the temperature where 50% of the plants in a treatment failed to exhibit regrowth (modification of the technique described by Gusta and Fowler, 1976).

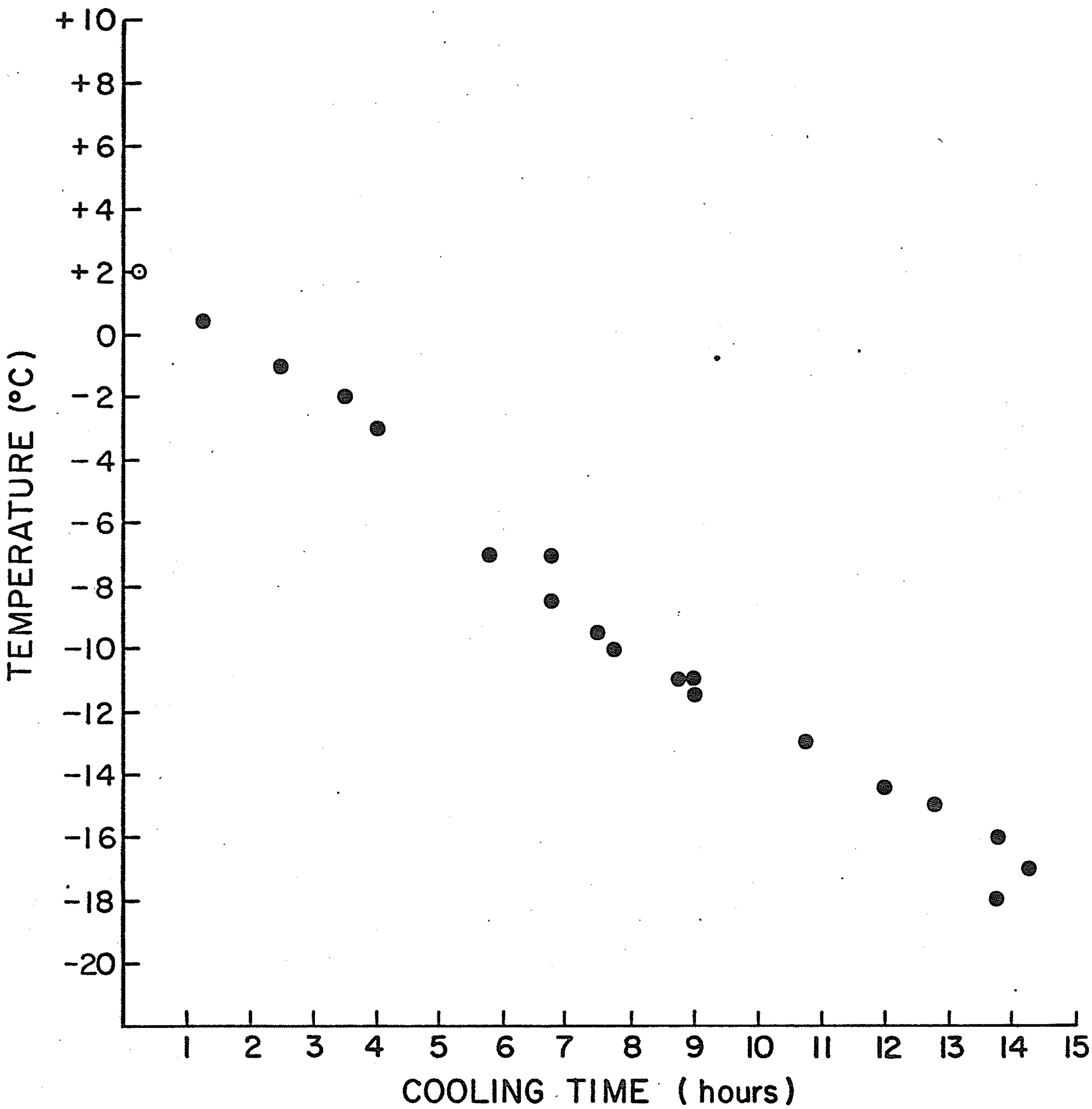


FIG. 2. Temperature of antifreeze solution as a function of cooling time.

Fall stand counts were taken from one-meter lengths of the ten centre rows, at a position one meter from the front of the plot. These counts were taken on October 25, 1980.

On November 3, 1980, plant samples were collected for tissue analysis of nitrogen, phosphorus and potassium. Phosphorus and potassium determination were done by the tissue testing laboratory at the University of Manitoba. Nitrogen determinations were made using the micro-kjeldhal method.

Spring stand counts, dry matter production, grain yield and percent protein, straw yield and percent protein and percent nitrogen recovery were determined as described previously.

Experiment 5: The effects of fall applied nitrogen and phosphorus on winter survival and growth of zero tilled Winalta winter wheat.

This experiment was laid out as a split plot design. Due to the late arrival of the seed, sowing was delayed until September 27. Phosphorus and nitrogen fertilizer was applied at time of seeding as described in Experiment 3.

On November 3, 1980, the coleoptiles of the plants were emerged to a height of approximately fifteen millimeters.

Measurements of spring stand, dry matter accumulation, grain yield and percent protein, straw yield and percent protein and percent nitrogen recovery were determined as described in the general procedures and the procedures for 1980-81.

Experiment 6: The effects of fall applied nitrogen and phosphorus on winter survival and growth of conventionally tilled Norstar winter wheat.

This experiment was laid out as a split plot design. Fertilizer treatments and rates were the same as in Experiment 3. Tillage was accomplished with two passes of a light duty cultivator prior to seeding. Fall stand counts were taken from one-meter lengths of the ten centre rows, at a position one meter from the front of the plot. Counts were taken on October 25, 1980.

Spring stand counts, dry matter production, grain yield and percent protein, straw yield and percent protein and percent nitrogen recovery were determined as described in the general procedures and procedures for 1980-81.

Experiment 7: The effects of fall applied nitrogen and phosphorus on winter survival and growth of conventionally tilled Winalta winter wheat.

This experiment was laid out in a split plot design. Tillage was accomplished with two passes of a light duty cultivator prior to seeding. Fertilizer treatments were applied at the time of seeding, as described in Experiment 3.

On November 3, the coleoptiles of the plants were emerged to a height of approximately fifteen millimeters.

Measurements of spring stand, dry matter accumulation, grain yield and percent protein, straw yield and percent protein and percent nitrogen recovery were determined as described in the general procedures and the procedures for 1980-81.

Experiment 8: The effects of fall, spring and split applications of broadcast nitrogen on growth parameters of zero tilled Norstar winter wheat.

This experiment was laid out in a 6x6 Latin Square design. Treatments were 0 kilogram per hectare nitrogen check, 45 kilograms per hectare actual nitrogen applied in the fall, 45 kilograms per hectare actual nitrogen applied in the spring, 90 kilograms of actual nitrogen applied in the fall, 90 kilograms of actual nitrogen applied in the spring and 90 kilograms of actual nitrogen applied as a split application with 45 kilograms per hectare applied in the fall and in the spring. Fall applied nitrogen was broadcast on September 12, 1980 and spring applied nitrogen was broadcast on April 27, 1981.

Spring stand counts, dry matter production, grain yield and percent protein, straw yield and percent protein and percent nitrogen recovery were determined as described previously.

Experiment 9: The effect of timing of nitrogen application on growth parameters of zero tillage Norstar winter wheat, 30 kg/ha.

This experiment was laid out in a Randomized Complete Block design. Nitrogen treatments were broadcast as 34-0-0 on September 12 (at seeding), November 3 (at freezeup), January 3 (on the snow), and April 26 (early spring). A 0 kilogram per hectare check was included for comparison.

Spring stand counts, dry matter production, grain yield and percent protein, straw yield and percent protein and percent nitrogen recovery were determined as described previously.

Experiment 10: The effect of timing of nitrogen application on growth parameters of zero tillage Norstar winter wheat, 60 kg/ha.

This experiment was established, treated and measured in the same fashion as Experiment 8, except for the rate of nitrogen fertilizer applied, as referred to in the title of the experiments.

TABLE 3. Monthly precipitation

Year	Month	Precipitation (mm)	Percent of Normal
1979	September	40.0	90.0
	October	11.3	48.0
	November	15.0	70.0
	December	11.2	72.0
1980	January	30.0	171.0
	February	18.0	116.0
	March	14.0	68.0
	April	0.0	0.0
	May	8.2	16.0
	June	73.5	92.0
	July	92.1	112.0
	August	195.8	327.0
	September	35.9	81.0
	October	17.6	75.0
	November	20.0	94.0
	December	12.2	79.0
1981	January	19.0	109.0
	February	6.0	39.0
	March	10.6	51.0
	April	30.2	126.0
	May	34.6	69.0
	June	87.7	110.0
	July	41.6	51.0
	August	81.5	136.0

TABLE 3. Minimum, maximum and mean monthly air temperature

Year	Month	Minimum Temperature °C	Maximum Temperature °C	Mean Temperature °C
1979	September	-0.5	0.3	-0.1
	October	-3.4	9.2	2.9
	November	-10.8	-0.8	-5.8
	December	-17.0	-5.5	-11.3
1980	January	-26.5	-13.4	-20.0
	February	-23.0	-10.1	-16.6
	March	-19.2	-4.4	-11.8
	April	-3.2	15.2	6.0
	May	4.0	22.0	13.0
	June	7.0	21.8	14.4
	July	9.5	24.5	17.0
	August	8.0	20.6	14.3
	September	2.9	15.8	9.4
	October	-3.4	8.2	2.4
	November	-9.2	1.6	-3.8
	December	-24.0	-9.8	-16.9
1981	January	-21.8	-7.2	-14.5
	February	-18.8	-5.6	-12.2
	March	-9.8	3.9	-3.0
	April	-5.1	10.5	2.7
	May	-11.0	27.5	10.8
	June	0.5	28.5	15.6
	July	3.0	35.0	19.9
	August	6.0	31.0	19.7

RESULTS AND DISCUSSION

Experiment 1: The effect of nitrogen, phosphorus and sulfur on winter survival and growth of winter wheat.

No differences were observed in the response of winter wheat to sulfur fertilization, and data from sulfur treatments were pooled.

Lethal Temperature Effects (LT_{50})

As the LT_{50} information collected was limited, statistical analysis was not conducted. There was no apparent difference in LT_{50}, between the check and the 120 kg/ha nitrogen treatment (Table 4). At additions of 50 kg/ha phosphorus applied alone the LT_{50} was -12.5°C. The tendency for LT_{50} to decrease in response to added phosphorus may have indicated a tendency for cold tolerance to increase as phosphorus fertilization increased.

Winter Survival

Addition of 120 kg nitrogen fertilizer/ha decreased percent survival at P_2O_5 rates of 25 kg and 50 kg/ha when compared to the 0 kg N/ha and 60 kg N/ha rates respectively (see Table 4). Addition of 120 kg N/ha led to a decrease in survival below that of the check when all phosphorus treatments were averaged. Phosphorus fertilizer had no influence on winter survival.

Grain Yield

Nitrogen fertilization increased the grain yield at the 60 kg/ha rate with a further yield increase when nitrogen was applied at the 120 kg/ha, at all rates of phosphorus fertilization (see Table 4). The response to added nitrogen tended to be greater when phosphorus fertilizer was added, but did not differ between 25 kg/ha phosphorus and 50 kg/ha phosphorus.

Addition of 25 kg/ha phosphorus produced an increase in grain yield over that of the check. Increasing the rate of phosphorus fertilization to 50 kg/ha produced no further yield increases.

TABLE 4. Lethal temperature, percent winter survival, grain yield, percent grain protein and percent nitrogen recovery in the grain at various rates of fall applied nitrogen and phosphorus fertilization in zero till Norstar winter wheat, 1979-80

Treatment (kg/ha) Phosphorus	Nitrogen	LT_{50}[1] °C	Winter Survival (%)	Grain Yield (T/ha)	Grain Protein (%)	Nitrogen Recovery in the Grain (%)
0	0	-10.0°C	56.68	1.274	13.59	--
	60	---	49.69	2.120	12.81	28.18
	120	-10.0°C	50.57	2.381	14.09	23.65
25	0	---	70.56	2.065	12.10	--
	60	---	56.49	2.567	13.41	45.44
	120	---	48.75	2.846	14.03	31.34
50	0	-12.5°C	55.46	2.373	12.11	--
	60	---	67.28	2.583	13.48	42.59
	120	---	50.25	2.869	13.73	29.55
LSD (0.05)[2]			14.20	0.233	0.75	ns
LSD (0.05)[3]			14.74	0.311	0.87	ns
Nitrogen (kg/ha)						
	0	---	60.90	1.904	12.60	--
	60	---	57.82	2.423	13.23	38.74
	120	---	49.86	2.699	13.95	28.18
LSD (0.05)			7.95	0.179	0.44	ns
Phosphorus (kg/ha)						
0		---	52.31	1.925	13.50	25.92
25		---	58.60	2.493	13.17	38.39
50		---	57.66	2.608	13.10	36.07
LSD (0.05)			ns	0.159	0.39	ns

1 Lethal temperature when 50% of the plants are killed.
2 Comparisons made within phosphorus treatments.
3 Comparisons made among differing phosphorus treatments.

