Yield and protein response of spring wheat (Triticum aestivum L.) to nitrogen fertilizer and the cycling of labelled fertilizer N with fallow and recrop management practices

by Alice Jane Jones

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
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Abstract:
Evaluation of plant growth and fertilizer N use was made on alternate crop-fallow and recrop management fields planted to 'Newana' spring wheat. Fertilizer N rates of 0, 30, 60, and 90 kg N/ha as NH4NO3 (33.5-0-0) were applied within each management plot; each fertilizer N plot was subdivided into areas receiving labelled (5.02 atom % 15NH415N03 or unlabelled N fertilizer.

Data variability between replications was high due to spatial variation in the soil and residue distribution. Based on averages of all replications no yield response to fertilizer N was obtained on fallow; large yield increases with fertilizer N occurred on recrop. Highest yields on all management practices were obtained with 90 kg N/ha. With the addition of 90 kg N/ha, recrop yield was equivalent to fallow yield at Bozeman, at Willow Creek recrop yield was only 60% of fallow yield, due probably to a P deficiency. Projecting these results to a two year cycle, recrop greatly outyielded fallow. Protein concentration was also greater on fallow than recrop. Protein yield reflected changes in both grain yield and protein concentration. Initial NO3-N levels prior to seeding greatly influenced the utilization of N.

Labelled fertilizer N results indicate substantial N turnover and net mineralization during the growing season on both fallow and recrop plots. Recovery of fertilizer N by the plant and the % N derived from fertilizer were greater on recrop than on fallow. Leaching of fertilizer N was not apparent. Greater than 85% of the fertilizer N in the soil at harvest was recovered in the surface 60 cm. A balance sheet at harvest showed recovery of fertilizer N to be 60% on fallow and 85% on recrop.

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YIELD AND PROTEIN RESPONSE OF SPRING WHEAT (*Triticum aestivum* L.)
TO NITROGEN FERTILIZER AND THE CYCLING OF LABELLED FERTILIZER
N WITH FALLOW AND RECROP MANAGEMENT PRACTICES

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ALICE JANE JONES

A thesis submitted in partial fulfillment
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in

Soils

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ABSTRACT

Evaluation of plant growth and fertilizer N use was made on alternate crop-fallow and recrop management fields planted to 'Newana' spring wheat. Fertilizer N rates of 0, 30, 60, and 90 kg N/ha as NH_4NO_3 (33.5-0-0) were applied within each management plot; each fertilizer N plot was subdivided into areas receiving labelled (5.02 atom % $^{15}NH_4{}^{15}NO_3$) or unlabelled N fertilizer.

Data variability between replications was high due to spatial variation in the soil and residue distribution. Based on averages of all replications no yield response to fertilizer N was obtained on fallow; large yield increases with fertilizer N occurred on recrop. Highest yields on all management practices were obtained with 90 kg N/ha. With the addition of 90 kg N/ha, recrop yield was equivalent to fallow yield at Bozeman, at Willow Creek recrop yield was only 60% of fallow yield, due probably to a P deficiency. Projecting these results to a two year cycle, recrop greatly outyielded fallow. Protein concentration was also greater on fallow than recrop. Protein yield reflected changes in both grain yield and protein concentration. Initial NO_3-N levels prior to seeding greatly influenced the utilization of N.

Labelled fertilizer N results indicate substantial N turnover and net mineralization during the growing season on both fallow and recrop plots. Recovery of fertilizer N by the plant and the % N derived from fertilizer were greater on recrop than on fallow. Leaching of fertilizer N was not apparent. Greater than 85% of the fertilizer N in the soil at harvest was recovered in the surface 60 cm. A balance sheet at harvest showed recovery of fertilizer N to be 60% on fallow and 85% on recrop.

INTRODUCTION

Alternate crop-fallow management is the traditional farming technique in the Northern Great Plains. However, due to problems associated with summer fallow, especially wind and water erosion and saline seep, flexible cropping has been advocated (Haas et al., 1974; Black et al., 1974; Sims, 1971). The long term goal of flexible cropping is to crop a field each season that there is a high probability of a profitable crop. The decision to crop or fallow in any one particular year is based primarily on the amount of stored soil water at seeding. If stored soil water is sufficient other parameters become important and may limit yields.

The success of a flexible cropping system is dependent upon knowledge of soil and climatic conditions, crop residue management, and consideration for soil fertility, disease, and weed problems that exist at a particular time and place. One important factor involving soil fertility with flexible cropping is increased straw residue levels which result in increased N immobilization during decomposition. A second factor involves the reduced time period between crops during which N mineralization can occur in years when fallow is eliminated. To increase N availability for crop growth, judicious rates of N fertilizer can be applied. However, to utilize N fertilizer efficiently and economically with flexible cropping practices, a better understanding of N ferlitizer transformations and utilization must be obtained.

