EFFECT OF ANNUAL LEGUMES ON THE NITROGEN STATUS OF SOILS

by

MICHEL R. GRENIER

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A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

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ABSTRACT

Annual legumes are grown in Manitoba for seed and occasionally as a green manure crop. The effects of annual legume crop residues on the N status of soil and the N nutrition of subsequent crops were investigated. Studies using coarse textured soils of the Almasippi Association were conducted in the growth chamber, lysimeters and in the field.

The growth chamber study indicated a linear relationship between the N content of the added crop residue and the amount of available N released or immobilized. It can be concluded that if the N content of an added crop residue is greater than 1.5 %N there will be net mineralization of N upon decomposition; and conversely if the N content is less than 1.5 %N there will be net immobilization of available N. From these data the following equation is proposed:

$$\begin{array}{l} \text{Kg of N released or} \\ \text{immobilized from 1 Mg} \\ \text{of residue in one year} \end{array} = \begin{array}{c} \text{mass of} \\ \text{residue} \\ \text{in Mg} \end{array} \times \left(\begin{array}{l} \text{N contained} \\ \text{in 1 Mg} \\ \text{residue} \end{array} - 15 \right)$$

N released from the high N content residues was similar in availability to N from $(NH_4)_2SO_4$. When N was not limiting decomposition, added crop residues increased the organic N pool to about the same size regardless of initial N content and acted the same during further decomposition.

Studies were conducted in lysimeters over two years in order to quantify the N_2 fixation capability, the amounts and N composition residues of lentil, pea and fababean as compared to wheat under Manitoba conditions. Two harvests, at mid-pod and maturity, were taken during the growing season. Results indicate that there is an appreciable amount of dry matter produced as roots by these legume crops. Dinitrogen fixation was highest for fababean and lowest for lentil. With one exception, N removed as seed was higher than that produced by N_2 fixation. Using equation 3.1 an attempt was made to predict the amount of N which would be released from each crop. As a green manure, the legumes would release a large amount of N ranging from 39 to 128 kg N ha^{-1}. When grown for their seed yield these annual legumes would either release or tie up only small amounts of N. The predicted results indicate a non-legume crop would require 59 kg ha^{-1} less fertilizer N on annual legume stubble than on wheat stubble. When these annual legumes are grown for seed, regardless of their N_2 fixation capability, there should be little difference between them in their effect on the N status of soil in the next year.

Field studies were conducted at three sites evaluating the effect on a crop of wheat following lentil, pea and fababean as compared to following wheat. Results indicate that fertilizer N applied at 25 kg ha^{-1} to wheat following an annual legume gave a yield comparable to 75 kg ha^{-1} applied to wheat following wheat. Results were consistent with the lysimeter study. The annual legumes contributed more to N nutrition than a preceding wheat crop, and there was little difference between the annual legumes in their N contribution.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

1. Introduction

Annual legumes are grown in Manitoba for their seed yields and occasionally as a green manure crop. In either case they make an impact on the soil's nitrogen and organic matter status. An important factor affecting organic matter or nitrogen status of soils is the amount and composition of organic residues added annually. The amounts of straw added to soil is easily determined by weighing the amounts of straw produced; estimating amounts of residue added to the soil via a crop root system is much more difficult. Since roots are always left in the soil it is important to have information about them in order to assess the effect of crop residues on the organic matter and N status of soils. Crop residues or freshly added plant material will either contribute to or immobilize soil available nitrogen depending on their nitrogen content. There exists a critical N content value, above which net mineralization of residue N will occur during decomposition, and below which net immobilization of soil N will occur. Minimal data exists concerning the fate of legume residue derived N under Manitoba conditions.

Lentil, pea and to a lesser degree fababean are grown as alternative crops in rotation with cereals and oilseeds in Western Canada. It is generally considered by producers that a legume crop does not require fertilizer N and will add fixed atmospheric N to the soil. However environmental conditions under which the legume is grown and the stage at which the legume is harvested is crucial to how much nitrogen, if any, it will fix and release to the soil. In Manitoba, soil N tests based on soil nitrate-N do not make allowances for the effects of legume stubble fields.

Studies were therefore conducted to evaluate the effect of annual legume crops such as lentil, pea and fababean on the N status of a Manitoba soil as compared to a crop of wheat. Growth chamber studies were conducted with the purpose of determining what the critical crop residue N content might be for a Manitoba soil and to determine the influence of the N contents of crop residues at time of incorporation on the contribution of nitrogen to a succeeding wheat crop. Lysimeter studies were conducted in the field with the objectives of quantifying both the amount of residues (straw and root) produced and N_2 fixation by the annual legumes as compared to a wheat crop. Further, the purpose of the lysimeter studies was to also the effects of the crops on soil N when used as a green manure and for seed. Field studies were conducted in order to evaluate the effects of the annual legumes as compared to wheat on the available N status of the soil and to determine the contribution of previous crops, in terms of fertilizer N to a subsequent wheat crop.

2. Literature Review

Positive effects of legumes on following crops have been widely reported in the literature. The beneficial effect of legumes on available N supply to succeeding crops is a function of the residue, the soil and climate. In order to exploit the benefit of including annual legume crops in rotations in Western Canada, we will require an understanding of the factors affecting the decomposition of legume residues and their interactions on available N supply to succeeding non-legume crops. The following literature review will emphasize the decomposition process and the impact of including leguminous crops in rotation.

2.1 Decomposition Processes and N Derived from Residues

2.1.1 Decomposition of Plant Residues

Significant quantities of plant residues are returned to the soil annually and act as a major source for nutrient cycling. Historically the decomposition of plant residues as a substrate have been characterized by the carbon-to-nitrogen (C/N) ratio of the organic material in question. Residue factors affecting decomposition rate will be influenced by those factors affecting soil environment, primarily soil type, soil management and climate. Effective crop residue management will require an understanding of the factors affecting straw decomposition and N dynamics simultaneously. (Christensen 1985, Lynch 1983, and Reinertsen et al. 1984).

Stojanovic and Broadbent (1956) reported that the immobilization or mineralization of N will be dependent on the chemical composition of the material undergoing decomposition, primarily on its C/N ratio. Thus, plant residues containing a high percentage of available C, when incorporated into the soil, will stimulate microbial growth and hence assimilate available N. The role of available C and N in wheat straw decomposition under laboratory conditions was studied by Reinertsen et al. (1984). Attention was focused on the relationships of soluble C and N on decomposition rate and N immobilization. The data indicated that initial available N and C will limit the size of the biomass and hence the decomposition rate of the straw. It was concluded that the overall rate of decomposition will be dictated by the size of soluble C pool and that available C pools are responsible for N immobilization. When available C was not limiting the decomposition of the wheat straw it was found that decomposition rate increased with increased %N and that all three straw lots immobilized additional N. Christensen (1985) studying wheat and barley straw decomposition, observed that regardless of initial straw N contents overall N dynamics were less influenced by straw type than soil type. It was concluded that the amount of N immobilized in straw will be dependent upon the mineral N supplying capacity of the soil. It was found that a net release of N from the decomposing straws began when the C-to-N ratio was between 28 and 35.

Investigations of initial chemical composition of grass roots decomposing in a Chernozemic soil by Herman et al. (1977) revealed that factors other than N content interact with it to control decomposition. Decomposition could not be predicted from the properties C/N ratio, lignin content or carbohydrate content when considered individually, but the relative rate of decomposition could be expressed through the relationship $[(C/N)*(\% \text{ lignin})]*(\% \text{ carbohydrate})^{-1/2}$. There was an effect of soil on rate of decomposition and it was postulated that this soil effect could be as great as the effect of substrate. Cheshire et al. (1988) comments on the problems associated with attempting to relate individual components to decomposability. With time there will be spatial inaccessibility to microorganisms with increasing degree of decomposition due to increasing physical barriers. These barriers will be caused for example by lignin and clay particles coating organic material during the decomposition process.

Field studies by Douglas et al. (1980), measured simultaneous effects of placement and straw composition for their effects on decomposition. Decomposition was found to be higher for buried versus surface straw placement. Net N mineralization increased with increasing initial N content and placement below the surface. Amato et al. (1984) in field studies, found no difference in decomposition rate of ground versus unground plant material. Leaf material was found to decompose faster than stem. This is consistent with studies conducted by Stephen et al. (1981) comparing wheat straw leaves, internodes and nodes. Companion laboratory studies by Amato et al. (1984) found that drying and rewetting promoted decomposition, with the longer the moist period following drying, and the greater the number of drying and wetting cycles, the greater the decomposition.

2.1.2 Mineralization-Immobilization of Plant Residues in Soil. Effect on N Uptake by Subsequent Crops and Soil N Pools.

Nitrogen mineralization is defined as the transformation of N from the organic state into the inorganic forms such as NH_4^+ or NH_3. N immobilization is defined as the transformation of inorganic N compounds (NH_4^+, NH_3, NO_3^-, NO_2^-) into the organic state (Jansson and Persson 1982). Mineralization-Immobilization of organic material by the soil biomass is a key component of the N cycling in soil. The opposing processes of mineralization and immobilization are always functioning in soil. Thus, the ability of decomposing plant residues to provide available N to growing crops will depend on the net result. The critical N content above which net mineralization will occur is generally considered to be in the range of 1.4 to 1.8 %N and C:N ratio <25 to 30 (Haynes 1986, Smith and Peterson 1982). Early studies measuring the availability of N from added residues in the field did not provide accurate quantitative data. More recently studies have been conducted using isotopic labelled organic material to measure the net mineralization-immobilization result and the subsequent fate of N derived from added plant residues.