Addition of 60 kg/ha nitrogen in the spring increased the average yield (Table 5). However, addition of nitrogen in the spring or in split applications of 60 kg/ha in the fall plus 60 kg/ha in the spring was not more effective in increasing the grain yield than application of an equivalent amount of nitrogen in the fall. Presumably, nitrogen losses over winter were not great enough to produce differences in response to applications in the fall and in the spring. Alternately, the nitrogen applied in the fall could have been more readily available to the crop during the initial stages of growth in the spring. Fall moisture and moisture from the snow melt would have carried the fall applied nitrogen into the soil. Since the moisture levels were low, the nitrogen would not have leached to a great extent. Spring applied nitrogen did not receive rainfalls to carry it into the soil where it could be readily available to the plant until later in the season. This moisture limitation could have decreased the response of the crop to the spring applied nitrogen fertilizer.

Percent Grain Protein

Fall application of 60 kg/ha nitrogen produced a significant increase in percent grain protein and an application of 120 kg/ha nitrogen produced a further increase (Table 4). An additional application of 60 kg/ha nitrogen applied in the spring produced an increase in percent protein at the 0 and 60 kg/ha fall applied nitrogen rates, but not at the 120 kg/ha nitrogen rate (Table 5 and 6). Application of 60 kg/ha nitrogen in the spring was superior to fall application in promoting increased percent protein at the 0 kg/ha and 50 kg/ha phosphorus rates but not at the 25 kg/ha phosphorus rate. Split applications of 60 kg/ha nitrogen applied in the fall plus 60 kg/ha nitrogen applied in the spring did not differ from application of 120 kg/ha nitrogen in the fall in promotion of grain protein.

TABLE 5. Grain yield, percent grain protein and percent nitrogen recovery in the grain at various levels of fall and spring applied nitrogen fertilizer in zero tilled Norstar winter wheat, 1979-80

Treatment (kg/ha) Fall Applied Nitrogen	Spring Applied Nitrogen	Grain Yield T/ha	Grain Protein %	N recovery in the Grain %
0	0	2.014	12.60	--
0	60	2.421	13.95	26.65
60	0	2.543	13.23	26.30
60	60	2.616	14.09	18.22
120	0	2.696	13.95	19.27
120	60	2.829	14.20	15.49
LSD (0.05)		0.134	0.44	ns

TABLE 6. Percentage grain protein produced without the addition of spring nitrogen and with the addition of 60 kg/ha spring nitrogen, at various rates of fall applied nitrogen and phosphorus fertilization, in zero tilled Norstar winter wheat, 1979-80

Treatment (kg/ha)		Spring Nitrogen Application (kg/ha)		
Phosphorus	Nitrogen	0	60	LSD
0	0	13.59	13.71	0.75
	60	12.81	13.70	0.75
	120	14.09	14.19	0.75
25	0	12.10	13.89	0.75
	60	13.41	14.45	0.75
	120	14.03	14.03	0.75
50	0	12.11	14.26	0.75
	60	13.48	14.14	0.75
	120	13.73	14.39	0.75
	LDS (0.05)[1]	0.75	0.75	
	LDS (0.05)[2]	0.73	0.73	
Nitrogen (kg/ha)				
	0	12.60	13.95	0.75
	60	13.23	14.09	0.75
	120	13.95	14.20	0.75
	LSD (0.05)	0.44	0.44	
Phosphorus (kg/ha)				
0		13.50	13.87	0.75
25		13.17	14.12	0.75
50		13.10	14.26	0.75
	LSD (0.05)	0.39	0.39	

[1] Comparisons made within phosphorus treatments.
[2] Comparisons made among differing phosphorus treatments.

Rainfall levels during the time of heading were extremely high, (Table 2) allowing for uptake of soil nitrogen by the plant at that time. Higher levels of nitrogen were available to the plant from spring nitrogen applications than from fall applications for uptake at this time. At low levels of nitrogen applications, this resulted in generally higher levels of percent protein. At higher levels of nitrogen fertilizer, the differences in available nitrogen were not large enough to translate into increased percent protein levels.

Nitrogen Recovery in the Grain

Nitrogen recovery in the grain was not significantly affected by fertility treatment. There was a trend towards decreasing efficiency of recovery as nitrogen fertilization increased and an increase in efficiency when phosphorus fertilizer was applied (Table 4).

When soil moisture produced a constraint on yield as it did in 1980, uptake and utilization of fertilizer nitrogen was restricted. High levels of nitrogen were not utilized by the plant, so efficiency of nitrogen recovery decreased as rate of nitrogen application increased.

Phosphorus would have tended to increase efficiency of nitrogen utilization by producing a nitrogen-phosphorus balance conducive to improved plant growth (Table 4). Phosphorus deficiency would decrease winter wheat root growth and seed production, which would limit the ability of the plant to absorb and utilize nitrogen. Correcting the phosphorus deficiency would allow more efficient utilization of nitrogen fertilizer application.

No difference existed between percent nitrogen recovery in the grain of nitrogen applied in the fall or in the spring (Table 4). Overwinter losses of fall applied nitrogen were limited due to the low moisture levels in the soil from the fall of 1979 throughout the winter and early spring. These soil conditions would result in decreased nitrogen losses due to leaching and denitrification.

<u>Experiment 2 and 3:</u> The effect of spring broadcast applications of nitrogen fertilizer on growth parameters of winter wheat, 1979-80, 1980-81.

<u>Grain Yield</u>

In 1979-80, grain yield was increased by the addition of nitrogen up to 60 kg/ha nitrogen (Table 7).

In 1980-81, yield was increased with each addition of nitrogen fertilizer to a level of 90 kg/ha actual nitrogen.

Yield in 1980-81 was significantly higher than in 1979-80 at all levels of nitrogen fertilizer (Table 8). In 1979-80, precipitation levels were much lower than normal during the early portion of the growing season, when yield parameters were determined (Table 2). The low available moisture for plant growth during the early stages reduced the yield potential of the crop. In 1980-81, sufficient rainfall occurred in April and June to supplement soil moisture reserves and produce high yields, allowing the crop to produce a yield response to higher levels of nitrogen fertilizer.

TABLE 7. Winter wheat grain yields, grain percent protein and percent nitrogen recovery in the grain for spring applied nitrogen treatments, zero tilled Norstar, 1979-80

Treatment kg N/ha	Grain Yield T/ha	Grain Protein %	Nitrogen recovery in the Grain %
0	1.476a[1]	10.42a	--
30	1.719 b	10.43a	19.29ab
60	2.326 c	11.50 b	34.36a
90	2.175 c	12.15 c	22.83ab
120	2.246 c	12.85 d	20.77ab
180	2.236 c	13.57 e	15.42 b
240	2.627 c	14.30 f	16.81 b

[1] Numbers followed by the same letter do not differ at the %5 level.

TABLE 8. Winter wheat grain yields, grain percent protein, percent nitrogen recovery in the grain and total percent nitrogen recovery for spring applied nitrogen treatments, zero tilled Norstar, 1980-81

Treatment kg N/ha	Grain Yield T/ha	Grain protein %	Nitrogen recovery in the grain %	Total Nitrogen recovery %
0	1.579a[1]	8.43 b	--	
30	2.755 b	7.82a	48.63a	60.60ab
60	3.444 c	8.18a	44.34ab	62.05ab
90	4.003 d	9.02 c	44.97ab	66.54a
120	4.162 d	9.57 d	39.58 bc	57.89ab
180	4.252 d	10.43 e	31.22 cd	48.40 bc
240	4.344 d	10.93 e	25.91 de	38.62 cd
300	4.337 d	10.97 e	20.93 e	32.92 d

[1] Numbers folowed by the same letter do not differ at the 5% level.

Percent Grain Protein

In 1979-80, percent grain protein was increased with each addition of nitrogen fertilizer between 60 kg/ha and 240 kg/ha actual nitrogen (Table 7). Percent protein ranged from a low of 10.42% at 0 kg/ha nitrogen to a high of 14.30% protein at 240 kg/ha nitrogen, with an overall average of 11.82%.

In 1980-81, percent protein decreased with additions of 30 and 60 kg/ha nitrogen (Table 8). Increases in percent protein occurred with each subsequent addition of nitrogen until 180 kg/ha was added. Further additions of fertilizer nitrogen produced no further increases in percent grain protein.

Percent protein in 1980-81 was lower than that attained in 1979-80 at each level of nitrogen fertilizer. In 1980-81, moisture levels in the early part of the growing season were high, leading to the production of high grain yields. However, during July, the time of grain filling, rainfall was low (see Table 2). Uptake of soil nitrogen was limited due to low moisture availability and the plant was unable to take up sufficient nitrogen to maximize protein in the grain. Protein production was not high enough to result in high percent protein levels throughout the large dry matter mass produced in the early stages of growth.

In 1979-80, rainfall patterns were reversed in comparison to 1980-81. Moisture levels during the early portion of the growing season were extremely low, resulting in reduced dry matter production (Table 2). In July and August, rainfall levels increased and the stand was able to take up and incorporate soil nitrogen into grain protein. Nitrogen assimilation into protein was high, and when distributed within the relatively small grain yield, resulted in elevated percent grain protein levels.

Nitrogen Recovery in the Grain

Percent nitrogen efficiency indicates the proportion of the fertilizer nitrogen that was recovered in the grain.

In 1979-80, there was no significant difference between percent recovery of nitrogen at fertilization levels between 30 and 120 kg/ha actual nitrogen (Table 7). Levels of 180 or 240 kg/ha nitrogen were utilized less efficiently than the 60 kg/ha level.

In 1980-81, nitrogen efficiency again declined as rate of nitrogen fertilization increased (Table 8). Nitrogen at rates less than 90 kg/ha were more efficiently utilized than rates of 180 kg/ha or higher.

Nitrogen was used more efficiently in 1980-81 than in 1979-80. In 1979-80, the drought conditions in the early portion of the growing season reduced the potential of the plant for grain dry matter production and protein storage (Table 2). In spite of the high moisture levels available in the later period of growth, the plants ability to take up nitrogen was limited. In 1980-81, adequate moisture in the early part of the season resulted in a high protein storage capacity and a high nitrogen uptake. In spite of the restriction placed on nitrogen uptake during the dry period in July, nitrogen utilization and total protein production were maintained at high levels.

The decreasing percentage utilization of added nitrogen with increasing levels of nitrogen fertilization apparent in both years indicates that the ability of the crop to take up and utilize nitrogen did not increase in proportion with the increase in nitrogen added. The restriction may have been due to low moisture levels during portions of the growing season leading to a reduced nitrogen movement to the roots and into the plant.

In 1980-81, nitrogen utilization in both the straw and the grain was calculated (Table 8). No significant difference existed between efficiency of utilization of levels of nitrogen fertilizer between 30 and 120 kg/ha, but there was a tendency for efficiency to increase as rate of fertilizer increased from 30 to 90 kg/ha. This trend differs from that noted for utilization in the grain alone, possibly indicating a "bottleneck" for protein mobilization from the leaves to the grain. Above 120 kg/ha, efficiency of added nitrogen utilization decreased until at 300 kg/ha efficiency was less than one-half of that observed at 90 kg/ha added nitrogen.

Percent Protein in Relation to Yield

Figure 1 illustrates the relationship between percentage protein and grain yield in 1979-80, and 1980-81. In this situation, where yield and protein were both increasing in response to increasing levels of nitrogen fertilization, there was a positive relationship between yield and protein.

The initial low or negative correlations between yield and protein existing at low yield levels are due to initial high responses of yield to added nitrogen fertilization. The large yield increase led to dilution of the grain protein by large amounts of dry matter, producing a net decrease in percent protein. As the yield response to nitrogen fertilizer decreased, the response of percent protein levels tended to increase, producing the steep upward slope with increased yield of grain.