Labelled N fertilizer experiments involving alternate crop-fallow and continuous cropping management practices were conducted to improve our understanding of N transformations which occur with flexible cropping systems. Specific objectives include the following:

1. Evaluate N application rates needed to maintain highest yields with alternate crop-fallow and recrop management.
2. Evaluate the relationship between optimum N fertilizer rates and initial soil fertility levels and environmental factors.
3. Determine the factors limiting production under alternate crop-fallow and recrop management.
4. Evaluate immobilization and mineralization of organic N under alternate crop-fallow and recrop management.
5. Evaluate the proportion of N in small grains derived from fertilizer and indigenous soil N under alternate crop-fallow and recrop management.
6. Evaluate leaching of fertilizer and indigenous soil N under alternate crop-fallow and recrop management.

REVIEW OF LITERATURE

Soil fertility information important to the success of flexible cropping includes crop residue management and nitrogen fertilizer management. Yield response data must prove that recropping a field (for one or more seasons) is more beneficial (economically or environmentally) than maintaining a rigorous alternate crop-fallow management scheme. Also, a knowledge of soil nutrient levels, following fallow or a crop will often alter fertilizer recommendations to compensate for nutrient withdrawals of different cropping systems.

Supplying adequate N is essential to small grain yields. Thus, nitrogen transformations and N availability in the soil provide important information for fertilizer N recommendations. Immobilization, a microbial process converting inorganic N (NH_4^+ and NO_3^-) to organic N, occurs when microbes are supplied with readily available carbon sources (i.e., straw residue) and inorganic N. Mineralization, a microbial process converting organic N to inorganic N, occurs when microbes decompose organic matter. Both processes occur simultaneously in the soil system and are very dependent upon moisture and temperature regimes. The rate at which immobilization and mineralization occur will be maximized when conditions for microbial growth are optimum. Plant available or inorganic N will accumulate in the soil only when mineralization is greater than immobilization.

Fertilizer N is used by microbes and by plants. The efficiency of fertilizer N, as measured by plant uptake and increased yields, must be great enough to pay for the related costs. Fertilizer N efficiency can be measured in several ways--plant uptake, percent of N (in the grain) derived from fertilizer, percent of fertilizer N recovered in the grain, percent of fertilizer N in the straw and soil that can be utilized by subsequent crops. All of these parameters will be altered when traditional alternate crop-fallow management is changed to a flexible cropping system.

Crop Residue Management

Residue from a 2688 kg/ha wheat crop will contain about 1.8 mt of straw (Fenster, 1977). Nutrients contained in this straw are equivalent to 100 kg N, 45 kg P, and 110 kg potash/ha. The majority of these nutrients can be returned to the soil if environmental conditions are favorable and adequate time for decomposition is allowed. If straw is not completely decomposed when the next crop is seeded, as may occur in continuous cropping of semiarid regions, nutrient availability will be decreased. Thus, understanding fertility levels of continuously cropped soils and requirements for maximum yields is of prime importance.

Yield Response

Black, et al.[1] conducted wheat experiments on fallow and continuously cropped fields to determine soil fertility requirements. Available P levels were very low while NO_3-N levels were very low on continuously cropped fields but were adequate for maximum yield on fallow. Response to management practice and fertilizer additions varied with initial soil fertility. Wheat yields on continuously cropped soils increased 10-15 bu/a over the check plot when 40 lb N/A and 20 or more lb P/A were applied. On fallow, with high NO_3-N levels, applied P was important to yield. For continuously cropped fields, yields at two locations averaged 34.4 and 49.6 bu/a for 0 and 80 lb N/a, respectively, when no other nutrients were applied. Maximum yields, with 80 and 40 lb N/a applied to continuously cropped fields, were 38 and 58 bu/a, respectively, when 60 lb P/a was also applied.

Long term yield trials were conducted by Dubbs (1976) on continuous barley and barley following winter wheat. Each of these two cropping sequences yielded 74% of barley grown on fallow for any one harvest when 40-50 lb N/a was applied. Protein was 1-2% lower than on fallow. When 40 lb N/a was applied, winter wheat in rotation with barley and continuous spring wheat, also outyielded the same crops grown on fallow based on a two year cycle.

[1] Black, A. L., F. H. Siddoway, R. H. Ford, L. L. Reitz, and M.G. Larson. Northern Plains Soil and Water Research Center. Sidney, MT. Unpublished data.