Ladd et al. (1981) conducted field studies measuring the decomposition of ^{15}N labelled legume residues and N uptake by a subsequent wheat crop. They reported that wheat plants took up only 10.9-17.3% of the ^{15}N as added legume material. They found that the soil organic ^{15}N pool accounted for 71.9-77.7% of original input. They concluded that the legume material contributes only a small proportion of N to the soil available pool and that in terms of supplying N to succeeding wheat crops the main value of legumes would be long term. Further, the legume material has the capacity to maintain or improve concentrations of soil organic N, to be decomposed at relatively slow rates in following years. They failed to report the percent utilization by the wheat crop of the legume residue derived N expressed either as a total of residue input or amount net mineralized from the residue.

In following up on the above results Ladd et al. (1983) evaluated the N uptake from decomposing legume residues in field lysimeters. Labelled legume residue equivalent to a plant N input of 48.4 kg ha^{-1} was added to the lysimeters and allowed to decompose for seven months before sowing the first successive wheat crop. After harvesting of the first wheat crop, residue amendments were allowed to decompose for an additional five months before seeding the second successive wheat crop. It was found that at the time of sowing of the first wheat crop 24.4 to 31.4% of added legume N had been released. The N recovered was nearly all nitrate and represented 9.7% of total soil inorganic N. Uptake by the first wheat crop indicated only 20.2-27.8% utilization of N incorporated as legume residue. These amounts represent 82-88% utilization of legume-N released as measured soil nitrate-N. This indicates that N released in excess of soil biomass requirements is more efficient than fertilizer which was not considered by the authors. They further found that utilization of incorporated legume-N by second wheat crop was <5% of input. The authors concluded that legume residues contribute only a small percentage of the added N to the soil available N and to crop N uptake.

Results are reported by Muller and Sundam (1988) who compared the release, availability, and soil retention of N derived from five legume ^{15}N labelled residues decomposing in field lysimeters. Unlabelled fertilizer N (NH_4NO_3-N) was added to the microplots at a rate of 50 kg ha^{-1}, no data was presented on its uptake. Uptake of released residue N by barley ranged from 17-25% of input. When based on the percentage of released N it was found that N derived from the various legume residues was equally available to the barley, with uptake ranging from 28-33% of residue released N. Due to the low uptake by the barley crop and low measured N losses it was concluded that the soil had a high retention potential for residue derived-N and that the value of legume residues as a supplier of N to subsequent crops is long term. In combination with these studies Muller (1988) reported on the effect of soil type on the fate of the clover-derived nitrogen in field microplots. ^{15}N labelled clover residue was placed in mesh bags and buried in seven different soil types contained in lysimeters. Uptake by a subsequent barley crop was 11-20% of clover-N input, whereas 27-37% of clover-N input was retained by the soils and 30-38% remained in the mesh bags. The barley crop took up a majority (90-94%) of its N requirement from sources (soil N, fertilizer N ...) other than the labelled clover material. Effect of soil type on release and retention of clover N was found to be small and statistically non-significant. This is in contrast to the findings reported by Christensen (1985) who studied the decomposition of wheat and barley straw buried in mesh bags under field conditions. It was found that the amount of N immobilized by the straw depended more on soil type than on initial N content. It was hypothesized that the amount of N immobilized in straw depends on the mineral N supplying capacity of the soil.

In monitoring the decomposition of doubly-labelled ^{14}C and ^{15}N legume residues in the field over a four year period, Ladd (1981) found that the percentage decline followed similar patterns independent of residue input levels in the range 25 to 100 kg N ha^{-1}. More than 50% of the ^{14}C had disappeared in the first four weeks and after 4 years 15-20% of input remained. It was estimated that 75% of the residue decomposed rapidly with a half life of 0.06 years and the remaining stable residues had a half life of about 8 years. After 32 weeks 60-65% of added ^{15}N remained as organic residues. Organic ^{15}N declined slowly thereafter with nearly one half still remaining as stable organic residue after 4 years. It was found that decomposition rates were not affected by grinding shoot legume material prior to incorporation, but grinding did increase root decomposition. It was also reported that despite low percentage utilization of legume residue N by wheat crops, N from legume residues is relatively more available than N from organic soil reserves.

Wagger (1985) found that the net N mineralization of N from wheat residues ranged from 12-15% of input versus 12-33% of sorghum residue. The difference in net N mineralization between the residues was attributed to the

C:N ratios of the residue materials as well as the proportion of other plant constituents. Addition of fertilizer N was found to stimulate the rate of mineralization particulary for the wheat straw. Utilization of mineralized residue N was reported to be 79% and 82% for wheat and sorghum respectively. Amato et al. (1987) compared the decomposition of doubly labelled ^{14}C and ^{15}N wheat and pasture legume residues incorporated in the field. It was found that mineralization was greatest for the legume with 56 to 63% residual organic ^{15}N after 1 year versus 78% for wheat. Early in the decomposition of the wheat straw, net immobilization of inorganic N occurred, however it was also found that during this time some interchange of unlabelled inorganic ^{14}N replacing organic ^{15}N had occurred. This amount of turnover interchange was found to be in excess to that of the interchange of inorganic ^{15}N for organic ^{14}N during decomposition of soil organic matter. The impact of this turnover interchange on the results was not addressed by the authors. An extensive review of the concurrent mineralization-immobilization of N and the impact of this turnover in tracer experiments is presented by Jansson and Persson (1982). Tomar and Soper (1987) studied the effect of added organic residues and placement on the fate of ^{15}N labelled urea fertilizer. Results indicated a difference in fertilizer recoveries between placement methods when using the direct ^{15}N and indirect methods of calculation. Where plant residues were added the mixed fertilizer N placement proved to be superior to the point-placed fertilizer N yet less ^{15}N was taken up for the mixed placement. This difference between methods was attributed to dilution of ^{15}N with the addition of organic residues, in part by the "priming effect" but more so to the occurrence of a large amount of biological interchange of labelled ^{15}N for unlabelled ^{14}N. Cochran et al. (1988) in studying the limitation effects of N or C on wheat straw decomposition believe N and C to flow through two microbial pools. To explain their results they postulate that a microbial biomass (pool A) is derived quickly from the readily available C in the straw and dies, while a separate and different biomass (pool B) is growing slowly on the less readily available C and is sustained for a longer growth period. They concluded that N mineralized from the dead biomass pool A is immobilized into biomass B resulting in net immobilization of N. This helps explain the process of mineralization-immobilization turnover during periods of net immobilization.

2.2 Legume Rotational N and Non-N Effects on Succeeding Crops

The inclusion of a legume in crop rotations either as a green manure, cover crop, or for their grain, has been shown to increase yields of succeeding non-legume crops. This benefit to succeeding crops is largely due to the legume effects on soil N supply, but can also be due in part to other rotational effects. The management practices used in growing the legume crop will significantly influence the benefits to succeeding non-legume crops.

2.2.1 Rotational N Effects of Legumes on a Succeeding Corn Crop

In North America legume cover or winter green manure crops have been shown to benefit succeeding corn crops. Mitchell and Teel (1977) found that in addition to using a legume cover crop as a no-tillage mulch for soil cover there was a beneficial effect on subsequent corn yields. This benefit was attributed to the release of biological N from the leguminous residues. Leguminous cover crops were found to produce corn yields comparable to those receiving 112 kg fertilizer N ha^{-1}. Similarly, Ebelhar et al. (1984) found that legume cover crops can release available N for corn production thereby reducing need for fertilizer N additions. They reported that averaged over 5 years, legume cover crops provided N equivalent to between 90 and 100 kg ha^{-1} fertilizer N. It was further found that the highest yields were obtained with a legume mulch and 100kg ha^{-1} fertilizer N. This indicates that the succeeding corn crop still responded to additional fertilizer N even in the presence of the legume cover crop residues. There was a tendency for corn yields to be higher after a cover crop over all levels of fertilizer N as compared to with no cover crop. This indicates a positive rotational effect which could not be overcome by additional fertilizer N. At the time of corn planting no significant differences in soil inorganic N or increase in total N content of the soil due to cover treatment were found. Fox and Piekielek (1988) studied the rotational effect of 3 years of legume hay production followed by 3 years of corn production. It was reported that the 3 years of hay rotation significantly affected each of the 3 years of corn production. The fertilizer N equivalence of the hay stands were estimated to be 147 to 187 kg ha^{-1} for 3 years of succeeding corn production. They concluded that the beneficial effect due to legumes on corn yields was primarily due to residual N rather than to a rotation effect which is in contrast to the rotational effects noted by Ebelhar et al. (1984).

2.2.2 Rotational N Effects of legumes on Cereal Crops

Data reported by Bailey (1986) from Brandon MB. indicate that while the use of annual legumes in rotations would not eliminate the need for N fertilizer, there would be a reduction in the amount of fertilizer N required. It was found when annual legumes such as lentil, pea and fababean were grown for their grain, the fertilizer N requirement of wheat or barley grown following them was less than that for the same yield of cereal grown on non-legume stubble. However highest yields of wheat and barley were obtained when the annual legume were used as green manures. Slinkard et al. (1987) evaluated annual legumes such as lentil, field pea, and fababean as fallow substitutes in western Canada. It was found that yield of wheat following incorporation of an annual legume as a green manure was less than wheat following fallow but higher than the yield of continuous wheat receiving N fertilization. In wet years the green manure rotation approached that of the fallow rotation. It was further found that wheat yield responses were similar for all annual legumes studied.