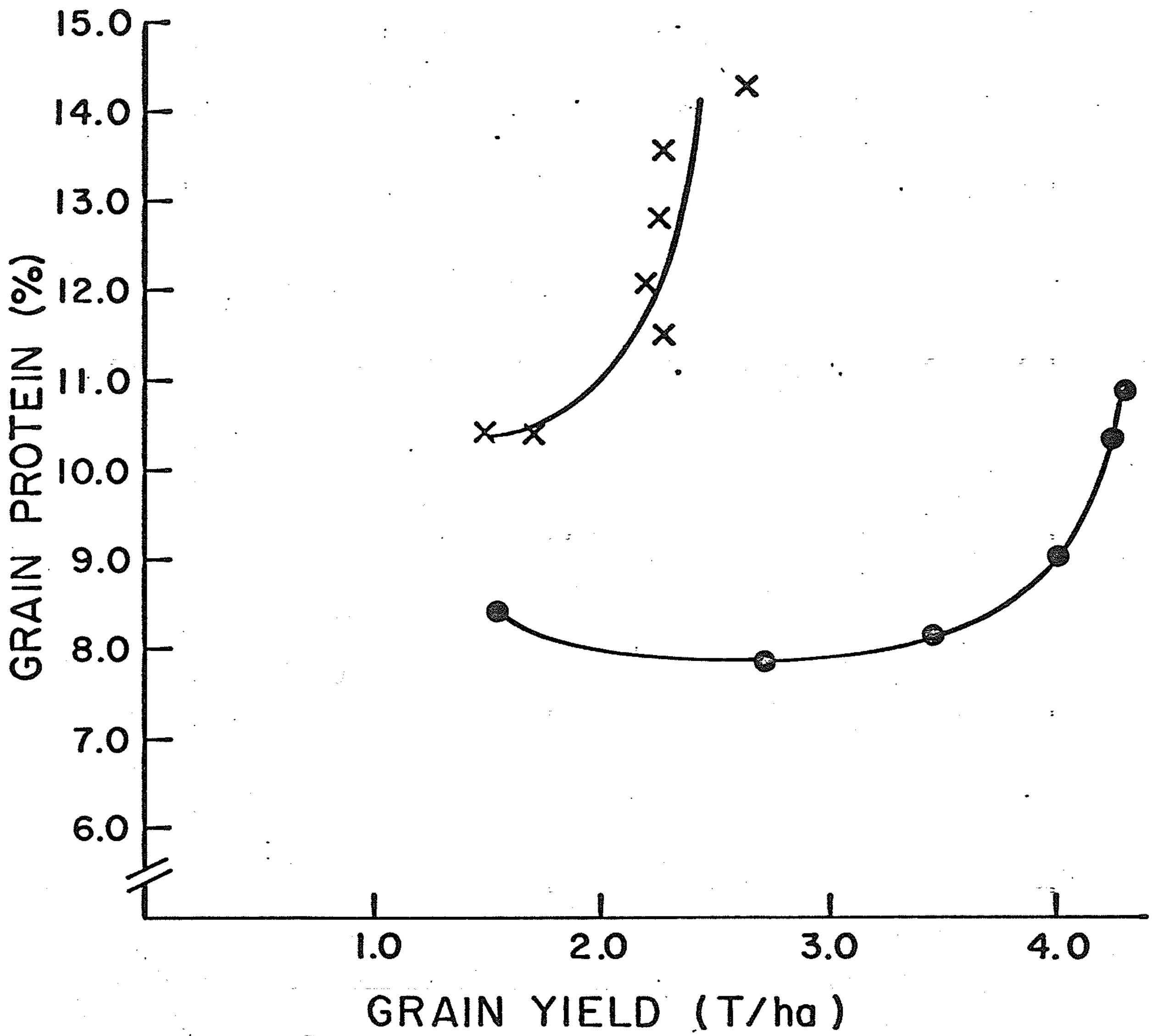


FIG. 3. Percent protein as a function of grain yield, at levels of nitrogen fertilizer from 0 to 240Kg/ha, in 1980 (x—x) and 1981 (●—●) for zero till Norstar winter wheat.

Experiment 4: The effects of fall applied nitrogen and phosphorus on winter hardiness and growth of zero tilled Norstar winter wheat.

Plant Tissue Nutrient Analysis

Addition of nitrogen fertilizer resulted in an increase in percent nitrogen content of the tissue, both at the 60 and at the 120 kg/ha rate (Table 9). Addition of phosphorus had no effect on nitrogen content of the tissue.

Addition of nitrogen fertilizer did not affect the percent phosphorus content of the tissue. Addition of 20 kg/ha phosphorus did not increase the tissue phosphorus content, but addition of 50 kg/ha phosphorus led to an increase in percent phosphorus in the tissue.

Addition of 60 kg/ha nitrogen fertilizer led to an increase in the percent potassium in the plant tissue. Increasing the nitrogen rate to 120 kg/ha led to no further increase in percent potassium. Addition of phosphorus fertilizer had no influence on potassium content of the tissue.

Lethal Temperature Effects (LT_{50})

Differences in LT_{50} observed in the fall were not considered significant (Table 9). However, there was a tendency for LT_{50} to become more negative as the rate of phosphorus fertilizer was increased. Where no phosphorus was added, the high rate of nitrogen fertilizer tended to have a lower negative LT_{50}, while increasing the phosphorus fertilizer rate at the high rate of nitrogen tended to lower the LT_{50} value. Results of the LT_{50} trial were not definitive.

Winter Survival

When phosphorus treatments were grouped, addition of 60 kg/ha nitrogen had no affect on winter survival of winter wheat (Table 10). When 120 kg/ha nitrogen was applied, winter survival decreased.

TABLE 9. Fall tissue content of nitrogen, phosphorus and potassium and LT_{50} at various rates of fall applied nitrogen and phosphorus in zero tilled Norstar winter wheat, 1980-81

Treatment (kg/ha) Phosphorus x nitrogen		Nitrogen %	Phosphorus %	Potassium %	LT_{50} °C
0	0	3.140	0.39	1.38	-18
	60	3.372	0.40	1.52	-20
	120	3.801	0.48	1.54	-18
20	0	3.406	0.43	1.41	--
	60	3.723	0.47	1.63	-20
	120	4.013	0.45	1.63	-20
50	0	3.573	0.48	1.49	-20
	60	3.913	0.51	1.62	-20
	120	4.256	0.46	1.54	--
LSD (0.05)[1]		0.417	n/s	0.20	ns
LSD (0.05)[2]		0.524	0.075	0.234	ns
Nitrogen (kg/ha)					
	0	3.373	0.43	1.42	-20
	60	3.669	0.46	1.59	-20
	120	4.023	0.46	1.57	-20
LSD (0.05)		0.241	n/s	0.12	n/s
Phosphorus (kg/ha)					
0		3.438	0.42	1.48	-18.7
20		3.714	0.45	1.56	-20.7
50		3.689	0.48	1.53	-20.7
LSD (0.05)		n/s	0.05	n/s	n/s

[1] Comparisons made within phosphorus treatments.
[2] Comparison made among differing phosphorus treatments.

When nitrogen treatments were grouped, application of 20 kg/ha phosphorus resulted in increased winter survival. Increasing the application rate to 50 kg/ha resulted in no further increase in survival.

An interaction existed between nitrogen and phosphorus fertilization. When no phosphorus was applied, application of nitrogen at the 120 kg/ha rate led to a decrease in winter survival. However, if 20 kg/ha or 50 kg/ha phosphorus was applied as well, nitrogen fertilization did not produce a significant decrease in winter survival.

Seedling Dry Matter Production

When phosphorus treatments were grouped, addition of nitrogen fertilizer had no overall effect on seedling dry matter production (Table 10). When nitrogen treatments were grouped, addition of 50 kg/ha phosphorus led to an increase in dry matter production.

TABLE 10. Percent winter survival, seedling dry matter production, grain yield, percent grain protein, percent nitrogen recovery in the grain, and total percent nitrogen recovery at various rates of fall applied nitrogen and phosphorus fertilization in zero tilled Norstar winter wheat, 1980-81

Treatment (kg/ha) Phosphorus x Nitrogen		Winter Survival %	Seedling Dry Matter T/ha	Grain Yield T/ha	Grain Protein %	N recovery in grain %	Total N recovery %
0	0	74.48	0.075	0.971	8.93	--	--
	60	69.91	0.126	2.755	8.05	39.49	51.47
	120	59.71	0.095	3.185	9.60	32.03	45.28
20	0	75.04	0.105	1.131	8.75	--	--
	60	76.64	0.096	2.816	8.03	37.88	53.32
	120	69.53	0.127	3.653	9.60	37.18	50.56
50	0	70.83	0.121	1.356	8.43	--	--
	60	78.58	0.172	3.114	8.65	44.85	55.51
	120	74.09	0.186	4.321	9.53	43.39	58.05
	LSD (0.05)[1]	9.3239	0.053	0.612	0.5750	ns	ns
	LSD (0.05)[2]	8.90	0.064	0.552	0.62	ns	ns
Nitrogen (kg/ha)							
	0	73.45	0.100	1.153	8.70	--	--
	60	73.35	0.132	2.899	8.24	40.74	53.43
	120	67.36	0.136	3.719	9.58	37.53	51.30
	LSD (0.05)	5.3832	ns	0.353	0.3223	ns	ns
Phosphorus (kg/ha)							
0		68.34	0.099	2.303	8.86	35.76	48.38
20		73.74	0.109	2.533	8.79	37.53	51.94
50		74.09	0.159	2.930	8.87	44.12	56.78
	LSD (0.05)	3.8059	0.047	0.238	ns	ns	ns

1 Comparisons made within phosphorus treatments.
2 Comparison made among differing phosphorus treatments.

An interaction existed between nitrogen and phosphorus. At low levels of phosphorus fertilization, additions of nitrogen fertilizer did not affect seedling dry matter production. However, at 50 kg/ha added phosphorus, additions of nitrogen fertilizer produced an increase in seedling dry matter.

Grain Yield

When phosphorus treatments were grouped, a yield response occurred when 60 kg/ha nitrogen was applied and again when the rate was increased to 120 kg/ha nitrogen (Table 10). When nitrogen treatments were grouped, no response in yield occurred when 20 kg/ha phosphorus was added, but applications of 50 kg/ha phosphorus produced an increase in yield.

The greatest influence of the phosphorus applications occurred at high rates of applied nitrogen. Addition of phosphorus with the nitrogen allowed the stand to produce higher yields in response to the added nitrogen than were produced when phosphorus was in short supply.

Percent Grain Protein

When phosphorus treatments were grouped, percentage grain protein was decreased by the addition of 60 kg/ha nitrogen and increased by the addition of 120 kg/ha nitrogen fertilizer (Table 10). The first increment of nitrogen produced a large increase in yield, which led to the dilution of the protein produced by the plant. This dilution effect resulted in a net decrease in percent protein. Addition of 120 kg/ha nitrogen presented the stand with sufficient nitrogen to produce both an increase in yield and an increase in percentage grain protein, since it surpassed the level of nitrogen fertilizer where yield response was high. As yield response lessened, superfluous nitrogen was directed towards an increase in percentage grain protein.

Phosphorus fertilization had no overall affect on percentage grain protein. However, at 50 kg/ha added phosphorus, no reduction in percent protein was observed when 60 kg/ha nitrogen fertilizer was added. This could be due to the effect of the 11 kg/ha nitrogen applied as part of the 11-48-0. Alternately, the addition of the phosphorus fertilizer could have led to more efficient utilization of the nitrogen applied to the stand. This increase in efficiency could have translated into the maintenance of percentage protein levels, even as the yield increased in response to the added nitrogen fertilizer.

Nitrogen Recovery in the Grain

No significant differences existed in nitrogen recovery in the grain in response to nitrogen or phosphorus fertilization (Table 10). There was a tendency, however, for nitrogen recovery in the grain to decrease with high levels of nitrogen fertilizer when no phosphorus was applied. If phosphorus was added, nitrogen recovery in the grain was essentially identical at 60 kg/ha and 120 kg/ha added nitrogen. There was a tendency for nitrogen recovery in the grain to increase with added phosphorus fertilizer, when 120 kg/ha nitrogen was applied.