Small grain yields during a three year period for various cropping sequences were compared by Black et al.[2] Results on a per year basis indicated continuous winter wheat outyielded winter wheat-fallow by 48%; continuous barley outyielded barley-fallow by 22%; continuous spring wheat and winter wheat (alternating years) outyielded winter wheat-fallow by 40%. No information was given for fertilizer applications since the research was not intended as a fertility study.

Read and Wardner (1974) identified factors influencing the response of wheat grown on stubble residue. Rainfall had the greatest influence on yield and quality of unfertilized crops. Stored soil water and initial soil fertility had the greatest influence on fertilized crops. Available P levels at 0-15 cm depth was important in yield variation and available P to 60 and 90 cm was important to protein concentration in grain.

Little research has been conducted comparing small grain yields with continuous cropping and crop-fallow management except in the Northern Great Plains region. Resulting from these cited studies are the following conclusions:

1. Long term, continuous crop small grain yields are generally greater than those on fallow with adequate fertilizer applications.

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[2]Black, A. L., F. H. Siddoway, P. L. Brown, R. H. Ford, L. L. Reitz, and M. G. Larson. Northern Plains Soil and Water Research Center, Sidney, MT. Unpublished data.

2. Fertilizer N and P applications increase yield above N applications alone.
3. Stored soil water and growing season precipitation greatly influence crop response which is also dependent upon soil fertility level.
4. Protein content on recrop is generally lower than on fallow unless additional N is applied.

Residue Management and Fertility Levels

An 18 month study, conducted by Brown and Dickey (1970) at Bozeman and Huntley, Montana, involved wheat straw decomposition. Field conditions of residue above the soil, on the soil, and below the soil surface were simulated to compare decomposition rates at each site. After 18 months residue losses above the soil were 22 and 34%, on the soil were 31 and 40%, and below the soil surface were 93 and 98% for Bozeman and Huntley, respectively. Time required for 50% decomposition of buried straw was 6 months at Bozeman and 3 months at Huntley.

The effect of straw placement and N rate on straw decomposition was studied by Unger and Parker (1968) in the greenhouse. Nitrogen rate did not alter straw decomposition rate; however, straw mixed with soil decomposed much faster than when placed on the soil surface.

Greb et al. (1974) related straw buildup to cropping practices. In long term studies at Bushland, Texas, continuous wheat plots, maintained since 1942, accumulated 5040 kg residue/ha compared to wheat-fallow plots having 3330 kg residue/ha in the surface soil.

Black (1973) applied various rates of straw mulch to alternate wheat-fallow fields and measured changes in soil properties after four crop-fallow cycles. In the 0-15 cm soil depth large increases occurred for soil organic matter, N, C, C:N ratio, and total NO_3-N as residue levels increased. Other changes in chemical composition included increased exchangeable K and decreased exchangeable Ca. Magnesium and Na levels were not significantly influenced.

Soil fertility relationships for continuous cropping were studied by Black and Ford (1976). Soil NO_3-N levels prior to seeding averaged 30 lb N/a; thus, 30-40 lb fertilizer N/a were required to obtain a 30 bu/a wheat yield. Yield reductions of 50% or more were incurred when no fertilizer N was applied. When water was available in excess of 10 in, low organic matter soils required an additional 10-15 lb fertilizer N/a/1000 lb residue incorporated at seeding to achieve the same yields. Phosphorous fertilization requirements for continuous cropping on an annual basis were similar to those on fallow. Greatest P response occurred when N needs of the crop were first satisfied. Potassium fertilization generally gave no response on continuous cropping unless N and P needs of the crop were met.

In a pot study, Black and Reitz (1972) determined P immobilization by wheat straw. Phosphorous rates of 0, 16, 32, 65, 130, and 260 ppm and straw rates of 0, 2500, 5000, and 10,000 ppm were established, all receiving 62 ppm N. Phosphorous recovery for all rates decreased during the first 12 day interval for all rates of straw. Recovery of P after 60 days increased with P rate, but, for any specific P rate, recovery decreased with increased straw rate.

Olson et al. (1976) obtained no yield response to fertilizer N when 90 or 135 kg NO_3-N/ha existed under continuous cropping or crop-fallow management, respectively. Maximum yields were obtained on continuously cropped fields containing 45-90 kg residual N/ha when 45 kg N/ha were applied, and on crop-fallow fields containing 90-135 kg residual N/ha when 22 kg N/ha were applied. An additional 50-60 kg N/ha was needed to produce maximum protein content.

These studies concerning residue decomposition and soil fertility levels for continuous cropping management are concerned with small grain production. General conclusions are:

1. Straw decomposition is accelerated if incorporated with soil under optimum temperature and moisture regimes for microbial growth.
2. Straw residue buildup indicates a change in soil fertility level proportionate to the quantity of residue added.
3. Continuously cropped soils are usually low in NO_3-N. Additional fertilizer N is required for maximum yields.