2.2.3 Legume Non-N Effects on Succeeding Crops

Not all studies have been able to attribute the legume benefit strictly to N effects. Baldock et al. (1981) maintain that the total effect of legumes on subsequent crop yields may be attributed to the effect on N supply and the net effect of all other contributions. Over a 10 year period they attempted to estimate the legume effect on corn yields for five various crop sequences. Succeeding corn yields were found to be increased by a previous legume, primarily due to N contributions. However, corn yields for all rotations including a legume were found to be higher than continuous corn. This increase in yield was attributed to an additional non-N legume effect. The additional non-N legume effect was found to decrease with time. Possible causes for the non-N effect were believed to be improved soil physical properties, reduced disease and phytotoxic substances, and added growth promoting substances in the legume residues. However no conclusive determinations of the additional non-N effect were made. Russelle et al.(1987) point out similar non-N effects and offer a method for estimating non-N effects. Their method is based on knowing the relationship between N accumulation and yield for a non-legume crop such as corn grown continuously. Based on this relationship corn yields are then predicted for various rotational treatments in which N accumulation was measured. Then, the difference between this predicted yield and the continuous corn treatment yield is attributed to the legume N contribution effect and serves as an estimate of the N effect. The difference between the predicted treatment yield and the actual treatment yield is interpreted as the rotation effect. In their study they estimate the non-N benefit of alfalfa grown in rotation with corn to be 38% of the total legume benefit. They found that as N supply becomes less limiting rotation effects become more relatively important. Bruulsema and Christie (1987) report plowdown yield contributions to a succeeding corn crop equivalent to 90 to 125 kg ha^{-1} of fertilizer N. This result suggests that N availability to a succeeding corn crop from green manure legume residues ranged from 65 to 71% for red clover and alfalfa respectively. They also found that corn yields were influenced by additional factors other than N supply effects from the residues. No reasons for this non-N legume effect were reported.

3 Growth Chamber Study of the Effect of Added Crop Residues on the N Status of the Soil.

3.1 Introduction

When crop materials are returned to the soil either as green manure or following harvest, they will impact the soil N status. The impact of the added residue on the soil will be a function of its composition and quantity returned. Many attempts have been made to relate the effect of added residue to its composition, mainly N content, C/N ratio and to also, %lignin content, %carbohydrates and %soluble C (Christensen 1985; Herman et al. 1977; Power et al. 1986; Reinertsen et al. 1984; Stojanovic and Broadbent 1956;).

Crop residues or freshly added plant material will, when they decompose, either contribute or immobilize soil available N. Mineralization - Immobilization of soil N because of the added plant residue will be dependent upon the nitrogen content of the added material. There exists a critical N content value, above which net mineralization of residue N will occur during decomposition, and below which net immobilization of soil N will occur.

Minimal data exists concerning the fate of legume residue derived N and added fertilizer N within the soil-plant system when both sources of N are present. The objectives of the growth chamber study were to determine what the critical crop residue N content might be for a Manitoba soil, and to determine the influence of the N content of crop residues, with and without added fertilizer N, at time of incorporation, on the contribution of nitrogen to a succeeding wheat crop. This study consisted of adding annual legume and wheat vegetative materials, of varying N contents, to a soil with and without added N, and assessing their effects on the N nutrition of a growing crop.

3.2 Method

3.2.1 Soil

The soil used was obtained from the surface 15 cm of a Willowcrest series loamy fine sand located near St.Claude MB (NE 22-8-7W), see section 5.2.1 for a detailed description of the soil type. The soil contained 0.205 percent total nitrogen and 4.23 percent organic matter. The soil was air dried and passed through a 2mm sieve.

3.2.2 Treatment and Experimental Design

A randomized complete block experiment consisting of twelve treatments and three replicates was conducted in a growth chamber.

Four lentil residues at various stages of growth and mature wheat straw were finely ground in a Willey mill prior to use. Fifty gram portions of each residue type were thoroughly mixed with 5 kg of soil. The total nitrogen and carbon contents of the residues are reported in Table 3.1; total C and N were measured by a CHN elemental analyzer. A

Table 3.1. Residue Characteristics

Residue	Growth Stage	Total %N	Total %C	C/N Ratio
Lentil	bud	3.1	39.8	13:1
Lentil	bloom	2.5	40.4	16:1
Lentil	mid-pod	2.1	40.3	17:1
Lentil	mature	0.9	41.5	46:1
Wheat	mature	0.5	41.5	83:1

control treatment of soil only was included. Two levels of N, 0 and 100 mg kg^{-1} were added to all treatments. ^{15}N labelled ammonium sulphate containing 85 atom percent ^{15}N was mixed with unlabelled ammonium sulphate and dissolved in water with intent of adding 50 atom percent ^{15}N. The ammonium sulphate was applied by spraying and mixing 100 mls of solution onto the soil. A stock solution containing phosphorous as H_3PO_4 was applied at a rate of 50 mg kg^{-1} to all treatments. Where no nitrogen was added, sulphur as H_2SO_4 was applied with the stock solution at a rate of 110 mg kg^{-1}.

The 5 kg lots of amended soil were placed in plastic pots, brought to field capacity and kept in a growth chamber at 24 C for 30 days. Pots were watered daily with distilled water to field capacity. After 30 days 8 wheat seeds (Triticum aestivum var. Columbus) were planted per pot and thinned to 4 plants after emergence. Plants were grown under a 16 hour photoperiod and day/night temperature was maintained at 22/18 C. Pots were watered daily with distilled water to field capacity. The plants were harvested 60 days after seeding. The roots were also collected by sieving while the soil was still moist, soil particles still adhering to the roots were removed by washing in distilled water. A 100 g sample of soil was also taken and air dried.

To measure the residual effect of these plant residue amendments on the soil, a second crop of wheat was grown on the treatments with no new addition of any nutrients. Once the roots of the first wheat crop were removed the soils were returned to their pots, placed in the growth chamber for another 30 days at 24 degrees celsius, and then seeded to a second crop of wheat. This second crop of wheat was grown under similar conditions as the first wheat crop, and harvested at 60 days after seeding. Roots were again removed by sieving while the soil was still moist. A sample of soil was also taken.

The roots, above-ground plant material and soil samples from both harvests were dried, finely ground and analyzed for total nitrogen and ^{15}N content.

3.2.3 N Analysis

All plant (shoot and root) and soil samples were analyzed for total NH_4^+-N, referred to as total N, by similar procedures for the macro-Kjeldahl method outlined by Bremner (1965). This involved the digestion of sample in concentrated sulphuric acid with a catalyst, followed by recovery of NH_4 by distillation with NaOH and captured in sulphuric acid mixed with an indicator. Amount of N was quantified by back titrating distillate with NaOH to the indicator end point. In preparation for ^{15}N analysis the titrated solutions were made slightly acidic by adding a few drops of sulphuric acid and concentrating NH_4^+ by evaporation to approximately 10 mls.

^{15}N analysis was carried out by converting NH_4^+ to N_2 gas with sodium hypobromite in the absence of air followed by determination of isotopic composition of the N_2 gas by the use of a Micromass 602 mass spectrometer (V.G. Micromass Ltd., Winsford England).

For the first crop plant samples, given that percent ^{15}N enrichment was above 10%, percent ^{15}N excess was calculated by using the ratio of 29/30 amu peak heights less measured background atmosphere ^{15}N abundance. For the second crop plant samples and all soil samples percent ^{15}N excess was calculated using the ratio of 28/29 amu peak heights. Isotopic analysis of added N solution indicated 48.9 $\%^{15}N$ excess.

3.3 Results and Discussion

3.3.1 Effect of Added Residues on First Wheat Crop at 60 Days

Yield of the first crop of wheat as affected by residue amendment and nitrogen treatment is shown in Table 3.2. Dry matter yield of wheat (shoot and root) was found to be significantly (p=0.05) influenced by the N content of the residue and nitrogen treatments. Under both levels of nitrogen treatment yield of wheat was higher than the control for those treatments receiving residue containing greater than 2.1 % N. This increase in yield is thought to be due to net mineralization or release of nitrogen from these high N residues during decomposition. For those treatments receiving residue containing 0.9 % or less nitrogen yield was less than half of that of the control, this decrease in yield is thought to be due to net immobilization of available nitrogen during decomposition. Addition of fertilizer N increased yields at all levels of

Table 3.2. Dry matter yield of wheat at 60 days

% N of Added Residue	Dry matter yield (g pot^{-1}) N added 0 (mg kg^{-1})	Dry matter yield (g pot^{-1}) N added 100 (mg kg^{-1})
Control	14.2 d[1]F[2]	44.9 cD
3.1	74.7 aA	73.4 aA
2.5	51.0 bC	62.5 bB
2.1	40.5 cD	60.0 bB
0.9	6.4 eG	24.9 dE
0.5	2.5 fG	16.1 eF

[1] Means followed by the same lowercase letter in each column are not significantly different at p=0.05 (Duncan's Multiple Range Test).

[2] Means followed by the same uppercase letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

added residue except for the 3.1 %N residue treatment. This lack of increase in yield for the 3.1 %N residue treatment due to fertilizer nitrogen addition would indicate maximum biological yield had been achieved.

Total nitrogen yield of the first wheat (shoot and root) crop after 60 days is reported in Table 3.3. Total N yield like dry matter yield was significantly (p=0.05) influenced by both the N content of the residue and fertilizer N treatments. For those treatments receiving residues containing greater than 2.1 %N total N yield was increased over the control, for those receiving less than 0.9 %N total N yield was decreased. Addition of fertilizer

Table 3.3. Total N yield of wheat at 60 days

% N of Added Residue	Total N yield (mg pot^{-1}) N added 0 (mg kg^{-1})	Total N yield (mg pot^{-1}) N added 100 (mg kg^{-1})
Control	131 d[1]F[2]	463 dE
3.1	780 aB	995 aA
2.5	478 bE	715 bC
2.1	364 cF	603 cD
0.9	60 eI	218 eG
0.5	18 eJ	151 fH

[1] Means followed by the same lowercase letter in each column are not significantly different at p=0.05 (Duncan's Multiple Range Test).