Total Nitrogen Recovery

No significant differences existed in total nitrogen recovery in response to nitrogen or phosphorus fertilization (Table 10). There was a tendency for nitrogen recovery to decrease with high levels of nitrogen fertilizer when no phosphorus was added. If phosphorus was applied, nitrogen recovery was very similar at 60 kg/ha and 120 kg/ha added nitrogen.

There was a tendency for percentage nitrogen recovery to increase with added phosphorus fertilizer. This tendency occurred both at the 60 kg/ha and the 120 kg/ha rate of nitrogen fertilization, although it was stronger at the high nitrogen rate. Balanced nitrogen and phosphorus fertilization may tend to facilitate the uptake and incorporation of nitrogen by the plant.

Experiment 5: The effects of fall applied nitrogen and phosphorus fertilizer on winter survival and growth of zero tilled Winalta winter wheat.

Spring Stand Density

Spring stand density showed a decrease in response to added nitrogen fertilizer when a rate of 120 kg/ha was applied (Table 11). No decrease in stand was observed in response to 60 kg/ha added nitrogen. Phosphorus fertilizer had no effect on stand density. Presumably, differences in spring stand density were due to differential winter kill.

Seedling Dry Matter

No significant differences in seedling dry matter production were observed due to fertilization treatments (Table 11). However, there was a tendency for dry matter to increase when phosphorus fertilizer was applied at a rate of 50 kg/ha.

Grain Yield

When phosphorus treatments were grouped, grain yield was increased by the addition of 60 kg/ha nitrogen and again by the addition of 120 kg/ha nitrogen (Table 11). When nitrogen treatments were grouped, grain yield was not increased by the addition of 20 kg/ha phosphorus, but was increased when the rate of phosphorus fertilization was increased to 50 kg/ha.

Phosphorus fertilization produced the largest yield response when applied with nitrogen fertilizer, particularly at the 120 kg/ha nitrogen rate. Balanced nitrogen phosphorus fertilization tends to produce the most efficient yield production in response to both fertilizer inputs.

TABLE 11. Spring stand, dry matter production, grain yield, percent grain protein, percent nitrogen recovery in the grain and total percent nitrogen recovery at various rates of fall applied nitrogen and phosphorus fertilization in zero tilled Winalta winter wheat, 1980-81

Treatment (kg/ha) Phosphorus	Nitrogen	Spring Stand Plants/M	Seedling Dry Matter T/ha	Grain Yield T/ha	Grain Protein %	N recovery in grain %	Total N recovery %
0	0	13.17	0.150	1.188	9.53	--	--
	60	14.17	0.170	2.643	8.65	33.74	49.65
	120	11.37	0.180	3.046	10.73	31.23	43.80
20	0	15.52	0.193	1.035	9.25	--	--
	60	12.27	0.169	2.686	8.50	31.26	49.47
	120	10.00	0.118	3.217	10.33	30.85	48.60
50	0	14.40	0.252	1.387	8.95	--	--
	60	11.69	0.201	3.276	8.45	40.17	55.91
	120	11.04	0.233	3.856	10.50	38.92	55.53
LSD (0.05)[1]		4.17	ns	0.646	0.71	ns	ns
LSD (0.05)[2]		4.20	ns	0.601	0.73	ns	ns
Nitrogen (kg/ha)							
	0	14.36	0.198	1.203	9.24	--	--
	60	12.71	0.180	2.868	8.53	35.06	51.67
	120	10.80	0.177	3.373	10.52	33.67	49.31
LSD (0.05)		2.40	ns	0.373	0.41	ns	ns
Phosphorus (kg/ha)							
0		12.90	0.167	2.292	9.63	32.49	46.73
20		12.60	0.160	2.312	9.36	31.06	49.04
50		12.38	0.228	2.839	9.30	39.55	55.72
LSD (0.05)		2.48	ns	0.292	ns	ns	ns

[1] Comparisons made within phosphorus treatments.
[2] Comparisons made among differing phosphorus treatments.

Percent Grain Protein

When phosphorus treatments were grouped, percentage grain protein decreased with the addition of 60 kg/ha actual nitrogen and increased when the rate of nitrogen fertilization was increased to 120 kg/ha. Low application rates of nitrogen led to a "dilution effect" where protein production could not be maintained at a high enough level to produce percentage protein comparable to that of the check as yield increased in response to the nitrogen application.

Phosphorus fertilization had no significant effect on percentage grain protein, although there was a tendency for percentage grain protein to decrease as phosphorus fertilization increased. This decrease in percent protein could be due to the production of higher yields in response to phosphorus fertilizer, which would increase the dilution of the produced protein.

Nitrogen Recovery in the Grain

Neither phosphorus nor nitrogen fertilization had any significant effect on nitrogen recovery in the grain (Table 11). However, there was a tendency for nitrogen recovery in the grain to decrease slightly at higher rates of nitrogen fertilizer. Also, nitrogen recovery in the grain showed a tendency to increase with the addition of 50 kg/ha phosphorus fertilizer. Phosphorus fertilization could have allowed the plant to absorb and incorporate the nitrogen fertilizer more efficiently than if phosphorus was deficient.

Total Nitrogen Recovery

Total nitrogen recovery was not significantly affected by phosphorus or nitrogen fertilization (Table 11). However, total nitrogen recovery tended to be slightly lower at the 120 kg/ha nitrogen rate than at the 60 kg/ha nitrogen rate. Also, nitrogen recovery tended to increase with increasing levels of phosphorus fertilizer, particularly at the higher nitrogen rate. Phosphorus fertilization appears to encourage more efficient utilization of applied nitrogen, especially at high nitrogen rates.

<u>Experiment 6</u>: The effects of fall applied nitrogen and phosphorus fertilizer on winter survival and growth of conventionally tilled Norstar winter wheat.

<u>Winter Survival</u>

Percentage winter survival was not affected by the addition of 60 kg/ha nitrogen when phosphorus treatments were grouped, but when the rate of nitrogen fertilization was increased to 120 kg/ha, percentage survival decreased (Table 12).

Grouping nitrogen treatments, percent winter survival was increased by the addition of 20 kg/ha phosphorus and further by the addition of 50 kg/ha phosphorus.

An interaction existed between nitrogen and phosphorus fertilization. Where no phosphorus was added, nitrogen fertilization led to a dramatic decrease in percentage survival. Addition of 20 kg/ha counteracted the effect of the added nitrogen. At 20 kg/ha, addition of up to 120 kg/ha had no effect on winter survival. When the rate of phosphorus fertilizer was increased to 50 kg/ha, at 0 kg/ha added nitrogen an actual increase in percentage winter survival over that of the check occurred. No change in winter survival as compared to the 0 kg nitrogen - 50 kg/ha phosphorus treatment occurred when 60 kg/ha nitrogen was added, but survival decreased when the nitrogen rate was increased to 120 kg/ha. However, the 120 kg/ha nitrogen plus 50 kg/ha phosphorus treatment produced survival comparable to that attained in the check.

TABLE 12. Percent winter survival, seedling dry matter production, grain yield, percent grain protein, percent nitrogen recovery in the grain and total percent nitrogen recovery at various rates of fall applied nitrogen and phosphorus fertilization in conventionally tilled Norstar winter wheat, 1980-81

Treatment (kg/ha) Phosphorus	Nitrogen	Winter Survival %	Seedling Dry Matter T/ha	Grain Yield T/ha	Grain Protein %	N recovery in grain %	Total N recovery %
0	0	35.42	0.087	1.394	8.15	--	--
	60	25.69	0.084	2.446	8.30	26.14	42.40
	120	25.99	0.043	2.836	9.83	24.15	34.57
20	0	42.72	0.072	1.355	7.93	--	--
	60	43.98	0.087	2.541	8.48	27.67	37.71
	120	40.01	0.100	3.430	9.88	31.72	46.75
50	0	51.20	0.094	1.876	7.93	--	--
	60	49.28	0.167	2.813	8.80	32.88	45.72
	120	39.03	0.185	3.652	9.68	32.02	46.23
	LSD (0.05)[1]	10.57	ns	0.557	0.81	ns	ns
	LSD (0.05)[2]	10.49	ns	0.519	0.79	ns	ns
Nitrogen (kg/ha)							
	0	43.11	0.084	1.541	8.00	--	--
	60	39.65	0.113	2.600	8.53	28.90	41.94
	120	34.95	0.110	3.308	9.79	29.30	42.52
	LSD (0.05)	6.10	ns	0.321	0.45	ns	ns
Phosphorus (kg/ha)							
0		29.03	0.070	2.225	8.76	25.15	38.49
20		42.24	0.086	2.442	8.76	29.70	42.23
50		46.50	0.149	2.780	8.77	32.45	45.97
	LSD (0.05)	4.26	ns	0.253	ns	ns	ns

[1] Comparisons made within phosphorus treatments.
[2] Comparisons made among differing phosphorus treatments.

Seedling Dry Matter Production

Seedling dry matter production was not significantly affected by nitrogen or phosphorus fertilization (Table 12). However, there was a tendency for seedling dry matter to increase as phosphorus fertilization increased. This tendency was strongest when phosphorus was applied with nitrogen fertilization. The balanced fertilization allowed for production of the highest dry matter levels.

Grain Yield

Grain yield was increased by the addition of 60 kg/ha nitrogen and again by the addition of 120 kg/ha nitrogen, when phosphorus treatments were grouped (Table 12). Grouping nitrogen treatments, no yield response occurred when 20 kg/ha phosphorus was applied but addition of 50 kg/ha phosphorus led to an increase in yield.

Highest yields were obtained when the applied nitrogen was balanced with phosphorus fertilization. Application of balanced levels of nitrogen and phosphorus fertilizers allowed for the most efficient use of both nutrients in yield promotion.

Percent Grain Protein

Averaging phosphorus treatments, percentage grain protein was increased by the addition of 60 kg/ha nitrogen and again by the addition of 120 kg/ha nitrogen (Table 12). Phosphorus had no overall effect on percentage grain protein.

Where no phosphorus was added, 60 kg/ha nitrogen produced no increase in grain protein. At 20 kg/ha added phosphorus, 60 kg/ha nitrogen still produced no increase in grain protein, but the difference between the 0 kg/ha and 60 kg/ha nitrogen treatments were greater. At 50 kg/ha added phosphorus, application of 60 kg/ha nitrogen produced an increase in percentage grain protein. Perhaps phosphorus allowed for increased efficiency in uptake or utilization of the applied nitrogen fertilizer, which resulted in increased percent grain protein at the 60 kg/ha fertilizer nitrogen rate.

Nitrogen Recovery in the Grain

No significant differences in percent nitrogen recovery in the grain occurred in response to nitrogen or phosphorus fertilization (Table 12). However, there was a tendency for nitrogen recovery in the grain to increase as phosphorus fertilization increased. Possibly phosphorus fertilization encourages more efficient utilization of applied nitrogen.

Total Nitrogen Recovery

No significant differences in percent nitrogen recovery occurred in response to nitrogen or phosphorus fertilization (Table 12). There was a tendency for nitrogen recovery to increase with phosphorus fertilization. Phosphorus may aid in the uptake and utilization of applied nitrogen.

Experiment 7: The effects of fall applied nitrogen and phosphorus fertilizer on winter survival and growth of conventionally tilled Winalta winter wheat.

Spring Stand Density

Spring stand density showed no response to nitrogen fertilization or to phosphorus fertilization (Table 13). Spring stand densities were extremely low and winterkill was apparent throughout this experiment. Winterkill appeared to be influenced to a great extent by the pattern of distribution of the snow.

Seedling Dry Matter

No differences in dry matter production occurred due to fertilization treatments (Table 13).