4. Phosphorous fertilization is important on continuous cropping once N requirements have been met.
5. Potassium fertilization has little effect on yield until N and P requirements have been met.

Nitrogen-15 Studies

Nitrogen-15 (^{15}N) has been widely used to identify N transformations in soil under varying conditions. Few, however, have conducted field experiments to verify laboratory and greenhouse results.

Laboratory and Greenhouse Studies

Broadbent (1965) determined that increased mineralization of soil N was independent of the presence of plants. Considerable N turnover occured when $(^{15}NH_4)_2SO_4$ and $K^{15}NO_3$ were added to soil. The immobilization of NH_4-N and mineralization of soil N with NO_3-N additions were directly related to the rate of N applied. Preferential assimilation of NH_4-N by microbes was revealed.

Other laboratory studies without plant growth involved N transformations with carbon additions. Chichester et al. (1975) added N-free carbon materials (sucrose and glucose) to soil. Fertilizer ^{15}N was mainly recovered in organic form but mineralization rates were significantly increased with higher levels of soil N. Stojanovic et al. (1965) determined that both $^{15}NH_4$-N and $^{15}NO_3$-N were rapidly immobilized in the presence of wheat straw but that N turnover was relatively high. For a

2-6 day interval the equivalent of 56 lb N/a/day and 38 lb N/a/day were immobilized and 34 lb N/a/day and 18 lb N/a/day were mineralized for $^{15}NO_3$-N and $^{15}NH_4$-N additions, respectively.

Stewart et al. (1963) have related N immobilization-mineralization and plant uptake to straw additions. Plant uptake of one-third to one-fourth of the fertilizer ^{15}N was observed. Approximately one-half of the fertilizer ^{15}N remained in the soil after cropping. Increased N uptake by plants receiving N fertilizer was mainly attributed to interchange of fertilizer and soil N during immobilization-mineralization and/or increased microbial activity resulting in increased organic matter decomposition.

Broadbent and Tyler (1962) provided data on the relationship between ^{15}N immobilization and other processes involving N. Results of sudangrass pot studies illustrated microbial competition for fertilizer N. Soil microbes preferentially assimilated $^{15}NH_4$-N rather than $^{15}NO_3$-N. Immobilization dominated N transformations with $^{15}NH_4$-N additions; whereas, mineralization dominated N transformations with $^{15}NO_3$-N additions. With straw additions, immobilization was greater than mineralization for both N sources. Immobilization was maximized in about five days. Mineralization began at approximately ten days and decreased with time. In all soils $^{15}NO_3$-N was immobilized at a slower rate than $^{15}NH_4$-N. Increased N immobilization with straw additions reduced the uptake of N by sudangrass. Plant N levels were greater with $^{15}NO_3$-N than with

$^{15}NH_4$-N fertilizer. The recovery of ^{15}N averaged 80% with straw additions but was much lower without straw additions. In these experiments soil texture greatly influenced immobilization. Generally, in sandy loam soils immobilization was greater than mineralization but in clay soils mineralization was equivalent to immobilization so that no reduction in plant N levels were observed.

Broadbent and Nakashima (1965) studied plant recovery of immobilized fertilizer N. Sudangrass recovery of urea-^{15}N was lower with straw additions than without. Seeding, immediately following fertilizer applications, opposed to delayed seeding, increased plant uptake of fertilizer N. Plant uptake of ^{15}N was 22 and 41% with and without straw additions, respectively. Soil type also affected the mineralization of soil N with straw additions. Net ^{15}N recovery was greater in a sandy loam than in a clay soil. In a 237 day study, N uptake by sudangrass was greater with straw additions than without; however, at extremely high N rates (250 ppm) equal recovery of N by plants resulted on soils with and without straw additions. Total ^{15}N recovery (plant plus soil) was 61-79%.

Broadbent and Nakashima (1967) also presented evidence that plant uptake of fertilizer N was substantially different with and without straw additions even though N immobilization occurred in both situtations. With straw additions, nitrogen availability declined sharply before the first cutting of sudangrass, while this decline did not occur until after the first cutting without straw additions. A balance sheet showed two-thirds of fertilizer N remaining in soil after 1.4 years of continuous cropping. Net immobilization-mineralization of fertilizer N was determined to be independent of intrinsic soil N levels. In comparing soils receiving 50 ppm N plus 1% straw and soil receiving 100 ppm N and 2% straw, the latter yielded lower mineralized N concentrations, higher N remaining in the soil, and greater accountability for total N.