[2] Means followed by the same uppercase letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

N increased yields over all levels of residue addition. Even though dry matter yield was not increased by addition of fertilizer N for the 3.1 %N residue treatment, there was an increase in total N uptake by the wheat crop at this residue level.

Fertilizer N uptake (FNU) and fertilizer use efficiencies (FUE) by the first wheat crop for the added fertilizer N treatments are reported in Table 3.4. FNU by the first wheat crop was estimated by both the indirect difference and direct ^{15}N methods. Total plant FNU values by the ^{15}N method were obtained from the summation of the root FNU and shoot FNU calculated from separate ^{15}N measurements for the root and shoot. Fertilizer use efficiencies represent the percent utilization by the wheat crop of the total added fertilizer N, which was 500 mg N per pot.

Table 3.4. Effect of added crop residues on nitrogen derived from fertilizer (FNU) and fertilizer use efficiency (FUE) by the wheat crop

% N of Added Residue	^{15}N Method		Difference Method	
	FNU (mg pot^{-1})	FUE (%)	FNU (mg pot^{-1})	FUE (%)
Control	225	45	332	67
3.1	188	38	215	43
2.5	141	28	237	48
2.1	122	24	239	48
0.9	50	10	158	32
0.5	33	7	133	27

FNU values by the ^{15}N method indicate that FNU was highest for the unamended residue treatment at 225 mg pot^{-1}; FNU for the residue amended treatments was highest for 3.1 %N residue at 188 mg FNU pot^{-1} and decreased with decreasing %N in the residues to only 33 mg FNU pot^{-1} for the 0.5 %N residue. Corresponding %FUE by the treatments show that percent utilization for the fertilizer alone was 45%, adding the plant residues decreased %FUE with values ranging from 38 to 7% utilization for the 3.1 to 0.5 %N residues respectively. This result would imply that the availability of fertilizer decreased with decreasing %N content of the residue, however estimates from the difference method do not support this result.

The effect of added crop residues on FNU values calculated by the difference between the added N control and added N treatments were all found to be higher than those estimated from the ^{15}N method. FNU estimated by the difference method for the unamended residue treatment was still the highest at 332 mg pot^{-1} representing a utilization of 67%. FNU by the wheat for the residue amendments containing 2.1 or more %N were found to be similar, ranging from 215 to 239 mg pot^{-1}. This represents fertilizer utilization by the wheat of 43 to 48% for these residue amended treatments. FNU for the low N residues was 158 and 133 mg FNU pot^{-1} representing utilization of 32 and 27% by wheat for the 0.9 and 0.5 %N residue amendments respectively. This trend in FNU values estimated by the difference method suggests that the high N residues containing 2.1 or more %N acted similarly on the availability of N fertilizer. While these residue amendments reduced FUE from 67%, they released additional N thereby reducing the need for fertilizer N while still increasing total N uptake by the wheat crop (see Table 3.3). The 0.9 and 0.5 %N residues reduced FNU by the wheat through immobilization of available N during decomposition as evident by yield data (see Tables 3.2 and 3.3)

Comparisons of the N fertilizer efficiency estimates by the ^{15}N and difference methods, suggests that dilution of the ^{15}N labelled pool occurred other than by the increase in the unlabelled ^{14}N available pool due to the released N from the high N residues. This dilution effect is most likely in part due to the interchange of labelled fertilizer ^{15}N for unlabelled ^{14}N in the residues during concurrent mineralization-immobilization (Cochran et al. 1988; Jansson and Persson 1982; Tomar and Soper 1987). It is likely, however that other mechanisms were operating such as the stimulation of N mineralization from soil organic matter due to the so called "priming effect" (Jansson and Persson, 1982). Also the choice of ammonium-N versus nitrate-N fertilizer no doubt affected possible fixation by clay (Cameron and Haynes 1986; Nomimik and Vahtras 1982) or the preferential utilization of NH_4-N by the biomass (Broadbent and Tyler, 1962).

3.3.2 Critical N Content

Table 3.1 of residues characteristics shows that there was little difference in the carbon content of the residues and that the differences in C:N ratio among the residues reflects mainly the change in N content of the residues. Thus the statistically significant effect of residue treatment on the yield and total N uptake of the wheat is primarily due to the N content of the added residue. The data indicate that there is a critical level of nitrogen between 0.9 %N and 2.1 %N, where above this level net mineralization of residue N will occur, and below which immobilization of available N will occur, during residue decomposition. This range of 0.9 - 2.1 %N is consistent with values reported in literature (Christensen 1985; Haynes 1986; Smith and Peterson 1982). From Table 3.3, at the added 100 mg N kg^{-1} level, the change in quantity of N available to wheat due to additions of plant residues containing various amounts of N was calculated and is represented by Figure 3.1. A linear relationship was found to exist between the N content of the residues added and the amount of available N released or immobilized over the range of 3.1 to 0.5 %N of the added residues. The results demonstrate that if the nitrogen content of the added residue is greater than 1.5 %N there will be net

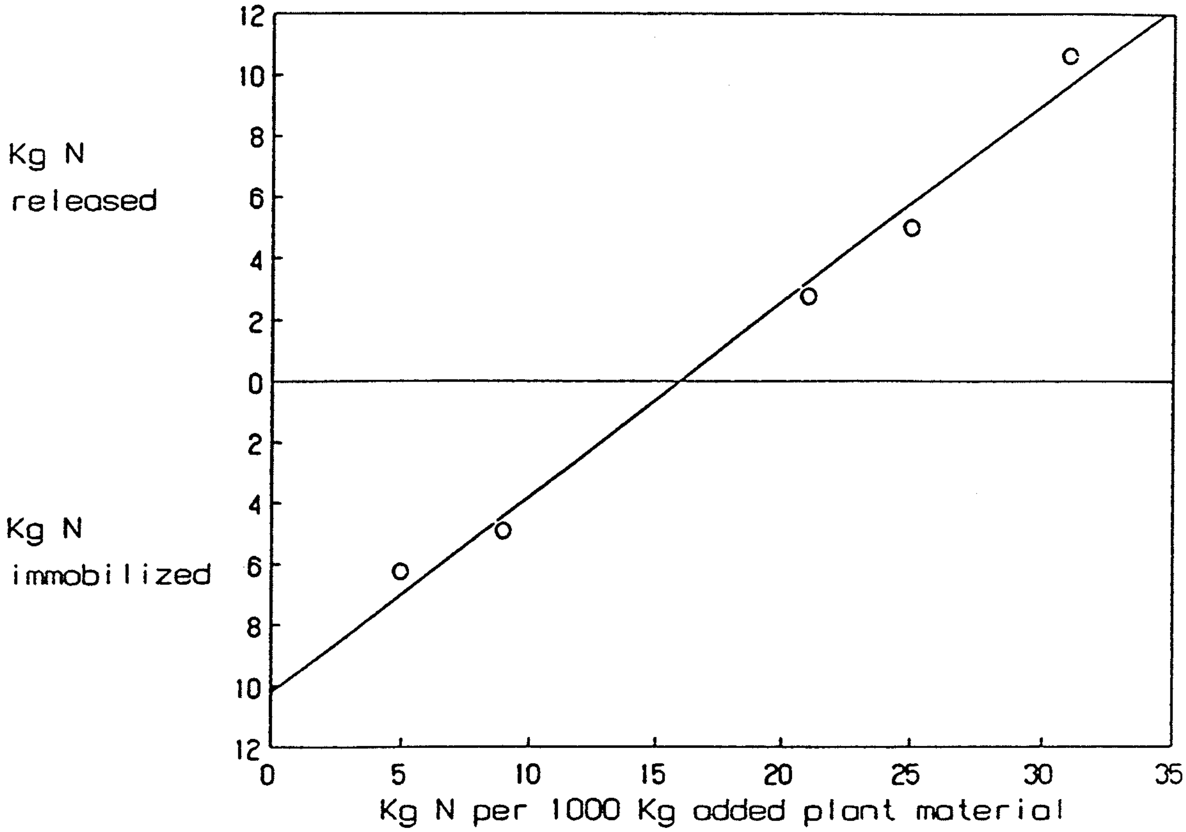

Figure 3.1. Change in quantity of N available to wheat due to additions of plant material containing various amounts of N.

mineralization of N upon decomposition; and conversely if the nitrogen content of the added residue is less than 1.5 %N there will be a net immobilization of available nitrogen. It is assumed that the 90 days the residues were allowed to decompose in the growth chamber would be similar to one year under Manitoba climate. From these data, the following equation is proposed:

Equation 3.1

$$\begin{array}{l} \text{Kg of N released or} \\ \text{immobilized from 1 Mg} \\ \text{of residue in one year} \end{array} = \begin{array}{c} \text{mass of} \\ \text{residue} \\ \text{in Mg} \end{array} \times \left(\begin{array}{l} \text{N contained} \\ \text{in 1 Mg} \\ \text{residue} \end{array} - 15 \right)$$

It is suggested that this equation may be used for crop residues such as those produced by annual legumes and cereals. Based on this equation one would then expect N availability from a residue containing 2.5% N (added at a rate of 100 mg residue kg^{-1} soil) to release an amount of available N similar to fertilizer N applied at 100 mg kg^{-1} soil. Looking at Table 3.3 one can see that this was indeed the case. Total N uptake by wheat for the 2.5 %N residue amendment and for the added N control were found to be 478 and 463 mg pot^{-1} respectively and were not significantly ($p=0.05$) different. This would then further indicate that N released from residues is equal in value to N from a fertilizer.