TABLE 13. Spring stand, seedling dry matter production, grain yield, percent grain protein, percent nitrogen recovery in the grain and total percent nitrogen recovery at various rates of fall applied nitrogen and phosphorus fertilization in conventionally tilled Winalta winter wheat, 1980-81

Treatment (kg/ha) Phosphorus	Nitrogen	Spring Stand Plants/M	Seedling Dry Matter T/ha	Grain Yield T/ha	Grain Protein %	N recovery in grain %	Total N recovery %
0	0	4.08	0.188	1.083	9.68	--	--
	60	4.71	0.192	1.374	9.70	8.32	10.68
	120	4.73	0.215	1.663	11.13	11.73	18.09
20	0	4.21	0.200	0.916	9.68	--	--
	60	5.04	0.198	0.9	10.23	-0.8	-0.50
	120	1.44	0.178	0.556	11.43	-5.8	-3.26
50	0	3.48	0.214	0.996	9.60	--	--
	60	4.44	0.039	1.575	10.13	13.43	29.15
	120	3.00	0.211	1.317	11.08	5.48	12.25
	LSD (0.05)[1]	ns	ns	ns	0.71	ns	ns
	LSD (0.05)[2]	ns	ns	ns	0.76	ns	ns
Nitrogen (kg/ha)							
	0	3.92	0.201	0.999	9.65	--	--
	60	4.73	0.233	1.315	10.02	6.98	13.11
	120	3.06	0.201	1.178	11.21	3.80	9.03
	LSD (0.05)	ns	ns	ns	0.41	ns	ns
Phosphorus (kg/ha)							
0		4.51	0.198	1.373	10.17	10.03	14.38
20		3.56	0.192	0.823	10.44	-3.30	-1.88
50		3.64	0.245	1.296	10.27	9.46	20.70
LSD (0.05)		ns	ns	ns	ns	ns	ns

1 Comparisons made within phosphorus treatments.
2 Comparisons made among differing phosphorus treatments.

Grain Yield

No differences in yield occurred in response to fertilization treatments (Table 13). Yield was primarily affected by the number of plants remaining in the plot area. The plant density was apparently determined largely by the winterkill, which was apparently determined by snow distribution rather than fertilization treatment. Yield, therefore, varied dramatically from plot to plot, but differences between averages of fertilization treatments were negligible.

Percentage Grain Protein

Percentage grain protein was not increased by the addition of 60 kg/ha nitrogen fertilizer, but the addition of 120 kg/ha nitrogen led to the production of higher percentage protein levels than occurred with 60 kg/ha added nitrogen or in the check (Table 13). Lower nitrogen additions apparently were utilized by the plant to produce yield, while higher levels of nitrogen fertilizer provided sufficient nitrogen for an increase in percentage protein.

Phosphorus fertilization had no effect on percentage grain protein.

Nitrogen Recovery in the Grain

Nitrogen recovery in the grain was not affected by the rate of nitrogen fertilization in this experiment, although at the 120 kg/ha rate, nitrogen recovery in the grain was 45% lower than at the 60 kg/ha rate (Table 13). Phosphorus fertilization did not affect the efficiency of nitrogen recovery in the grain. Presumably, nitrogen recovery in the grain was affected to a greater extent by stand density than by the fertilization management.

Total Nitrogen Recovery

Total nitrogen recovery was not affected by nitrogen or phosphorus fertilization (Table 13). Again, it is likely that the factor having the most effect on nitrogen recovery was stand density rather than fertilization treatment.

Experiment 8: The effect of fall, spring and split applications of broadcast nitrogen on growth parameters of zero tilled Norstar winter wheat.

Spring Stand Density

High rates of nitrogen applied in the fall tended to produce higher spring stand densities than occurred in treatments not receiving fertilizer in the fall (Table 14). As this experiment received an overall treatment of 40 kg P_2O_5/ha with the seed, it appears that the additional fertilizer nitrogen applied in the fall, when balanced adequately with phosphorus, produced a healthier stand, more capable of overwintering and spring recovery.

Seedling Dry Matter

Additions of fertilizer nitrogen led to the production of higher levels of dry matter than was produced with no addition of nitrogen (Table 14). However, no differences were observed between the 45 kg/ha and the 90 kg/ha rate, or between the different times of application of nitrogen. Apparently, nitrogen reserves were not as yet depleted in any treatment at the time of seedling dry matter sampling, so differences in growth response due to nitrogen rate or timing were not yet apparent.

Grain Yield

Grain yield was increased by the addition of 45 kg/ha nitrogen and further by the addition of 90 kg/ha nitrogen (Table 14). Spring application of nitrogen at the 45 kg/ha rate showed a significantly higher yield increase than did fall application of 45 kg/ha nitrogen. At the

TABLE 14. Spring stand density, dry matter production, grain yield, grain percent protein, grain percent nitrogen recovery and percent total nitrogen recovery at various rates and timings of broadcast nitrogen

Treatment Rate in kg/ha	Time of Application	Spring Stand Plant/M	Dry Matter[1] T/ha	Grain Yield T/ha	Grain Protein %	Grain Nitrogen Recovery %	Nitrogen Recovery %
check		12.74a[2]	0.904a	1.109a	8.90 c	--	--
45	Fall	13.69ab	2.218 b	2.419 b	7.67a	36.58a	46.88a
45	Spring	12.49a	2.606 b	2.803 c	7.40a	43.67 b	59.73 b
90	Fall	14.71 b	2.318 b	3.850 d	8.57 bc	45.53 b	56.60 b
90	Split	14.57 b	2.608 b	3.637 d	8.35 b	40.88ab	54.19ab
90	Spring	13.87ab	2.462 b	3.905 d	8.60 bc	46.57 b	61.70 b

1 Samples taken on July 3, 1982.
2 Numerals followed by the same letter do not differ at the 5% level.

90 kg/ha rate there was no significant difference in yield between treatments applied in the fall, in the spring or as a split application. At the 90 kg/ha rate, yield response to added nitrogen was beginning to decline, since the yield capacity of the plant under the growing conditions of that season was nearly satisfied. The increased level of nitrogen available to the plant due to application in the spring was not sufficient to produce a significant yield response at these high rates of application. At the 45 kg/ha nitrogen rate, crop response to nitrogen was still high. The increased level of nitrogen available to the plant due to application in the spring was sufficient to produce a significant yield response.

Percent Protein

Addition of 45 kg/ha nitrogen produced decreases in percent grain protein when applied either in the spring or in the fall (Table 14). No difference existed due to the timing of nitrogen application. Applications of 90 kg/ha nitrogen produced no alteration in percent grain protein from the check. Percent protein levels at 90 kg/ha nitrogen were higher than those produced by additions of 45 kg/ha added nitrogen. At 90 kg/ha added nitrogen, no difference in grain protein percent was observed due to timing of nitrogen application.

Total Nitrogen Recovery

Fall application of 45 kg/ha nitrogen was less efficient in utilization of added nitrogen than was spring application of 45 kg/ha nitrogen (Table 14). There was no difference in efficiency of utilization of the 90 kg/ha rate due to timing of application. Utilization of the 45 kg/ha rate applied in the fall was less efficient than utilization of the 90 kg/ha rate applied at any time.

Losses of fertilizer nitrogen due to denitrification, mineralization, and volatalization may have decreased the amount of nitrogen from fall application available to the plant in the spring. Decreased nitrogen availability could have reduced the percentage utilization of applied nitrogen.

At the 45 kg/ha rate, the reduction in utilization was significant since the application rate was low. The proportionate loss was higher at low rates of application than at higher rates. At low levels of application, total nitrogen available to the plant was lower so losses due to fall application were more important.

Although the nitrogen applied in the spring was available in greater amounts than that applied in the fall, at 90 kg/ha added nitrogen differences in efficiency of utilization were not significant.

<u>Nitrogen Recovery in the Grain</u>

The percent nitrogen recovery in the grain was lower for 45 kg/ha nitrogen applied in the fall than for any other treatment. No differences existed between the other treatments (Table 14).

Differences between percent recovery in the grain and total percent recovery were highest when nitrogen was applied in the spring. With spring applications, nitrogen accumulated in the plant more quickly than it could be incorporated into the grain.

<u>Percent Protein in Relation to Yield</u>

A graph of percentage grain protein as a function of yield is presented in Figure 4.

Initial additions of 45 kg/ha nitrogen produced large increases in yield, resulting in the distribution of protein produced in response to the added nitrogen throughout a large amount of dry matter. The dilution of a limited amount of protein by a large amount of dry matter led

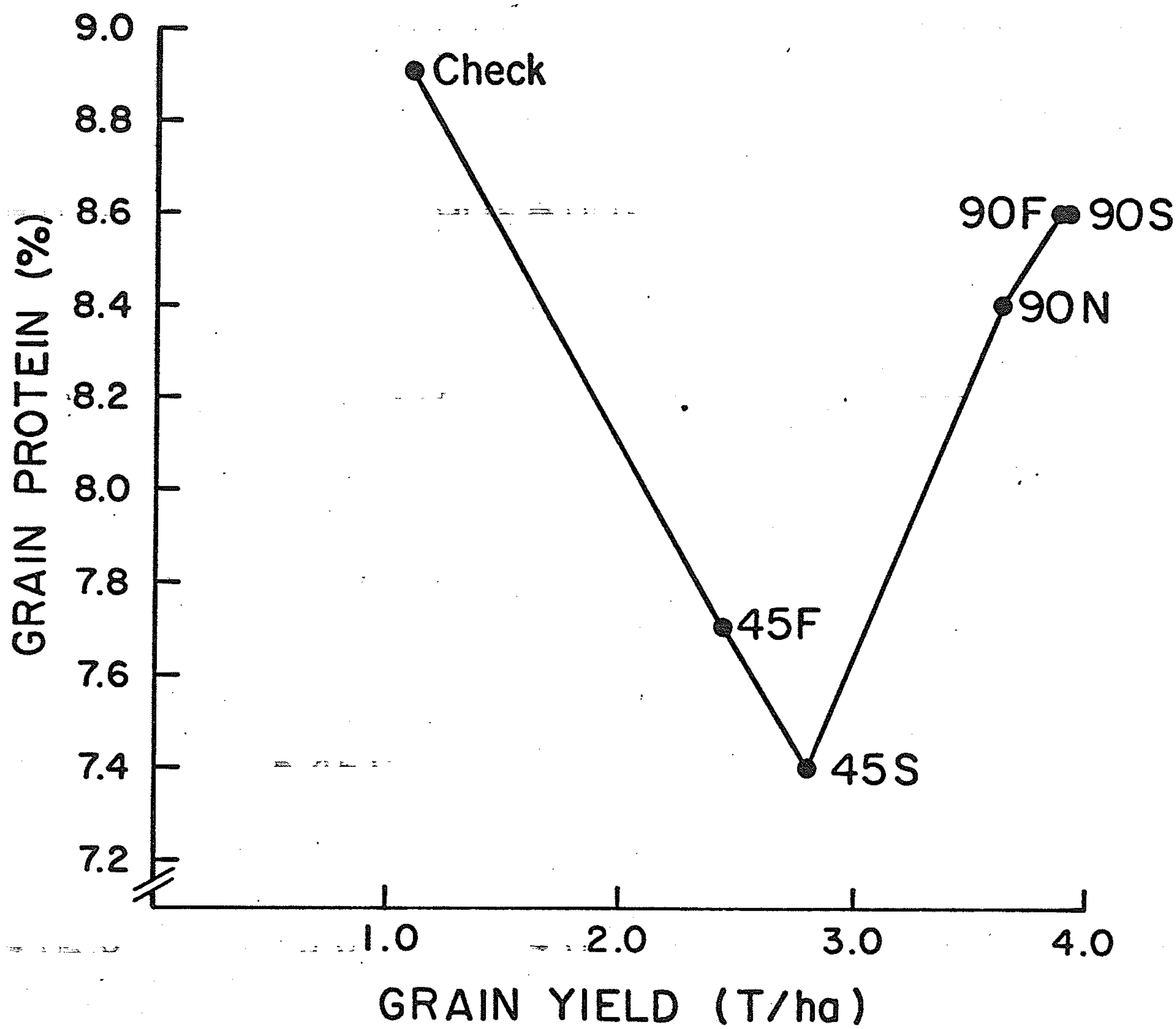


FIG. 4. Percent grain protein as a function of grain yield at 0, 45 and 90 Kg N/ha applied in fall (F), spring (S) and split (N) applications.

to a decrease in percent grain protein. Largest decreases in percent protein at 45 kg/ha occurred in the treatment producing the largest increase in yield which was the spring timing treatment.

When rate of application was increased to 90 kg/ha, the decrease in percentage grain protein was no longer significant. As with the 45 kg/ha rates, yield did increase in response to addition of nitrogen, but the high rate of nitrogen application was sufficient to essentially satisfy the yield potential of the plant. At 90 kg/ha added nitrogen, protein produced in response to added nitrogen was sufficient to distribute among the dry matter production in adequate quantities to maintain percent protein at levels comparable to those in the check. In this situation, timing of application which increased yield also tended to increase protein percent, although neither was increased significantly. When total protein production increased at this rate of nitrogen application, yield and percent protein increased simultaneously.

Experiments 9 and 10: The effect of the timing of nitrogen application on growth parameters of zero tilled Norstar winter wheat.