Other studies have dealt only with plant uptake of fertilizer N. Broadbent and Nakashima (1968) experimented with a four crop rotation of two years of sudangrass, tomatoes, and corn. Total ^{15}N uptake by these crops was significantly different when grown in different soil and on the same soil but receiving different N rates. Plant recovery of ^{15}N was good with $^{15}NO_3$-N and relatively poor with $^{15}NH_4$-N. Nitrate-N proved to be more efficient for plant utilization.

Jansson (1963) observed plant utilization of fertilizer N during a six year oat study. Oats took up a greater percentage of fertilizer N from $^{15}NO_3$-N fertilizer than from $^{15}NH_4$-N fertilizer (77% $^{15}NO_3$-N vs. 67% $^{15}NH_4$-N). This suggests that microbial immobilization of NH_4-N was greater than that of NO_3-N. During the second year of study, residual ^{15}N uptake was small compared to gross uptake (5.9% $^{15}NO_3$-N vs. 7.6% $^{15}NH_4$-N). The uptake of ^{15}N increased to 21.9% of gross N uptake when large amounts of $^{15}NH_4$-N remained in the soil following the first cropping season. During study years 3-6 gross N uptake generally increased, with $^{15}NO_3$-N treatments being superior to $^{15}NH_4$-N treatments. Jansson suggested that increased gross ^{15}N uptake with time may partially be due to accumulated ^{15}N in crop residues which later decompose and mineralize. A balance sheet showed increasing quantities of N removed from soil with time and constant uptake of residual ^{15}N over the years.

Legg and Allison (1967) varied $^{15}NO_3$-N fertilizer rates on several soils in greenhouse studies. Nitrogen uptake by oats increased with N rate. Total ^{15}N recovery averaged 94%. Nitrogen rate was inversely related to fertilizer N remaining in soil. The availability of ^{15}N decreased with time and was affected by the N-supplying capacity of the soil. Soils with low N-supplying capacity had the greatest amount of residual ^{15}N while soils with high N-supplying capacity had less residual ^{15}N.

Tyler and Broadbent (1958), using three $^{15}NH_4$-N fertilizers, studied N uptake by ryegrass. Nitrogen immobilized soon after application resulted in low ^{15}N recovery by plants with total recovery (plants and soil) ranging from 83-97%.

Legg and Stanford (1967) found increased soil N uptake by oats with increasing ^{15}N rate. These results were attributed to rhizosphere microbes. They speculated for field studies that poor soil and fertilizer N recovery would result due to increased root exploration and residue decomposition which may outweigh the effect of rhizosphere microbes in the immobilization-mineralization process.

These laboratory and greenhouse experiments contribute to the knowledge of N transformations, some of which may be applicable to field conditions. General conclusions from the aforementioned findings are:

1. The mineralization of soil N varies with the rate of fertilizer N applied.
2. Immobilized N is remineralized slowly and tends to become progressively stabilized in the soil.
3. Straw residue results in increased microbial incorporation of fertilizer N into the soil and decreased plant uptake.
4. Decreased N availability increases the time required for mineralization.
5. Ammonium-N is preferentially immobilized by microbes; NO_3-N is preferentially taken up by some plants.

Field Studies

Bartholomew et al. (1950) conducted one of the earliest field experiments using ^{15}N. Labelled $(^{15}NH_4)_2SO_4$ fertilizer, applied to oats at rates of 0, 20 and 40 lb N/a resulted in increased N uptake with increased N rates. Rates of 20 and 40 lb N/a produced grain N levels of 2.44 and 2.54% respectively. Generally, 16.9% of the ^{15}N was recovered by the crop with higher N rates yielding greater N recovery.

In a two year study, Owens (1960) used lysimeters to follow N movement and transformations in corn fields. Ammonium sulfate was applied at a rate of 120 lb ^{15}N/a to three sets of plots, each under a different moisture regime (12, 18 and 24 inches by volume). Approximately 38% of the ^{15}N remained in the soil following the experiment; 27-39% of the ^{15}N was unaccounted for. Leaching losses of 5-20% were directly proportional to water percolation. Soil moisture in excess of 12 inches allowed 1-1.9 lb ^{15}N to be leached per acre inch of water.

Carter et al. (1967) placed open-ended cylinders in field soils, cropped to sudangrass or fallowed, to study the movement of N from $Na^{15}NO_3$ and $(^{15}NH_4)_2SO_4$ fertilizers. Total average ^{15}N recovery from soil and plants was 99%. Little vertical movement of ^{15}N was observed in cropped plots, but $^{15}NO_3$-N movement was greater than $^{15}NH_4$-N movement. In both treatments, only traces of ^{15}N were found in the 45-75 cm depth samples. Covered plots, protected from precipitation, contained 0.3 and 0.6 ppm ^{15}N in the 45-60 cm layer while uncovered plots contained 4.4 and 5.6 ppm ^{15}N in the 45-60 cm layer for cropped and fallow plots, respectively, during a two month period.