Estimates of nitrogen derived from the residues (NdfR), and the utilization by wheat of this source are reported in

Table 3.5. NdfR values were determined by the difference in N uptake by wheat where no fertilizer N was added for the residue amendments less the control treatment of soil only. NdfR by the wheat was 650, 348 and 233 mg NdfR pot^{-1} for the 3.1, 2.5 and 2.1 %N residues respectively. Expressed as percent utilization of the total input of N added in the residues we find that the wheat utilized 42 to 22% of the NdfR which is slightly higher than the range of 12 to 28% utilization of NdfR by cereals reported in the literature (Ladd et al. 1983; Muller and Sundam 1988; Wagger 1985). This would indicate that N derived from the residues is less available to the wheat than the added fertilizer N. If we consider the utilization of NdfR by wheat as only that portion released in excess of biomass requirements estimated from Equation 3.1, we find much higher utilization by wheat of this source of available N. Predicted N release for the

Table 3.5. Effect of added crop residues on nitrogen derived from residue (NdfR) and utilization of NdfR by wheat

% N of Added Residue	NdfR by Difference Method (mg pot^{-1})	NdfR Utilization as % of Total N Input from Residue	Predicted N Release (mg pot^{-1})	NdfR Utilization as % of Predicted N Released
3.1	650	42	800	81
2.5	348	28	500	70
2.1	233	22	300	78

3.1, 2.5, and 2.1 %N residues was 800, 500 and 300 mg pot^{-1} respectively. Percent utilization of NdfR by wheat based on the predicted N release from the residues indicates utilization varying from 70 to 81% of the NdfR, this result would suggest that N released from residues is slightly more available than N from fertilizer. This high utilization of NdfR expressed as that portion mineralized from residues has been observed in other studies (Bruulsema and Christie 1987; Wagger 1985).

Figure 3.2 illustrates what might happen to the nitrogen content of crop residues with time. Using data available from other University of Manitoba studies, we find that wheat straw can vary in N content from 0.25 to 0.8 %N and as illustrated by Figure 3.2, usually immobilizes N when it decomposes. Whereas mature annual legume straws can vary greatly in their N content and can either release N or immobilize N. Annual legumes which are harvested before maturity, such as green manures, will usually release N when they decompose. After approximately one year, it is assumed that all residues will contain the same amount of N (15 kg) per Mg of original residue and have a half-life of four years.

3.3.3 Effect on Second Wheat Crop at 60 Days

Data from the second wheat crop supports the illustration in figure 3.2. Dry matter yields of the second

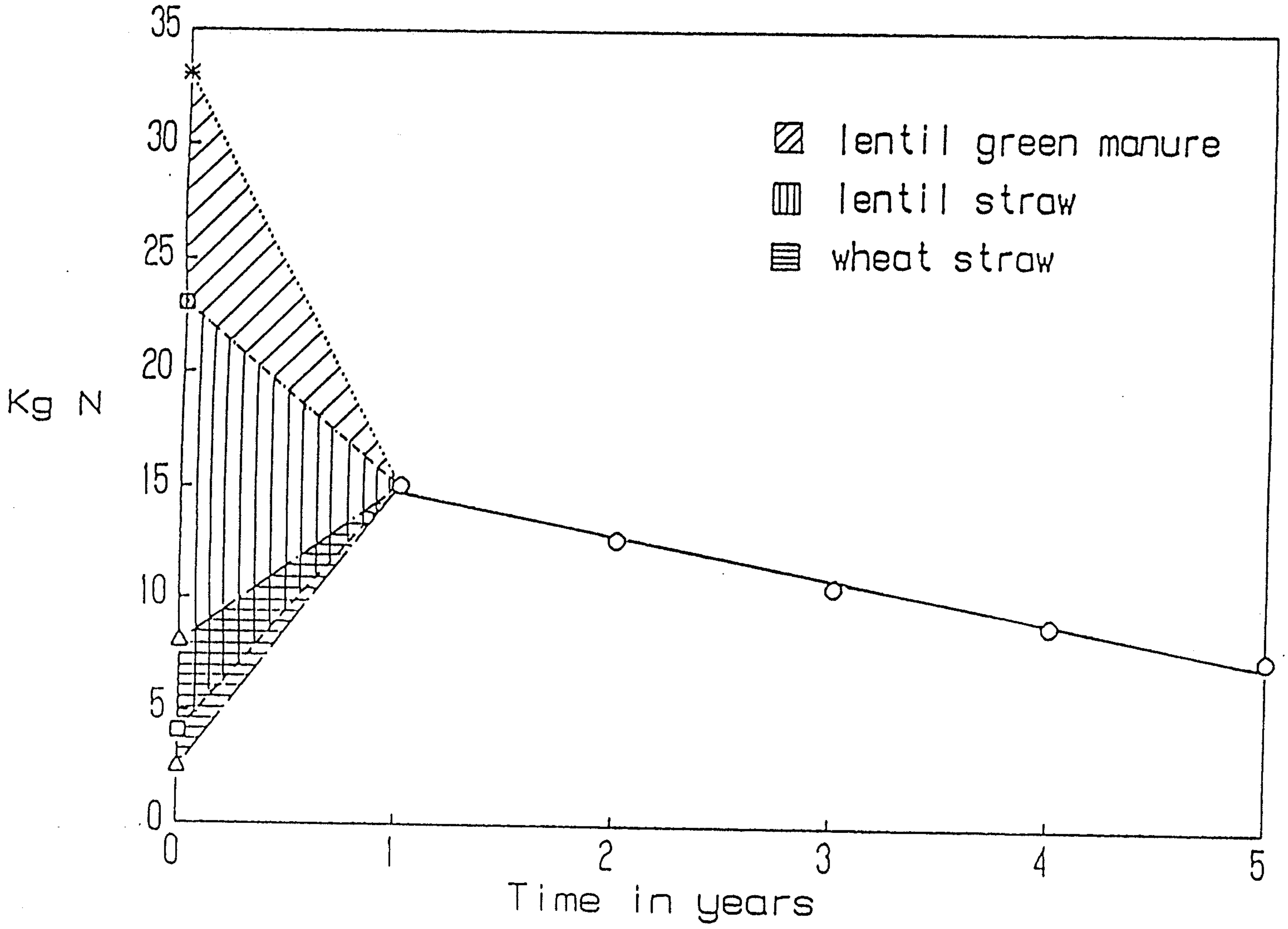

Figure 3.2. Nitrogen contained in soil from 1 Mg of added plant material with time.

wheat crop are shown in table 3.6. Yield of wheat is much lower than in the first crop due to no new addition of nitrogen. Dry matter yield of wheat is still being significantly (p=0.05) influenced by previous residue and nitrogen treatments but not to the same extent as in the first crop. Where 100 mg kg^{-1} of fertilizer N was added, the yield of the second wheat crop was not significantly (p=0.05) different among the treatments receiving crop residue amendments, but all residue treatments were nearly double those receiving no residue. These results would suggest that all the residues had decomposed to form new humus containing (15 kg N per Mg of original residue) the same amount of N regardless of initial residue content

Table 3.6. Dry matter yield of second wheat crop at 60 days

% N of Added Residue	Dry matter yield (g pot^{-1}) N added 0 (mg kg^{-1})	100 (mg kg^{-1})
Control	6.3 c[1]D[2]	7.8 bD
3.1	16.2 aA	15.3 aAB
2.5	16.1 aA	13.9 aABC
2.1	15.6 aA	14.9 aAB
0.9	11.7 bC	12.6 aBC
0.5	8.6 cD	14.3 aAB

[1] Means followed by the same lowercase letter in each column are not significantly different at p=0.05 (Duncan's Multiple Range Test).

[2] Means followed by the same uppercase letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

and are now acting the same. Thus the residues had increased the organic N pool or organic matter content thereby increasing soil fertility, hence the higher yield over the unamended soil. This effect has been observed by Smith and Peckenpaugh (1986) who found that despite a wide range in initial C:N ratios of 23 cereal straws, during decomposition all straws approached a similar point of C:N ratio of 41 after one year in the field.

Where no fertilizer nitrogen had initially been added we find no significant differences amongst the high N content residues, nor are these treatments significantly different from the residue treatments where fertilizer N was added, and as well, these treatments yielded more than double that of the unamended soil. For the low N residues, 0.9 and 0.5 %N content residues, we find that where no fertilizer N was added, the yields of wheat while higher than that of the unamended soil are still lower than the high N content residues or the residue treatments which received fertilizer N. These data would imply that during decomposition N was lacking and took longer for the residue to decompose forming a new humus (containing 15 kg N per Mg of original residue) and then began releasing N as it further decomposed. Further, since all crop residues originally contained nearly the same amount of C, it is assumed that C was not responsible for this effect.

Total N yield of the second wheat crop reflects dry matter yield (Table 3.7) and supports suggestions made about dry matter yield data. Given that total N uptake for the high N residues tended to be higher where no fertilizer N was added versus those receiving added fertilizer N, although not significantly ($p=0.05$) in all cases, would indicate that mineralization of N from the residues began slightly earlier when fertilizer N was added.

It can be concluded from second crop results that when N is not limiting decomposition, added residues increase the organic N pool during decomposition to about the same size regardless of initial N content and will act similarly during further decomposition. This is consistent with the conclusion made by Ladd et al (1981) that the main value of the legume is long term in maintaining soil organic N

Table 3.7. Total N yield of second wheat crop at 60 days

% N of Added Residue	Total N yield (mg pot^{-1}) N added 0 (mg kg^{-1})	 100 (mg kg^{-1})
Control	124 d[1]E[2]	142 cE
3.1	305 aA	279 aAB
2.5	303 aA	252 aBC
2.1	312 aA	276 aAB
0.9	229 bC	222 aC
0.5	182 cD	252 aBC

[1] Means followed by the same lowercase letter in each column are not significantly different at p=0.05 (Duncan's Multiple Range Test).