Spring Stand Density

Timing of nitrogen application had no significant effect on spring stand density, either at the 30 kg/ha nitrogen rate or the 60 kg/ha rate (Table 15 and 16). The lack of significant differences indicates that applied nitrogen at rates up to 60 kg/ha does not influence overwintering of the winter wheat stand when applied with 40 kg P_2O_5/ha.

TABLE 15. Spring stand density, seedling dry matter production, grain yield, grain percent protein, grain percent nitrogen recovery and total percent nitrogen recovery at various times of application of broadcast nitrogen at a rate of 30 kg/ha

Treatment (Time of Application)	Spring Stand Plants/M	Dry Matter[1] T/ha	Grain Yield T/ha	Grain Protein %	Total Nitrogen Recovery %	Grain Nitrogen Recovery %
Check	13.63a[2]	0.994a	1.082a	8.83a	--	--
Seeding	14.60a	1.401 bc	1.951 c	8.08 bc	48.81 b	39.49 b
Freezeup	15.07a	1.475 bc	2.137 cd	7.45 d	45.32 b	40.20 b
on snow	13.89a	1.178ab	1.557 b	8.15 b	28.50a	25.73a
spring	14.67a	1.696 c	2.270 d	7.68 cd	63.64 c	46.98 b

[1] Samples taken on June 29, 1982.
[2] Numerals followed by the same letter do not differ at the 5% level.

TABLE 16. Spring stand density, seedling dry matter production, grain yield, grain percent protein, grain percent nitrogen recovery and total percent nitrogen recovery at various times of application of broadcast nitrogen at a rate of 60 kg/ha

Treatment (Time of Application)	Spring Stand Plants/M	Dry Matter[1] T/ha	Grain Yield T/ha	Grain Protein %	Grain Nitrogen Recovery %	Total Nitrogen Recovery %
Check	13.58a[1]	1.116a	1.293a	9.17a	--	--
Seeding	13.51a	2.517 c	2.517 b	8.02 b	27.76 b	42.14 b
Freezeup	13.90a	2.449 c	2.576 b	7.93 b	28.36 b	40.92ab
on snow	13.04a	2.005 b	2.115 b	7.88 b	18.82a	26.67a
spring	13.82a	2.773 c	3.173 c	7.97 b	40.70 c	57.14 c

[1] Samples taken on June 30, 1982.

Seedling Dry Matter Production

Nitrogen Applied at 30 kg/ha

When 30 kg/ha nitrogen was applied in the spring, dry matter production was significantly higher than the check and than any other time of nitrogen application (Table 15). Seedling dry matter production was similar when nitrogen was applied on the snow, at seeding or at freezeup. Application at seeding and at freezeup were superior to the check in encouraging dry matter production. Application on the snow, produced dry matter levels similar to those produced by the check.

At the 30 kg/ha level of fertilization, sufficient nitrogen losses occurred from application at seeding or at freezeup to produce lower levels of dry matter than those produced by spring fertilizer applications, although an adequate amount of nitrogen remained to produce dry matter levels superior to those produced by the check. Application of nitrogen on the snow was subject to greater losses and so produced dry matter levels no higher than those produced by the check.

Nitrogen Applied at 60 kg/ha

At 60 kg/ha added nitrogen dry matter production did not differ if application occurred in the spring, at freezeup or at time of seeding (Table 16). Application of nitrogen on the snow was less efficient in promoting seedling dry matter production than applications of nitrogen at other times. All treatments produced dry matter levels higher than those of the check.

At 60 kg/ha applied nitrogen rate, sufficient losses occurred from application on the snow to produce lower dry matter production than produced by applications in the spring. Sufficient nitrogen remained, however, to produce a dry matter increase over the check. With application at the time of seeding or at freezeup, losses did occur, but there was sufficient nitrogen remaining to provide for dry matter production comparable to that produced by spring applied nitrogen. At the time of sampling, nitrogen stress had not become severe enough to provide a limit on plant growth.

Comparing results obtained in the 30 kg/ha and the 60 kg/ha trials, nitrogen stress becomes apparent earlier at the lower nitrogen rate. Addition of 60 kg/ha is sufficient to mask the differences in nitrogen availability between application at freezeup or at seeding and application in spring that become apparent at the low nitrogen rate. Addition of 60 kg/ha nitrogen is required before sufficient nitrogen is available to produce a dry matter increase when nitrogen is applied on the snow.

Grain Yield

Nitrogen Applied at 30 kg/ha

All timings of nitrogen application produced yield increases over the check (Table 15). Application on the snow produced a lower yield increase than application of nitrogen at any other time. There was no difference between yields if nitrogen was applied at time of seeding or at freezeup. Application of nitrogen in the spring produced a higher yield than did application at the time of seeding.

Nitrogen losses from fertilizer applied on the snow were apparently sufficient to produce a reduction in yield when compared to application at any other time, although yield was still increased above that of the check. From these data it appears as if losses from the applications at seeding and at freezeup would not differ, but that applications at seeding would have sufficient losses to produce a yield decrease compared to application in the spring.

Nitrogen Applied at 60 kg/ha

When rate of nitrogen application was increased to 60 kg/ha, all treatments again produced yields higher than the yield of the check (Table 16). At this rate, no difference in yield occurred between applications at time of seeding, at freezeup or on the snow. Application in the spring was more effective in increasing yield than was any other treatment.

At 60 kg/ha differences in losses of nitrogen between application on the snow, at time of seeding and at freezeup were not large enough to produce significant differences in yield. However, losses in all cases were great enough to produce lower yields than those attained with spring fertilizer applications.

Rankings in yield production for the different times of application were the same in both experiments. Differences only occurred in the classification of differences between treatments as being significant or insignificant.

Percent Grain Protein

Nitrogen Applied at 30 kg/ha

At 30 kg/ha, all timings of nitrogen application produced a percent protein depression from the check (Table 15). Application at time of seeding and on the snow did not differ from one another, but were higher in percent protein than the treatment of nitrogen applied at freezeup. Application at freezeup and in the spring produced similar percentage protein levels. There was a tendency for treatments that produced the highest yield to produce the lowest percent protein.

Nitrogen Applied at 60 kg/ha

At the 60 kg/ha rate, all treatments produced a significant decrease in percent grain protein from the check, but no difference existed between grain protein levels due to timing of application (Table 16).

At 30 kg/ha there was a greater proportionate yield response to the differences in nitrogen availability due to timing than at the 60 kg/ha rate. Therefore, dilution of the grain protein and differences in percent grain protein would be comparatively larger at the low rate than at the high rate of nitrogen application.

At the 30 kg/ha rate, the response curve percent protein to added nitrogen was on the downward swing in 1980-81. Increases in amount of nitrogen available led to decreases in percent grain protein. At 60 kg/ha, the response curve was beginning the upward swing. Percent protein was beginning to increase in response to higher levels of available nitrogen. But, differences were not as large as at the 30 kg/ha rate since added amounts of protein produced were adding to both yield and percent protein.

Total Nitrogen Recovery

Nitrogen Applied at 30 kg/ha

At 30 kg/ha, applications of nitrogen on the snow led to a lower efficiency of nitrogen recovery than applications at any other time (Table 15). Application at the time of seeding and at freezeup did not differ from one another, but were both less efficient than application in the spring.

Application on the snow was subject to losses via runoff with the snowmelt. Thawing of the snow would proceed prior to melting of the soil surface, so the fertilizer would wash away before it could penetrate the soil surface. Application at seeding would be subject to denitrification and leaching losses over the fall period, but this apparently was not adequate to produce differentials in efficiency between applications at time of seeding and at freezeup. Losses by denitrification, leaching, erosion and runoff between freezeup and time of spring application were apparently the most important losses.

Nitrogen Applied at 60 kg/ha

Application of nitrogen in the spring was more efficient in nitrogen utilization than application at any other time (Table 16). No difference existed between applications on the snow and at freezeup or between applications at freezeup and at time of seeding.

The form of losses from each time of application were presumably the same at the 60 kg/ha and the 30 kg/ha rate. Overall efficiency was higher at the 30 kg/ha rate but the difference was not great.

Nitrogen Recovery in the Grain

Nitrogen Applied at 30 kg/ha

With 30 kg/ha applied nitrogen, there was no difference in nitrogen recovery in the grain when nitrogen was applied at seeding, at freezeup or in the spring (Table 15). Nitrogen applied on the snow was recovered in the grain less efficiently than at any other time of application.

Nitrogen Applied at 60 kg/ha

With 60 kg/ha applied nitrogen, there was no difference in nitrogen recovery in the grain when nitrogen was applied at seeding or at freezeup (Table 16). Nitrogen applied on the snow was recovered by the grain less efficiently than nitrogen applied at any other time. Nitrogen applied in the spring was recovered by the grain more efficiently than nitrogen applied at any other time.

Nitrogen recovery in the grain was greater at the 30 kg/ha rate than at the 60 kg/ha rate. The difference between recovery of nitrogen at the 30 kg/ha rate and 60 kg/ha rate was higher when nitrogen recovery in the grain was considered than when total nitrogen recovery was observed.

Apparently, the ability of the plant to incorporate nitrogen into the grain was a greater limitation to protein production than the ability of the plant to absorb nitrogen from the soil. Where the amount of nitrogen available to the plant in the soil was low, differences between nitrogen recovered by the plant and nitrogen recovered in the grain were low. Increasing available nitrogen led to slight decreases in efficiency of nitrogen recovery by the total plant, but large decreases in efficiency of nitrogen recovery by the grain.

GENERAL DISCUSSION

Winter Hardiness

Data collected from the fall applied nitrogen and phosphorus trials in 1980-81 showed distinctly higher levels of winter survival under zero tillage conditions as opposed to the conventionally tilled treatments. The increase in survival could be attributed to higher soil temperatures at the 5 cm level under zero tillage conditions as noted by Gauer et al. (1980). The increased snow cover trapped by the standing stubble would have formed an insulating layer, moderating soil temperatures over the winter months, as stated by Aase and Siddoway (1980).

No correlation was observed between plant tissue nutrient content and winter hardiness. Nitrogen and phosphorus fertilization produced consistent and significant effects on winter survival in these studies in both 1979-80 and 1980-81 (Tables 4, 9, 10). Addition of high rates of nitrogen fertilizer in the fall resulted in a decrease in winter survival. A decrease in survival in response to added fall nitrogen fertilizer was also reported by Freyman and Kaldy (1979). Pyiklik (1963), as cited by Alden and Herman (1971) observed a decrease in winter survival in response to fall applied nitrogen, except in situations where the available nitrogen in the soil was at extremely low levels.

Fall phosphorus fertilization, even at low levels, resulted in a net increase in winter survival. Increasing survival in response to phosphorus fertilization was also reported in studies conducted by Freyman and Kaldy (1979) and Gusta and Fowler (1979).

The simple effects of phosphorus and nitrogen fertilization were compounded by a NxP interaction. When no phosphorus fertilizer was added, nitrogen fertilization led to an extreme decrease in winter survival. When phosphorus fertilizer was applied, additions of nitrogen had little effect on survival. Additions of phosphorus in the absence of applied nitrogen had very little effect on winter survival, but when applied with high levels of nitrogen, the phosphorus reversed the deleterious effect of the nitrogen and maintained survival at levels comparable to that of the check. The interaction of nitrogen and phosphorus fertilization on winter survival was also observed by Freyman and Kaldy (1979) in growth chamber studies. The interaction of phosphorus and nitrogen fertilization on winter survival may indicate the importance of dry matter and carbohydrate accumulation in winter hardiness as noted by Gusta and Fowler (1979), Freyman (1978), Fowler and Carles (1979), Paulsen (1968), Green and Ratzlaff (1975), Newton and Anderson (1932), and Steponkus (1979).

Timing of nitrogen fertilization had no influence on the spring stand density, when applied with a fall phosphorus treatment of 40 kg/ha (Tables 14, 15, 16) indicating that 40 kg/ha phosphorus was sufficient to counteract the effects on winter survival of additions of fall nitrogen fertilizer at rates of up to 90 kg/ha. Since no fall stand counts were made it was assumed that differences in the spring stand density resulted from winter kill.