Fertilizer N transformations were determined by Bobritskaya et al. (1975) using bottomless pots in fields cropped to oats. Plant ^{15}N uptake ranged from 35-57% and was highly dependent upon the N source. Approximately 30% of the ^{15}N was immobilized; leaching was insignificant. Nitrogen unaccounted for at the end of the experiment was 5.4 - 30.6% of the total. Environmental conditions such as moisture and pH seemed to greatly affect crop growth and N uptake.

Musherraf (1974) studied vertical movement and plant accumulation of fertilizer N in continuous corn and corn-oat-meadow rotation fields. Optimum yield for continuous corn was obtained with 60 lb N/a/yr. No significant movement or accumulation of ^{15}N occurred below five feet; however, at rates of 80 lb N/a/3 yr, fertilizer N had a one year carry over value. A two year carry over value of fertilizer N was obtained with 160 lb N/a/3 yr applied.

Uptake, storage, and loss of fertilizer N applied at a rate of 100 lb N/a as $(^{15}NH_4)_2SO_4$ on wheat fields was studied by Krauter (1975). Fertilizer ^{15}N had the following distribution--29.6% in wheat, 2.7% weeds, 10.3% as inorganic soil N, and 34.9% as organic soil N. Losses amounted to 22.5% of the ^{15}N. Heavy rains and irrigation caused ^{15}N movement below the root zone.

Westerman et al. (1972) applied urea-^{15}N and oxamide-^{15}N to a sorghum-sudan hybrid to study fertilizer N uptake. Plants harvested early took up more ^{15}N from urea than from oxamide; plants harvested later took up more ^{15}N from oxamide. This difference in N uptake with time correlates with N release from the two carriers. Crop recovery of ^{15}N ranged from 51-99%.

Field studies conducted by Campbell and Paul (1978) involved the use of $K^{15}NO_3$ to determine N transformations. Fertilizer N uptake by spring wheat was positively related to N rate up to 82 kg N/ha beyond which uptake leveled off; uptake of soil N was inversely related to rate.

Average ^{15}N recovery was soil 34.6%, grain 37.3%, straw 12.2%, roots 2.6%, error 6.0%, and unaccounted 7.0% on dryland. Fertilizer N remaining in the soil for rates up to 82 kg N/ha was about 28%; at 164 kg N/ha about 57% of the ^{15}N was left in the soil. The majority of residual ^{15}N remained in the 0-30 cm soil depth at low N rates (less than 82 kg N/ha) while greater than one-half of the residual ^{15}N was located in the 30-60 cm soil depth with higher N rates. Fertilizer N below 60 cm was negligible.

These field experiments, conducted on various crops and under wide-ranging environmental conditions, illustrate the magnitude of fertilizer N transformations and the factors influencing the transformations. General conclusions that may be drawn are:

1. Total fertilizer N recovery fluctuates widely and is highly dependent upon N application rate, crop, and environmental conditions.
2. Increased fertilizer N application rates can increase crop N uptake, potential leaching losses, and accumulation of inorganic N at lower soil depths.
3. Fertilizer N leaching losses are increased with increasing water content and percolation.
4. Environmental conditions such as precipitation, pH and soil texture can markedly alter N transformations.

RESEARCH METHODS

Field Design

Experimental sites at Bozeman and Willow Creek, Montana were selected to give a range in soil properties and environmental conditions (Table 1; Appendix I). At each location, management plots were established on adjacent fields, one of which had been fallowed and the other cropped the previous year. The field which was fallowed is designated fallow; the field which was cropped is designated recrop throughout this thesis. Uniform applications of 50 kg P/ha, as triple superphosphate (0-45-0), and 25 kg K/ha, as KCl (0-0-62), were broadcast on all management plots. Also at the Bozeman site 70 kg $CaSO_4$/ha was applied to the recrop field to balance previous applications of a gypsum formulation by the farmer to the fallow field.

Fertilizer N rates of 0, 30, 60, and 90 kg N/ha, as NH_4NO_3 (33.5-0-0), were applied and replicated three times within each management plot. Each fertilizer N plot was subdivided into areas receiving double labelled or unlabelled NH_4NO_3 fertilizer (Appendix II). Unlabelled N fertilizer (granular) was broadcast by hand. Labelled N fertilizer was dissolved in 1 liter of water and sprinkled onto the plot. Immediately following fertilization all plots were seeded to Newana spring wheat (*Triticum aestivum* L.).