[2] Means followed by the same uppercase letter are not significantly different at p=0.05 (Duncan's Multiple Range Test).

concentrations to ensure adequate delivery to future cereal crops. In other words that fertilizer N which was initially immobilized is now being made available, as depicted by figure 3.2.

3.3.4 Effect on Total Soil N, Soil ^{15}N and Total ^{15}N Recovery from the Wheat Crops and Soil

Total soil N levels following the first and second wheat crops are reported in Tables 3.8 and 3.9 respectively. Values for treatments receiving a residue amendment were all found to be slightly higher than the controls for both levels of added N, but with little differences amongst them. It would appear that while the residue amendments had a dramatic effect as measured by plant responses, the effect on large soil N pools is less apparent. Results reported by Yaacob and Blair (1980) indicate total soil N content to be an insensitive parameter as a guide to N supplying power of soil, in comparing soils under different cropping rotations. They further emphasized the need to use ^{15}N tracer techniques wherever possible in such studies.

Effect of added residues on residual soil ^{15}N following the two wheat crops is illustrated in figure 3.3 as a function of the %N of the added residue. Immediately following the first wheat crop residual soil ^{15}N the control was found to be 94 mg pot^{-1}. The addition of the low N residues containing 0.9 or less %N increased residual soil ^{15}N by about 90 - 100 mg pot^{-1}, whereas for the residues

Table 3.8. Effect of added residues on total soil N after first crop

% N of Added Residue	Total soil N (g pot^{-1}) N added 0 (mg kg^{-1})	 100 (mg kg^{-1})
Control	10.2	9.8
3.1	10.3	10.5
2.5	10.8	10.1
2.1	10.7	10.7
0.9	10.6	10.4
0.5	10.7	10.5

Table 3.9. Effect of added residues on total soil N after second crop

% N of Added Residue	Total soil N (g pot^{-1}) N added 0 (mg kg^{-1})	 100 (mg kg^{-1})
Control	9.6	9.6
3.1	10.2	10.3
2.5	10.1	10.3
2.1	10.3	10.4
0.9	10.1	10.3
0.5	10.0	10.7

containing 2.1 or more %N, residual soil ^{15}N remained only 20 - 50 mg pot^{-1} above the control. This result is in agreement with Table 3.4 where total plant FNU was highest for the control and decreased with decreasing %N of added residue. Soil residual ^{15}N values immediately following the second wheat crop are slightly less and parallel those after the first crop. It would appear that mineralization rates

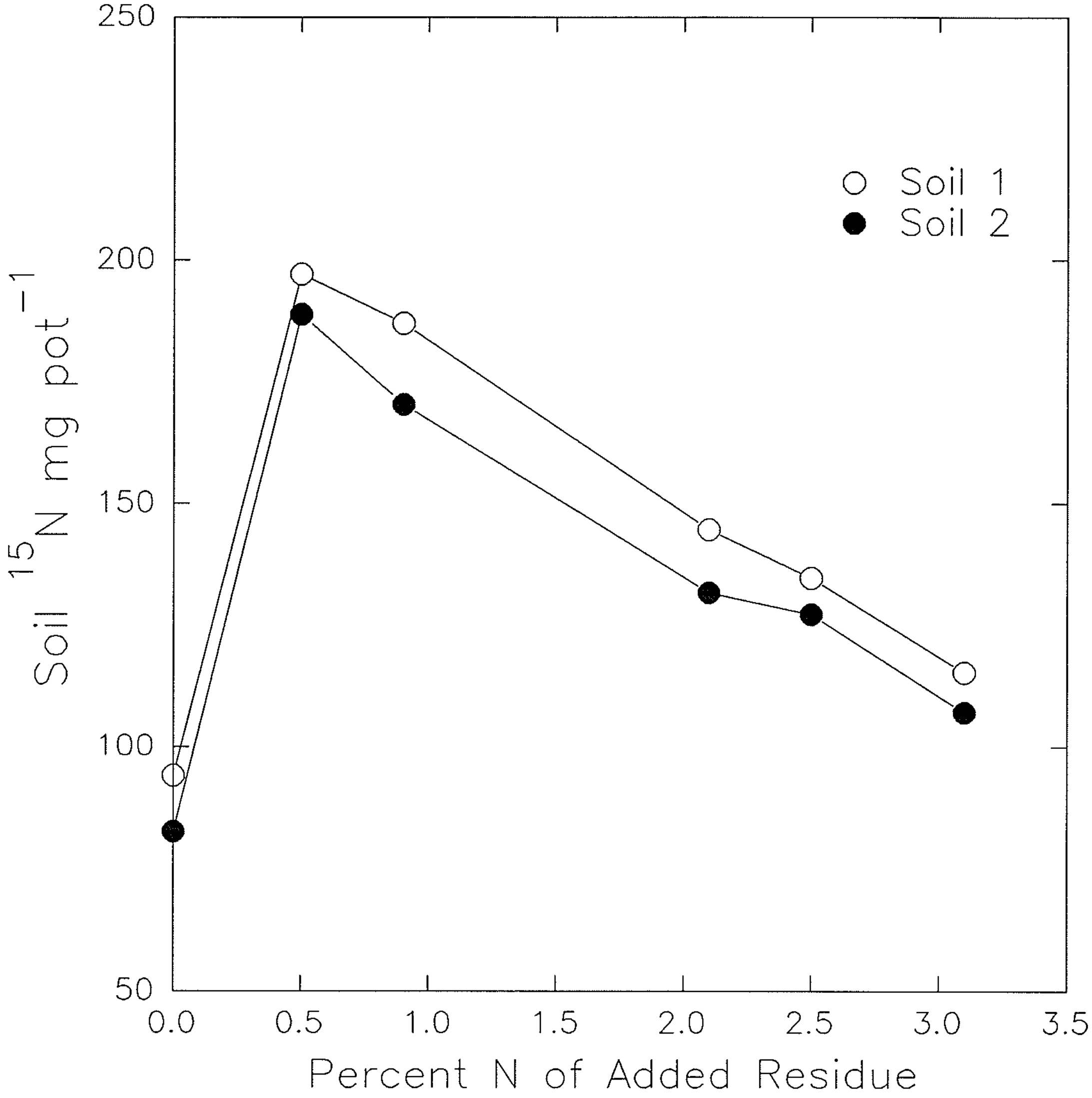

Figure 3.3. Soil residual ^{15}N (mg pot^{-1}) after first and second wheat crops as a function of the %N of the added residue

of nitrogen during the second crop were similar for all the residue amendments and while low they are higher than the control.

Total ^{15}N recovered from the two crops and the soil are shown in Table 3.10. Total ^{15}N recovered from the study is expressed as percent of original fertilizer ^{15}N initially added. Total % ^{15}N recovered for the control was 85.3%, whereas % ^{15}N recoveries were improved for those treatments receiving a residue amendment. This increase in overall recovery for soil amended with organic material has been previously observed (Broadbent and Tyler (1962); Tomar and Soper 1987). Percent ^{15}N recoveries were similar for all residue treatments and ranged from 90.0 to 94.8%. Whilefertilizer N recoveries were good there was 5 - 15% which could not be accounted for, it is thought that this was lost through volatilization of added fertilizer, however no provisions were made to detect this. Pots were watered daily with great care to maintain the soil moisture content at field capacity to minimize the potential for denitrification, however losses due to denitrification cannot be totally ruled out.

Table 3.10. Recovery of fertilizer ^{15}N in the first crop, the second crop, the final soil and overall recovery obtained during the study

% Not Added Residue	First Crop ^{15}N (mg pot^{-1})	Second Crop ^{15}N (mg pot^{-1})	Soil ^{15}N (mg pot^{-1})	Total % ^{15}N Recovered
Control	111.1	14.6	82.5	85.3
3.1	94.8	27.5	107.0	94.0
2.5	71.2	25.2	127.2	91.6
2.1	61.1	26.9	131.6	90.0
0.9	24.8	24.4	170.3	90.0
0.5	16.7	25.9	188.8	94.8

4 Field Lysimeter Studies of the N_2 Fixation of Lentil, Pea and Fababean 1986 and 1987

4.1 Introduction

Lentil, pea and to a lesser degree fababean are grown as alternative crops in rotation with cereals and oilseeds in Western Canada. These annual legumes are grown in Manitoba for seed and occasionally as green manure crops. In either case they make impact on the N status of the soil. It is generally considered that a legume does not require fertilizer N and will add fixed atmospheric N to the soil. Recent research in western Canada has shown that this may be the case when grown as a green manure, but when these annual legumes are grown for their grain yield most of this fixed N will be removed as seed with only that portion remaining in the straw and roots returned to the soil. Bailey (1986) indicates that most grain legumes fix between 50 to 70% of their total nitrogen requirements. Rennie and Dubetz (1986) found that nitrogen derived from N_2 fixation was around 80% for irrigated chickpea, lentil, fababean and pea under western Canadian environmental conditions.

As stated earlier, the impact of returned crop residue to soil will be a function of its N content and quantity returned. Little quantified data exists concerning the amount of legume residues produced (shoot and root) when grown under Canadian prairie conditions. The amounts of straw added to soil is easily determined by weighing the amounts of straw produced, however estimating the amounts of residue added to the soil from crop roots is much more difficult. Since roots are always left in the soil it is important to have information about them in order to assess the effects of crop residues on the organic matter and N status of soils and to determine N_2 fixation.