Seedling Dry Matter Production

In the trials assessing the influence of fall applied nitrogen and phosphorus fertilizer, additions of phosphorus fertilizer tended to increase seedling dry matter production (Tables 4, 10, 11, 12, 13). This increase in dry matter production with additions of phosphorus is consistent with results obtained by Freyman and Kaldy (1979) and Gusta and Fowler (1979). In the fall nitrogen and phosphorus trials, nitrogen fertilization did not produce a consistent increase in seedling dry matter. In experiments examining the effect of timing of nitrogen application (Tables 14, 15, 16), seedling dry matter was increased by nitrogen fertilization. The variation in results may be due to the fact that samples for seedling dry matter evaluation were collected earlier from the nitrogen-phosphorus trials than from the timing of nitrogen fertilization trials. At the earlier sampling date, nitrogen utilization by the stand may not have been great enough to produce a response in seedling dry matter due to a nitrogen restriction. Timing of nitrogen did effect seedling dry matter production to a limited extent. Application of low rates of nitrogen on the snow produced no increase in seedling dry matter above that of the check, while applying the same rates at any other time did increase seedling dry matter. The differential illustrates that application of nitrogen fertilizer as ammonium nitrate (34-0-0) on the snow provides less available nitrogen to the stand for crop growth than application at seeding, at freezeup or in the spring.

Grain Yield

Fall applications of nitrogen and phosphorus led to increases in grain yield in 1979-80 and 1980-81 (Tables 4, 10, 11, 12, 13). With nitrogen fertilization, addition of 60 kg/ha increased yield above that of the check and addition of 120 kg/ha increased yield above that of the 60 kg/ha treatment. Increases in grain yield in response to added nitrogen fertilizer have been noted by numerous researchers, including Boswell et al. (1976), Cochran et al. (1978), Finney et al. (1957) and Johnson et al. (1973).

In 1979-80, the addition of 25 kg/ha phosphorus produced an increase in yield. No further increase was noted when phosphorus was increased to 50 kg/ha. In 1980-81, under the zero till conditions and with conventionally tilled Norstar, yield was not increased by the addition of 20 kg/ha phosphorus, but increasing the phosphorus rate to 50 kg/ha produced a significant yield increase. Possibly the higher yields obtained in 1980-81 due to the more favorable climatic conditions resulted in utilization of higher levels of phosphorus fertilizer than in 1979-80. Differences in available phosphorus in the soil may also have had an effect, but climatic factors were the more probable reason (Tables 1, 2 and 3).

Timing of nitrogen fertilization led to yield differentials at low nitrogen fertilizer rates (Tables 15 and 16). At both 30 kg/ha and 60 kg/ha added nitrogen, the ranking of yield obtained at various timings of application, from largest to smallest was: (1) Spring (2) Freezeup (3) At seeding (4) On snow. At 45 kg/ha, application in the spring was superior to application in the fall in promotion of yield increases (Table 14). This higher yield resulting from application of nitrogen in the spring rather than in the falls concurs with the results of Welch _et al_. (1966) and Boswell _et al_. (1976). When the rate of nitrogen fertilization was increased to 90 kg/ha, no difference existed between yields obtained when nitrogen was applied in the fall, in the spring or in a split application of 45 kg/ha in the fall and 45 kg/ha in the spring. The lack of differentials is contrary to results obtained by Welch et al. (1966), Boswell et al. (1976) and Ellen and Spiertz (1980). However, these researchers were utilizing rates of nitrogen fertilizer much lower than 90 kg/ha. As the rate of nitrogen fertilizer was increased, in the studies at Minnedosa, to levels where the yield response of winter wheat to added nitrogen was beginning to level off, differentials in yield due to timing of applied nitrogen declined to a point where they were not significant.

In 1979-80, grain yield was increased by levels of nitrogen fertilizer up to 60 kg/ha (Table 7) while in 1980-81, yield was increased by levels of nitrogen up to 90 kg/ha (Table 8). Grain yield in 1980-81 was higher than in 1979-80. Low precipitation levels during the early portion of 1980, (see Table 2) resulted in a decreased yield potential and decreased nitrogen utilization in the 1979-80 season. The higher levels of moisture available during the 1980-81 season allowed the stand to utilize higher levels of nitrogen fertilizer and produce higher yields than in 1979-80.

Percent Grain Protein

Percentage grain protein varied greatly between 1979-80 and 1980-81 (Table 7 and 8). In 1979-80, low available moisture during the early portion of the growing season resulted in a yield constraint, limiting the dry matter production of the stand (see Table 2). During filling, rainfall was ample, allowing the plants to take up soil nitrogen. These two conditions apparently combined to produce a situation where high levels of nitrogen taken up during the later portion of the growing season were distributed as protein throughout a limited amount of dry matter, resulting in high percentage protein production.

In 1980-81, moisture levels were adequate in the early portion of the growing season and high dry matter yields were produced. Lack of rainfall in July apparently led to a constraint on uptake of nitrogen from the soil. Protein available for translocation to the head during grain filling was limited presumably due to the climatically imposed nitrogen deficiency. Percent protein was decreased dramatically over that of the previous year due to the allocation of a limited protein production throughout a large mass of dry matter. Such an inverse relationship between yield and protein has also been noted in studies conducted by Terman et al. (1969), Hunter and Stanford (1973), Miezan et al. (1977), Pushman and Bingham (1976) and Johnson and Mattern (1979).

Percentage protein in Winalta winter wheat tended to be slightly higher than that of Norstar winter wheat (Tables 10, 11, 12, 13). The higher percent protein in Winalta could be linked to the slight lower yield demonstrated by the Winalta cultivar.

Fall applications of phosphorus had no influence on percentage grain protein. Fall applications of nitrogen did influence percent protein (Tables 4, 10, 11, 12, 13).

In 1979-80, addition of fall nitrogen led to an increase in percent protein both at the 60 kg/ha nitrogen rate and at the 120 kg/ha nitrogen rate (Table 4). In 1980-81, a percentage protein interaction existed between nitrogen fertilization and tillage method. Under zero tillage conditions, fall application of 60 kg/ha nitrogen produced a significant decrease in percentage protein below that of the check (Tables 10 and 12). Addition of 120 kg/ha elevated percentage protein above that of the check. This initial decrease in percent protein occurred in both Winalta and Norstar winter wheat. Under conventionally tilled conditions, no decrease in percentage protein was observed with the low application of nitrogen (Table 11 and 13). Percentage protein increased with the addition of 60 kg/ha and further with the addition of 120 kg/ha in both Winalta and Norstar, although with Winalta, the increase at 60 kg/ha just failed to reach significance. Levels of nitrogen in the soil under zero tillage are lower than under conventionally tilled soils due to immobilization of nitrogen in crop residue, and losses of nitrogen by leaching and denitrification have been reported to be greater (Baeumer and Bakermans, 1973; Engle et al., 1980). Available nitrogen added to very N-deficient soils is first directed to promoting a yield increase (Terman et al., 1969; Miezan et al., 1977). Increasing yield can produce a decrease in percent protein, due to the dilution effect (Hunter and Stanford, 1973; Johnson and Mattern, 1979; Miezan et. al., 1977; Pushman and Bingham, 1976; Terman et. al., 1969). The extremely low available nitrogen under zero tillage conditions, combined with the climatic factors of the season which promoted high yields, apparently led to a net decrease in percentage protein at low levels of applied nitrogen. In the conventionally tilled trials, presumably less nitrogen was tied up than under the zero till conditions, so available soil nitrogen was higher. Therefore, initial nitrogen additions increased yield, but sufficient nitrogen was still available to maintain protein levels as higher or higher than in the check. The fact that average yields were lower in the conventionally tilled trials than in the zero till trials (average yield 1.82 T/ha and 2.53 T/ha respectively) could also have led to higher percent protein levels at the 60 kg/ha nitrogen treatment.

Timing of extremely low (30 kg/ha) rates of nitrogen fertilizer had an influence on percentage protein produced (Table 15). Nitrogen application which produced the highest increase in yield tended to produce the lowest percentage protein. As these experiments were conducted on zero tilled winter wheat, additions of 30 kg/ha nitrogen resulted in a decrease in percent protein compared to that of the check. Treatments which produced the highest yield "diluted" the available nitrogen to the greatest degree, therefore producing the lowest percentage protein.

When the rate of nitrogen fertilization was increased to 45, 60 or 90 kg/ha, timing of nitrogen application did not affect percentage protein. Presumably, at these levels, the interaction between increasing yield and increasing availability of nitrogen due to more efficient timing of application was beginning to balance at a point where percentage protein did not fall due to increases in yield from more efficient nitrogen fertilization.

During the 1979-80 growing season, percentage protein increased with each addition of nitrogen fertilizer between 60 and 240 kg/ha (Table 7). In 1980-81, percent protein increased with additions of nitrogen between 90 and 180 kg/ha, but remained constant between 180 and 300 kg/ha (Table 8). The differences in protein response to added nitrogen may again be attributed to weather. Additions of nitrogen above rates where yield response ceased to occur normally result in increased percentage protein (Teman et al., 1969; Pushman and Bingham, 1976; Nelson et al., 1978; Olson et al., 1976; Johnson et. al., 1973; and Cochran et al., 1978). Increasing percent protein with increasing nitrogen fertilization occurred in both 1979-80 and 1980-81. However, in 1980-81, an unexpected plateau occurred. The plateau was apparently caused by the dry conditions in July, which restricted uptake of available nitrogen from the soil. Increase in percentage protein began at a higher level of applied nitrogen in 1980-81 than in 1979-80 due to the adequate moisture available during the early portion of 1981 (Table 2), which allowed the plants to utilize rates of added nitrogen up to 90 kg/ha for production of yield. These same growing conditions conducive to high yield led to the depression in percentage protein at low nitrogen levels noted in all zero tillage trials in 1980-81.

Nitrogen Recovery in the Grain

Nitrogen recovery in the grain was markedly higher in 1980-81 than in 1979-80, due presumably to the superior moisture conditions in the 1980-81 season.

Fall fertilization did not significantly effect the recovery of nitrogen in the grain (Tables 4, 10, 11, 12, 13). There was a tendency for the 60 kg/ha rate of fall applied nitrogen to be recovered more efficiently than the 120 kg/ha rate. A decrease in recovery at high rates of nitrogen fertilization would result as the plants response to applied nitrogen declined. At high rates of fertilization, nitrogen would no longer be the most limiting factor, since a restriction on production would occur due to the shortage of some other critical growth component.

With the exception of the conventionally tilled Winalta, where excessive winter kill destroyed the validity of the results, additions of phosphorus fertilizer produced a consistent, but nonsignificant increase in nitrogen recovery in the grain (Tables 4, 10, 11, 12, 13). Where phosphorus was deficient, restrictions were placed on crop growth, and therefore on nitrogen utilization. Correcting the phosphorus deficiency removed this limitation, resulting in greater recovery of applied nitrogen.

Recovery of applied nitrogen was affected by the timing of nitrogen application (Tables 15 and 16). At both the 30 kg/ha rate and the 60 kg/ha rate of applied nitrogen, applications on the snow were recovered less efficiently than applications at any other time. Nitrogen applied in the spring was consistently recovered most efficiently, but differences between recovery of spring applications and of applications at seeding and at freezeup were only significant at 60 kg/ha nitrogen rate. At 45 kg/ha applied nitrogen, delaying application until spring resulted in greater efficiency of recovery in the grain than from application in the fall (Table 14). However, when the rate of nitrogen application was increased to 90 kg/ha, no difference in recovery existed between applications in the fall, the spring or split application between fall and spring. At the 90 kg/ha rate the stand was provided with sufficient nitrogen to meet its requirements, regardless of the time of application, so differentials in recovery due to timing were not apparent.

Recovery of the 30 kg/ha rate of applied nitrogen tended to be higher than recovery of the 60 kg/ha rate, although the relationship was not examined statistically (Table 15 and 16). Application of 90 kg/ha nitrogen in the fall was recovered more efficiently in the grain than an application of 45 kg/ha in the fall. The 90 kg/ha fall treatment performed better throughout the entire experiment than expected. A rational explanation for this has not been developed.

In the spring applied nitrogen trials in 1979-80 and 1980-81, low rates of applied nitrogen were recovered most efficiently in the grain (Tables 7 and 8). As rate increased, efficiency of recovery decreased. In both years, applications of 60 kg N/ha were recovered more efficiently than were applications of 180 kg/ha nitrogen or more. Differentials in nitrogen efficiences between treatments were more evident in 1980-81, when drought was not as severe a complicating factor. However, in both years at rates of nitrogen application approaching 180 kg/ha, limitations on growth were primarily due to factors other than nitrogen supply, resulting in a decrease in efficiency of nitrogen utilization.