Fertilizer N subplots receiving labelled ^{15}N were sampled for soil and/or plant material three days following seeding, at midsummer, and at harvest. Soils were sampled at 0-15 and 15-30 cm depths at three days and at midsummer. At harvest, soil samples were collected to 120 cm, at depth intervals of 0-15, 15-30, 30-60, 60-90, and 90-120 cm. Soil samples collected at three days were a composite of four soil cores obtained with an Oakfield sampler. Soil samples collected at midsummer and harvest consisted of one-4 cm diameter soil core obtained with a hydraulic soil sampler. A representative plant sample at midsummer and harvest was obtained by cutting approximately 1/8 of the plants from the $5m^2$ ^{15}N subplot. Fertilizer N subplots receiving unlabelled N were harvested to determine yield.

Laboratory Analysis

In the laboratory soil samples were air dried, crushed in a flail-type grinder and screened to remove the greater than 2 mm fraction. Plant tissue and grain were air dried and ground in a Wiley mill to pass a 40 mesh screen.

Standard soil analyses were determined on surface soil samples obtained prior to fertilization to indicate soil fertility conditions at each location. Analyses included pH and conductivity with a 2:1 dilution, NH_4Ac extractable Ca, Mg, Na, and K (Chapman, 1965), modified Bray P (Smith, et al., 1957; Olson and Dean, 1965), organic matter (Sims and Haby, 1971), and NO_3-N (Sims and Jackson, 1971; as modified by Haby and Larson, 1976). Nitrate N analyses were also conducted on these initial soil samples and harvest soil samples to a depth of 120 cm.

Soil samples from 3 days, midsummer, and harvest were collected from 0-15 and 15-30 cm depths. Plant samples from midsummer and grain samples from harvest on all ^{15}N subplots and straw samples on 90 kg N/ha ^{15}N subplots were analyzed for total N (Bremner, 1965a). Harvest soil samples to a depth of 120 cm from one 90 kg N/ha replication on each management practice were also analyzed for total N. These samples were then prepared and analyzed for ^{15}N concentration on a Consolidated Electrodynamics Corporation mass spectrometer (Appendix III, Bremner, 1965b).

Plant samples obtained at midsummer were analysed for nutrient concentration to include P, K, Ca, and Mg. These determinations involved a perchloric acid digest (Appendix IV, Kresge, 1976) followed by atomic absorption analysis for K, Ca, and Mg, and vanadomolybdic acid color development for P (Jackson, 1958). Total N determinations were analyzed according to Bremner (1965a).

Calculations

Calculations used in this thesis are as follows:

Protein concentration:

$$\% \text{ N in grain} \times 5.7 = \% \text{ protein}$$

Protein yield:

$$\text{grain yield (kg/ha)} \times \frac{\%\ \text{Protein}}{100} = \text{protein yield (kg/ha)}$$

Atom % N:

$$\frac{100\ R}{2+R} = \text{atom \% N}$$

$$R = \text{ratio of } ^{15}N : ^{14}N.$$

Atom % N excess:

$$\text{atom \% N} - 0.366\ \%\ \text{(nat. abund.)} = \text{atom \% N excess}$$

Mineralization and immobilization rates: (outlined by Kirkham and Bartholomew (1954)

$$m = \frac{M_o - M_t}{t} \; \frac{\log \frac{H_o M}{H M_o}}{\log \frac{M_o}{M}} \quad \text{and} \quad i = \frac{M_o - M_t}{t} \; \frac{\log \frac{H_o}{H}}{\log \frac{M_o}{M}}$$

where m = mineralization rate, i - immobilization rate, H_o = mass of tracer atoms at t=0, H_t = mass of tracer atoms at t, M_o = mass of total mineral atoms at t=0, and M_t = mass of total mineral atoms at t.

Assumptions made in deriving this equation include:

1) tracer and nontracer atoms behave similarly;
2) atoms once immobilized do not significantly contribute to the mineralized fraction;
3) mineralization and immobilization are constant during a given time period.

Data used to calculate these variables were:

Period	0-60	60-harvest	0-harvest
t	60 days	28 days (Willow Ck) 68 days (Bozeman)	88 days (Willow Ck) 128 days (Bozeman)
M_o	kg NO_3-N/ha (in soil) to 30 cm for prefertilizer sampling	kg NDFS/ha[3] in plants at midsummer (assumes total uptake of inganic N from soil)	as for 0-60 days
M_t	kg NDFS/ha in plants at midsummer (assumes total uptake of inorganic N from soil	kg NDFS/ha in grain and straw at harvest plus kg NO_3-N/ha in soil to 30 cm	as for 60 days-harvest
H_o	kg ^{15}N/ha in soil to 30 cm for 3 day sampling (assumes no plant uptake of ^{15}N between fertilization and 3 day sampling	kg ^{15}N/ha in plants and soil to 30 cm at midsummer	as for 0-60 days
H_t	kg ^{15}N/ha in plants and soil to 30 cm at midsummer	kg ^{15}N/ha in grain, straw, and soil to 30 cm	as for 60 days-harvest

[3]Defined on page 25.