The objectives of the lysimeter studies were: a) to determine the amounts of residue (shoot and root) produced by such crops as lentil, pea, fababean and wheat; b) to determine by the ^{15}N dilution technique dinitrogen fixation by these annual legumes under Manitoba conditions; and c) to predict the effects of these crops on soil N when used as a green manure crop and for seed as compared to a wheat crop. This study consisted of growing these crops in open ended lysimeters in the field and at harvest time retrieving the lysimeters and recovering root material using a root washing technique.

4.2 Method

4.2.1 Treatment and Experimental Design

A lysimeter study was conducted at the St.Claude site in 1986 and 1987 (for a description of soil type see section 5.2.1) using Lentil (*Lens culnaris* var. Eston), Pea (*Pisum sativum* var. Century), Fababean (*Vicia faba* var. Ackerperle) and wheat (*Triticum aestivum* var. Columbus) as test crops.

The lysimeters were open ended steel cylinders measuring 30 cm in length, a diameter of 35.6 cm, and having a cross sectional area of $0.10m^2$. In spring 1986, lysimeters were arranged in 4 blocks containing 8 lysimeters in 2 rows of 4 spaced 30 cm apart. Lysimeters were sunk approximately 28 cm into the soil surface. At seeding time each crop was seeded in a block of 8 lysimeters and a border area extending 2 m around the block was also seeded to the respective crop. Although ideally lysimeters should have been randomly designated for each crop the fact that the entire lysimeter was to be removed at harvest put constraints on the design. In the spring of 1987, to improve randomization and to reduce error, lysimeters were arranged in four blocks spaced 1 m apart containing 4 sets of 2 lysimeters spaced 30 cm within the set and 1 m between the sets. At seeding time each crop was seeded in one set of lysimeters as well as a border area extending 0.5 m around the set per block.

Prior to seeding, the surface 15 cm from each lysimeter was removed and spread on a plastic sheet, all visible organic material was removed by hand picking. A solution containing an amount equal to 30 kg N ha^{-1} (labelled with 5 atom percent ^{15}N in 1986, and 10 atom percent ^{15}N in 1987) as ammonium sulphate, 50 kg P ha^{-1} as H_3PO_4, and 200 kg K ha^{-1} as KCl was sprayed onto the soil using a hand held sprayer. Following spraying of the fertilizer solution the soil was thoroughly mixed and then returned to the lysimeter and packed gently.

Following fertilizer application, in both years, 20 lentil seeds,18 pea seeds, 15 fababean seeds, and 40 wheat seeds were seeded in the respective lysimeters. Following emergence plants were thinned to 15 lentil, 9 pea, 7 fababean and 29 wheat per respective lysimeter. Prior to seeding legume seeds were inoculated with a recommended commercial inoculant at 3 times the recommended rate.

During the growing season, weeds were controlled by handpicking, crops were sprayed with a commercial insecticide to control insect damage, and during severe periods of heat stress and dryness lysimeters were watered by adding 1 - 2.5 L of distilled water per lysimeter. Total irrigation water applied was 5.6 and 4.1 cm in 1986 and 1987 respectively.

In each year two harvests, one at the mid pod stage of growth for the legumes and soft dough stage of filling for wheat, and the second at maturity were taken. At mid-pod harvest, above ground dry matter from four lysimeters for each crop was cut near the soil surface and placed in bags to dry. Lysimeters were then removed from the ground, transported back to the laboratory and submerged in water, after 24 hours lysimeters were placed on a 2mm sieve table and soil was washed from the plant roots using a gentle stream of water from a garden hose. Roots were then further washed using distilled water in sinks. A sample core 15cm diameter by 15cm deep was taken following removal of lysimeter and washed to check for any appreciable root growth below the Lysimeters. At final harvest, above ground dry matter was removed from four lysimeters as at mid-pod harvest, dried and separated by hand into straw and seed components. In 1987 at final harvest roots were also removed as at mid-pod harvest. All plant samples were dried, weighed for yield determination and finely ground for total N and %^{15}N analysis.

4.2.2 N Analysis

All plant (root, shoot and grain) samples were analyzed for total N and percent ^{15}N in the same manner as for the growth chamber samples outlined in section 3.2.3.

4.2.3 Dinitrogen Fixation Estimates

Symbiotically fixed nitrogen was estimated by the ^{15}N isotope dilution method.

4.3 Results and Discussion

4.3.1 Dry Matter Yield and N Uptake by Shoot and Root

Dry matter yield and nitrogen accumulation in the shoot and root of lentil, pea, fababean, and wheat at the mid-pod harvest for 1986 are reported in Table 4.1. Results show that there is a significant amount of dry matter produced as roots for these crops. Majority of root mass was found to be located in the upper 15cm of removed soil, most likely due to the change in physical condition and applied fertilizer. Root washing of cores taken below the lysimeters indicates that any root growth that may have occurred in this zone could not be recovered by this method and would have made a minor contribution to dry matter yield. For low residue producing crops such as lentil and pea, the root mass contained nearly 20% of accumulated nitrogen as that found in their shoots, for fababeans and wheat we find nearly 30%.

Table 4.1. Dry matter and nitrogen accumulation in the shoot and root of lentil, pea, fababean and wheat at mid-pod harvest 1986

	Dry matter yield ($kg\ ha^{-1}$)		Shoot to root	N accumulation ($kg\ ha^{-1}$)	
Crop	Shoot	Root	ratio	Shoot	Root
lentil	5380	1178	4.6	127	27
pea	6259	1605	3.9	171	29
fababean	7433	2948	2.5	202	66
wheat	7725	2037	3.8	101	30

At final harvest in 1986 root washings were not conducted, grain yield and straw yield are reported in Table 4.2. Yields for all crops except lentil were above the Manitoba provincial average. Pea and fababean produced amounts of straw similar to that produced by wheat. They removed more nitrogen as seed, yet still contained more than double the nitrogen in their straw.

Table 4.2. Yield and nitrogen accumulation in the grain and straw of lentil, pea, fababean and wheat at maturity 1986

Crop	Yield (kg ha^{-1}) Grain	Straw	N accumulation (kg ha^{-1}) Grain	Straw
lentil	1041	2610	60	52
pea	3102	3772	119	59
fababean	3528	5615	167	72
wheat	3653	4281	96	26

Dry matter yield and nitrogen accumulation for mid-pod harvest of 1987 are reported in Table 4.3. Results are similar to that of 1986, differences are most likely due to different growing weather conditions between the years. Root mass produced by all crops was higher than in 1986 except for pea. Fababean root N accumulation was still the highest at 70 kg ha^{-1} followed by wheat, lentil and pea at 54, 42 and 28 kg ha^{-1} respectively. The amount of N contained in the roots as compared to that accumulated in the shoots was higher than in 1986. Fababean, lentil and wheat roots contained 31-54% of accumulated N as that found in their shoots while pea roots contained 16%.

Yields at maturity are reported in Table 4.4. Seed yield of pea was only half of that in 1986, while lentil was higher and fababean and wheat similar to that of 1986. Root mass at maturity is lower than that at mid-pod harvest, and is most likely due to sloughing off of roots by the crops. There were losses of N and dry matter from mid-pod to final

Table 4.3. Dry matter and nitrogen accumulation in the shoot and root of lentil, pea, fababean and wheat at mid-pod harvest 1987

	Dry matter yield ($kg\ ha^{-1}$)		Shoot to root	N accumulation ($kg\ ha^{-1}$)	
Crop	Shoot	Root	ratio	Shoot	Root
lentil	5207	2029	2.6	103	42
pea	6899	1211	5.7	173	28
fababean	8318	3044	2.7	226	70
wheat	9085	4728	1.9	103	54

Table 4.4. Dry matter and nitrogen accumulation in the grain, straw and root of lentil, pea, fababean and wheat at maturity 1987

	Dry matter yield ($kg\ ha^{-1}$)			Shoot to root	N accumulation ($kg\ ha^{-1}$)		
Crop	Grain	Straw	Root	ratio	Grain	Straw	Root
lentil	1684	1970	1126	1.8	58	24	25
pea	1517	3989	634	6.3	69	48	15
fababean	2864	5085	2441	2.1	119	66	55
wheat	3480	4711	2676	1.8	80	22	31

harvest for all crops. With the exception of pea nearly as much nitrogen can be found in the roots of the legumes as in the straw. For wheat, roots contained 41% more N than did the straw. Except for lentil, about as much nitrogen can be found in the straw of the legumes than in the straw of wheat.

4.3.2 Prediction of N Contribution to Succeeding Crop

Table 4.5 gives the results from 1986, comparing yield, dry matter yield and N_2 fixation for the four crops. The dry matter or residue yield is the total of the straw yield measured at final harvest and the root yield from mid-pod harvest. Dinitrogen fixation was highest for fababean and lowest for lentil. The nitrogen removed as seed (from Table 4.2) was in all cases greater than the dinitrogen which was fixed, which means that the soil had a net loss in total nitrogen. From these data and the proposed Equation 3.1, an attempt was made to predict the amount of N which would be released or immobilized in the next year from each crop. At the early harvest (mid-pod), all legumes would release considerable quantities of N with fababeans being the best. If wheat were to be incorporated at this stage of growth, it would immobilize some available soil N. The results would be considerably different if the crops were harvested at

Table 4.5. Predicted N release from annual legume crops - 1986

Crop	Yield ($kg\ ha^{-1}$)	Residue ($kg\ ha^{-1}$)	N_2 fixed ($kg\ ha^{-1}$)	Predicted N release ($kg\ ha^{-1}$) Mid-pod	Predicted N release ($kg\ ha^{-1}$) Maturity
lentil	1353	3788	31	57	25
pea	2528	5377	61	84	0
fababean	3102	8563	123	113	-19
wheat	3653	6318		-16	-57

maturity and the seed removed. Calculations at final harvest indicate that the annual legumes would either release or tie up small amounts of available N while wheat would immobilize considerable N. On average, the calculated difference between the annual legumes and the wheat crop is 59 kg N ha^{-1}.