Figure 5 illustrates the recovery of nitrogen in the grain for zero tillage Norstar winter wheat and conventionally tilled Neepawa spring wheat (Loewen-Rudgers et. al., 1977) grown under similar moisture conditions at a number of fertilizer nitrogen rates. Although the two situations are not strictly comparable, the similarity of the two crops in the recovery and incorporation of applied nitrogen is marked.

Total Nitrogen Recovery

Patterns in total nitrogen recovery differed little from patterns in nitrogen recovery in the grain. However, there appeared to be a consistent tendency for the differentials between nitrogen recovered in the grain and total nitrogen recovery to be greater with spring applications of nitrogen than with applications at any other time. Possibly, application of nitrogen in the spring allowed for uptake of nitrogen later in the season. Nitrogen may have accumulated in the foliage but not have had sufficient time to be incorporated and translocated to the grain.

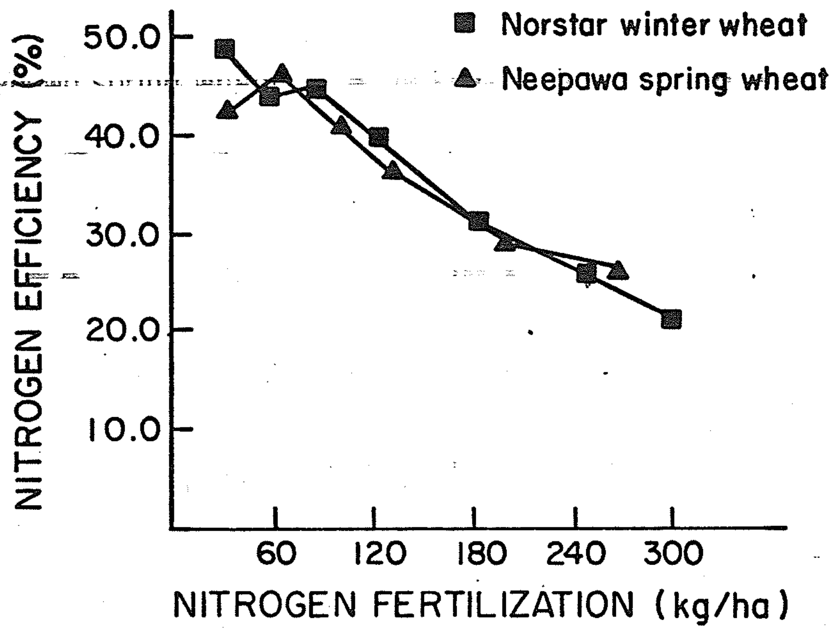


FIG. 5. Percent nitrogen efficiency as a function of spring nitrogen fertilization in Norstar and Neepawa wheat.

SUMMARY AND CONCLUSIONS

Results from this study indicate that winter wheat can be grown successfully in Manitoba using zero tillage management. Fertility management affects the success of zero tillage winter wheat production.

High rates of nitrogen fertilizer applied in the fall resulted in decreased winter survival. Application of phosphorus in combination with nitrogen counteracted the nitrogen influence, resulting in satisfactory overwintering.

The most effective time of application of nitrogen fertilizer was in the spring, if low rates of fertilizer were utilized. Application at time of seeding and at freezeup differed little in efficiency. Application of ammonium nitrate on the snow was inefficient in comparison to other times of application. If rates of nitrogen fertilizer were increased to levels approaching the yield response threshold of application, timing of placement had little effect on efficiency.

Rate of nitrogen fertilizer utilized most effectively by the stand varied greatly from year to year. Under good growing conditions, as occurred in 1980-81, utilization of 90 kg/ha was effective in promotion of yield. Percentage protein responses occurred at rates up to 240 kg/ha. In 1979-80, yield responses leveled off at only 60 kg/ha and percentage protein responses occurred to 240 kg/ha. Efficiency of nitrogen utilization in both years decreased dramatically at rates of higher than 120 kg/ha actual nitrogen.

Influence of weather, particularly rainfall, on yield, protein content and efficiency of nitrogen utilization was extreme. Low moisture availability produced lower yields, high percentage protein and inefficient utilization of applied nitrogen. Rate of nitrogen applied could have been reduced for the greatest production efficiency under conditions of low soil moisture.

Balanced nitrogen-phosphorus fertilization was important in winter wheat production, both to ensure adequate winter survival and to produce optimum yields.

A possible relationship existed between timing of nitrogen application and the proportion of nitrogen taken up by the plant that was translocated to the grain.

From these experiments, a number of preliminary fertilizer recommendations may be presented for zero tillage production of winter wheat in Manitoba.

1. Nitrogen fertilization should be postponed until spring for maximum overwintering and fertilizer efficiency.
2. Phosphorus fertilizer should be applied at the time of seeding, for optimum efficiency and promotion of winter hardiness, particularly if nitrogen is applied in the fall.
3. Balanced nitrogen and phosphorus fertilization is required for production of highest yields and maximum fertilizer efficiency.
4. The most efficient rate of fertilization will depend on available nutrients in the soil and on climatic conditions. These factors should be taken into consideration when fertilization rates are selected.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Examination of the relationship between banded and broadcast nitrogen at various times of application on winter wheat.
2. Studies on different soil types with varying nutritional status.
3. Efficiency of different nitrogen carriers such as urea for application on frozen ground and on the snow.
4. Effect of timing of nitrogen application on the proportion of nitrogen translocated from the leaves to the grain.
5. Studies to determine the actual reasons for the effects of nitrogen and phosphorus on winter survival.

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APPENDIX

TABLE 17. Soil test results

Year	Depth (cm.)	Texture	Carbonate Content	Ph	Salinity mmhos/cm	Nitrate-Nitrogen		Avail Phosphorous		Avail Potassium		Sulphate-Sulphur	
						ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha
1979-80	0-15	SiC	VL	7.2	0.6	41.2	74.2	19.8	35.6	333	599	8.2	14.8
	15-60	SiC	H		1.2	28.0	162.4					20+	116+
	0-15	SiC	VL	7.5	0.5	4.4	7.9	7.4	13.3	440	792	8.4	15.1
	15-60	SiC	H		0.8	3.4	19.7					20+	116+
	0-15	SiC	VL	7.6	0.5	6.0	10.8	4.8	8.6	365	657	20+	36+
	15-60	SiC	M		1.2	4.8	27.8					20+	116+
	0-15	SiC	VL	7.5	0.5	2.2	4.0	9.0	16.2	465	837	6.4	11.5
	15-60	SiC	H		0.5	1.2	7.0					20+	116+
	0-15	SiC	VL	7.5	0.4	7.4	13.3	9.6	17.3	400	720	8.8	15.8
	15-60	SiC	L		0.4	3.8	22.0					9.2	53.4
1980-81	0-15	SiC	VL	7.6	0.3	4.4	7.9	5.6	10.1	295	531	5.2	9.4
	15-60		H		0.7	4.2	24.4					20+	116+
	0-15	C	VL	7.8	0.2	3.0	5.4	13.0	23.4	320	576	5.8	10.4
	15-60	C	M		0.3	2.6	16.4					4.2	26.5
	0-15	C	VL	7.4	0.2	3.8	6.8	13.2	23.8	278	500	4.2	7.6

TABLE 17. Soil test results

Year	Depth (cm.)	Texture	Carbonate Content	Ph	Salinity mmhos/cm	Nitrate-Nitrogen		Avail Phosphorous		Avail Potassium		Sulphate-Sulphur	
						ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha
1980-81	15-60	C	M		0.3	2.8	17.6					3.0	18.9
	0-15	C	VL	7.3	0.2	4.2	7.6	17.0	30.6	285	513	6.6	11.9
	15-60	C	M		0.2	3.0	18.9					2.4	15.1
	0-15	C	VL	7.3	0.2	2.0	3.6	10.2	18.4	325	585	7.6	13.7
	15-60	C	H		0.3	3.6	22.7					8.0	50.4
	0-15	C	VL	7.3	0.2	1.6	2.9	37.0	66.6	263	473	10+	18+
	15-60	C	H		0.3	3.4	21.4					3.8	23.9
	0-15	C	VL	7.2	0.2	4.0	7.2	15.2	27.4	199	358	5.0	9.0
	15-60	C	M		0.3	3.0	18.9					2.6	16.4
	0-15	C	VL	7.3	0.2	2.4	4.3	13.0	23.4	265	480	6.0	10.8
	15-60	C	M		0.3	1.8	11.3					4.4	27.7
	0-15	C	VL	7.4	0.2	3.6	6.6	14.6	26.3	280	504	10+	18+
	15-60	C	M		0.2	2.8	17.6					2.2	13.9
	0-15	C	VL	7.3	0.2	5.4	9.7	11.8	21.2	208	374	1.6	2.9
	15-60	C	VL		0.3	1.8	11.8					2.4	15.1

TABLE 18. Precipitation

1979		1980						1981			
Period	Precipitation (mm)	Period	Precipitation (mm)	Period	Precipitation (mm)	Period	Precipitation (mm)	Period	Precipitation (mm)	Period	Precipitation (mm)
Sept. 1-7	3.2	Jan. 1-7	9.0	May 1-7	0.0	Sept. 1-7	9.3	Jan. 1-7	0.0	May 1-7	0.0
8-14	33.7	8-14	10.0	8-14	0.0	8-14	4.0	8-14	0.0	8-14	1.0
15-21	0.0	15-21	0.0	15-21	0.0	15-21	15.0	15-21	0.0	15-21	9.0
22-28	3.1	22-28	11.0	22-28	8.2	22-28	4.6	22-28	15.0	22-28	24.6
29-31	0.0	29-31	0.0	29-31	0	29-30	3.0	29-31	4.0	29-31	0.0
September		January		May		September		January		May	34.6
Total	40.0 (90)[1]	Total	30.0 (171)	Total	8.2 (16)	Total	35.9 (81)	Total	19.0 (109)	Total	(69)
Oct. 1-7	0.0	Feb. 1-7	4.0	June 1-7	21.1	Oct. 1-7	2.0	Feb. 1-7	4.0	June 1-7	8.2
8-14	2.0	8-14	2.0	8-14	10.1	8-14	4.6	8-14	0.0	8-14	19.4
15-21	9.3	15-21	7.0	15-21	9.3	15-21	8.0	15-21	2.0	15-21	21.7
22-28	0.0	22-28	5.0	22-28	33.0	22-28	3.0	22-28	0.0	22-28	37.6
29-31	0.0	29	0.0	29-30	0.0	29-30	0.0	February		29-30	1.0
October		February		June		October		Total	6.0 (39)	June	87.7
Total	11.3 (48)	Total	18.0 (116)	Total	73.5 (92)	Total	17.6 (75)	March 1-7	2.0	Total	(110)
Nov. 1-7	0.0	March 1-7	2.0	July 1-7	16.5	Nov. 1-7	14.0	8-14	0.0	July 1-7	19.0
8-14	8.0	8-14	3.0	8-14	20.3	8-14	3.0	15-21	0.0	8-14	5.0
15-21	0.0	15-21	1.0	15-21	40.8	15-21	0.0	22-28	8.6	15-21	8.8
22-28	2.0	22-28	8.0	22-28	13.1	22-28	1.0	29-31	0.0	22-28	3.8
29-30	7.0	29-31	0.0	29-31	1.4	29-30	2.0	March		29-31	5.0
November		March		July		November		Total	10.6 (51)	July	41.6
Total	15.0 (70)	Total	14.0 (68)	Total	92.1 (112)	Total	20.0 (94)	April 1-7	1.0	Total	(51)
Dec. 1-7	1.0	April 1-7	0.0	Aug. 1-7	50.0	Dec. 1-7	1.2	8-14	4.0	Aug. 1-7	14.5
8-14	10.2	8-14	0.0	8-14	17.8	8-14	5.0	15-21	11.2	8-14	10.6
15-21	0.0	15-21	0.0	15-21	100.0	15-21	4.0	22-28	14.0	15-21	12.4
22-28	0.0	22-28	0.0	22-28	21.0	22-28	2.0	29-31	0.0	22-28	0.0
29-30	0.0	29-30	0.0	29-31	7.8	29-31	0.0	April		29-31	44.0
December		April		August		December		Total	30.2 (126)	August	81.5
Total	11.2 (72)	Total	0.0 (0)	Total	195.8 (327)	Total	12.2 (79)			Total	(136)

1 Monthly precipitation as percent of average.