Calculations made in obtaining these variables were:

M_t: soil (for 15 cm soil depth)

$$\text{ppm } NO_3\text{-N in soil} \times \frac{2 \times 10^6 \text{ kg soil}}{\text{ha}} = \text{kg mineral N/ha in soil}$$

plant (straw, grain)

$$\text{kg/ha plant tissue} \times \frac{\text{\% N in plant tissue}}{100} - \text{kg/ha plant tissue} \times \frac{\text{\% N in plant tissue}}{100} \times \frac{^{15}\text{N excess in plant}}{^{15}\text{N excess in fertilizer}} - \text{kg NDFS/ha}$$

H_t: soil (for 15 cm soil depth)

$$\text{ppm total N in soil} \times \frac{2 \times 10^6 \text{ kg soil}}{\text{ha}} \times \frac{\text{atom \% } ^{15}\text{N}}{100} = \text{kg } ^{15}\text{N/ha in soil}$$

plant (straw, grain)

$$\text{kg/ha plant tissue} \times \frac{\text{\% N in plant tissue}}{100} \times \frac{\text{atom \% } ^{15}\text{N in plant tissue}}{100} = \text{kg } ^{15}\text{N/ha in plant.}$$

Calculations made in obtaining other ^{15}N results are as follows:

Plant N uptake:

$$\text{kg/ha grain (straw)} \times \frac{\text{\% N in grain}}{100} = \text{kg N/ha in grain.}$$

Percent of N derived from fertilizer (% NDFF): (outlined by Rennie and Paul, 1971)

$$\frac{^{15}\text{N excess in sample}}{^{15}\text{N excess in fertilizer}} \times 100 = \%\ \text{NDFF}$$

Nitrogen derived from fertilizer (NDFF):

$$\text{kg N/ha in sample} \times \frac{\%\ \text{NDFF}}{100} = \text{kg N/ha as NDFF.}$$

Nitrogen derived from soil (NDFS):

$$\text{kg N/ha in sample} - \text{kg N/ha as NDFF in sample}$$

$$= \text{kg N/ha as NDFS.}$$

Proportion of fertilizer N recovered:

$$\frac{\text{kg N/ha as NDFF}}{\text{kg N/ha applied}} \times 100 = \%\ \text{N recovered.}$$

Residual fertilizer N in soil:

$$\text{ppm N in soil} \times \frac{2 \times 10^{6}\ \text{kg soil}}{\text{ha}} \times \%\ \text{NDFF} = \text{kg fertilizer N/ha}$$

Location of residual fertilizer N in soil:

$$\frac{\text{kg fertilizer N/ha in depth sample}}{\text{kg fertilizer N/ha in soil profile (to 120 cm)}} \times 100$$

$$= \%\ \text{residual fertilizer N located in depth sample.}$$

Statistics

These and other results were analyzed statistically using Duncan's multiple range mean comparison values to test significant differences between means.

RESULTS AND DISCUSSION

Grain Yield

Grain yields for the 1977 growing season are shown in Figure 1. Grain yield on fallow averaged 3669 kg/ha in Bozeman and 2929 kg/ha at Willow Creek. Little N response was obtained on fallow at either location. Slight decreases in yield resulted with 30 and 60 kg N/ha on fallow at Bozeman. These plots were also highly infested with volunteer grain and wild oats. Control plot grain yields on recrop were 1722 and 669 kg/ha at Bozeman and Willow Creek, respectively. The addition of N increased yield on recrop. When 90 kg N/ha was applied yields increased to 3719 kg/ha at Bozeman and to 1858 kg/ha at Willow Creek. These amount to 116% and 178% yield response over the check. Factors greatly influencing and/or limiting production on recrop include general soil fertility, NO_3-N level at seeding, and available water during the growing season (Table 1).

Highest yields on fallow at Willow Creek and recrop at both locations were obtained with 90 kg N/ha. The highest yield on fallow at Bozeman was obtained with 0 kg N/ha. Fallow at Bozeman yielded 3991 kg/ha on the control plot but was not significantly different from the yield on 90 kg N/ha plots (Appendix Table 17); the field contained 146 kg NO_3-N/ha in the soil profile at seeding, enough to produce a maximum yield without additional N. The recrop field at Bozeman