Table 4.6 gives the results of 1987, comparing yield, dry matter or residue yield, and dinitrogen fixation for 1987. Results are similar to those obtained in 1986. Dinitrogen fixation in 1987 was highest for fababean and lowest for lentil. Calculations of nitrogen released in the next year by these crops indicate that at the early harvest the annual legumes would release considerable quantities of N with fababean being the best. If wheat were to be incorporated at this early harvest it would immobilize a large amount of N. At final harvest, the annual legumes would release or immobilize small amounts of N, while the wheat crop would immobilize considerable N. On average the calculated difference between the annual legumes and the wheat crop is 59 kg N ha^{-1}.

Results from both 1986 and 1987 (table 4.5 and 4.6) suggest that when annual legumes are grown as green manure crops, considerable amounts of N will be returned to the soil and substantially reduce the need, if any, for N fertilizer to succeeding non-legume crops. The amount of N released as green manure crops ranged from 39 to 128 kg N

Table 4.6. Predicted N release from annual legume crops - 1987

Crop	Yield (kg ha^{-1})	Residue (kg ha^{-1})	N_2 fixed (kg ha^{-1})	Predicted N release (kg ha^{-1}) Mid-pod	Maturity
lentil	1684	3096	20	39	2.3
pea	1517	4623	70	80	-7.1
fababean	2864	7326	143	128	9.1
wheat	3480	7387		-48	-58.0

ha^{-1} over the 2 years, this range is in agreement with estimates of N released from winter legume cover crops to succeeding corn (Bruulsema and Christie 1987, Ebelhar 1984, Mitchell and Teel 1977). The data further indicate that when grown for their seed yield, annual legumes will either release or tie up only small amounts of N. This result implies that non-legumes would require 59 kg ha^{-1} less fertilizer N following annual legume stubble than following wheat stubble. This requirement for less fertilizer N following an annual legume crop is not due to released nitrogen but due in most part to the lack of immobilization of soil N as compared to following a cereal crop such as wheat. It is apparent that when annual legumes such as lentil, pea, or fababean, regardless of dinitogen fixation capability, are grown for their seed there will be little difference between them in their effect on the available N status of the soil in the next year.

5 A Field Study of the Effect of Annual Legumes on a Succeeding Wheat Crop

5.1 Introduction

In North America legume crops grown as cover crops or in rotation have been shown to benefit a succeeding corn crop, with the residual benefit being related to N (Fox and Piekielek 1988, Ebelhar et al. 1984, Mitchell and Teel 1977) or related to N and non-N effects (Baldock et al. 1981, Bruulsema and Christie 1987). Similar effects on succeeding cereal crops have been reported in Australia (Ladd et al. 1981). In western Canada quantitative data relating an annual legume effect on succeeding cereal crops, in terms of fertilizer equivalence, is lacking. In Manitoba, soil N tests based on soil nitrate-N do not make allowances for the effects of legume stubble fields. Data reported out of Brandon MB by Bailey (1986) indicate a reduction in need for fertilizer N by subsequent barley on fababean stubble and wheat on lentil stubble. A study conducted near Morden MB, (see appendix 1) showed that annual legumes did not seem to have a significant effect on the soil nitrate-N analysis. This study, did however find that subsequent wheat yields, and the amount of fertilizer N needed for maximum yields were appreciably altered. Field studies were initiated in 1985 to investigate the effect on a wheat crop grown on annual legume stubble.

The objectives of the field studies were: a) to study the effects of such annual legumes as lentil, pea, fababean compared to a non-legume such as wheat on the available N status of the soil, and b) to determine the contribution of previous crops, in terms of fertilizer N, to a subsequent wheat crop.

5.2 Method

5.2.1 Sites

Experimental sites for field studies were established in the spring of 1985 at two locations in Manitoba. One site, designated St. Claude, was established near St. Claude (NE 22-8-7W) on a soil of the Willowcrest Series which is classified as a Gleyed Black Chernozem in the Canadian system of soil classification. According to the Manitoba Soil Survey data base (1987) soils of the Willowcrest series are imperfectly drained and have developed on weakly to moderately calcareous, deep, uniform, sandy lacustrine deposits. Typically, Willowcrest soils occur in the middle positions of the undulating landscape. These soils have moderately rapid permeability.

A second site, designated Haywood, was established near Haywood (Sw 25-8-6W) on an Almasippi series, which is classified as a Gleyed Rego Black Chernozem, carbonated phase, in the Canadian system of soil classification. According to the Manitoba soil survey database (1987), soils of the Almasippi series are imperfectly drained and have developed on moderately calcareous, uniform sandy lacustrine sediments over a lacustrine clay substrate usually within 3 meters of the surface which impedes downward water movement. Typically, Almasippi soils occur in the middle to lower slope position of level to very gentle slopes of the undulating landscape. They possess rapid permeability, moderately slow surface runoff, and a high water table during the growing season.

5.2.2 Treatment and Experimental Design

A two year experiment using a split-plot randomized complete block design was conducted at each site to investigate the residual effect of various annual legumes on the soil system. Three annual legumes, lentil, pea, and fababean as well as wheat unfertilized and fertilized with 100 kg N ha^{-1}, were used as main plot treatments in year one of the study. Mainplot treatments were 8 m by 8 m. In year two of the study, mainplot treatments were subdivided into five subplots 1.6 m by 8 m, and received subplot treatments of 0, 25, 50, 75, and 100 kg N ha^{-1}. All subplot treatments were seeded to wheat. Response to nitrogen treatment by wheat as affected by the previous crop (main plot treatments) was measured by assessing dry matter yield and total N uptake.

In the spring of 1985 prior to seeding, basal applications of 100 kg P ha^{-1} as 0-46-0, and 200 kg K ha^{-1} as 0-0-60 were handbroadcast on all mainplots. Mainplot treatments of fertilized wheat received 100 kg N ha^{-1} as 34-0-0 hand broadcast prior to seeding. After broadcast fertilizer applications were complete the entire plot was rototilled to a depth of 15cm to incorporate fertilizer into the soil. Following fertilizer application mainplot crop treatments were seeded at rates of 50 kg ha^{-1} for lentil, 200 kg ha^{-1} for pea and fababean, and 100 kg ha^{-1} for Wheat. Prior to seeding legume seeds were inoculated with an appropriate commercial inoculant. At time of seeding P at 17 kg ha^{-1} as 0-46-0, and K at 33 kg ha^{-1} as 0-0-60 was placed with the seed.

At maturity all crops were harvested and crop residues were incorporated into their respective mainplots after seed harvest.

In the spring of 1986, mainplot treatments were divided into five subplots and recieved either 0, 25, 50, 75, or 100 kg N ha^{-1} as urea handbroadcasted. Following subplot nitrogen treatments, the entire plot was rototilled and wheat (var Columbus) at 100 kg ha^{-1} was seeded over all subplot treatments. P at 17 kg ha^{-1} as 0-46-0, and 33 kg K ha^{-1} as 0-0-60 was placed with the seed at time of seeding. Weed control during the growing season was achieved through the use of commercially recommended herbicides.

During the growing season three harvests of 1 m^2 of above ground dry matter were taken from each subplot. The first harvest was taken when the wheat crop was 50% headed, the second was taken at the soft dough stage of filling and the final harvest was taken at maturity. Plant samples were dried, with the final harvest separated into seed and straw components. All samples were weighed for yield determination and finely ground for nutrient analysis.

Soil samples to 120 cm were taken in the spring of 1985 and 1986 prior to seeding, and late fall of 1985 to measure effect on soil nitrate-N levels.

5.2.3 N analysis

Total nitrogen content of plant material (shoot and seed) was determined by a modified Kjeldahl-Gunning method as described by Jackson (1958). Samples were digested in a aluminum block digester and nitrogen content was determined using a Tecator Kjeltec Auto 1030 Analyzer.

Soil nitrate nitrogen for the soil samples was determined by the method described by Kamphake et al. (1967).

5.3 Results and Discussion

5.3.1 Effect of Previous Annual Legumes on a Succeeding Wheat Crop at the St.Claude Site

Final grain yield of wheat as affected by the previous crop at the St.Claude site is reported in Table 5.1 and illustrated in Figure 5.1. Statistical analysis of variance did not show significant (p=0.05) differences due to mainplot effects over all subplot levels of added N.

Table 5.1. Grain yield (kg ha^{-1}) as affected by the addition of N and previous crop at the St. Claude site

	N added kg ha^{-1}					
Previous Crop	0	25	50	75	100	Mainplot
wheat	1929	2353	3119	3347	2878	A[1]
wheat 100 N	2120	3028	3177	3189	2941	A
fababean	2309	3014	3036	3114	2695	A
lentil	2206	2914	2950	3066	2697	A
pea	2642	2808	2953	3074	2858	A
subplot	c[2]	b	ab	a	b	

[1] Means of previous crop followed by same upper case letter within the same rate of added N are not significantly different at p=0.05 (Duncan's Multiple Range Test).

[2] Means of added N followed by same lowercase letter within a previous crop are not significantly different at p=0.05 (Duncan's Multiple Range Test).

Differences among subplot treatments within a mainplot treatment were found to be significantly (p=0.05) different when increasing from 0 to 75 added kg N ha^{-1}. There was no significant (p=0.05) interaction between previous crop mainplot effects and added N subplot effects indicating thatresponse in yield due to added N by wheat was similar for each previous crop treatment. Yield of wheat was found to be significantly lower at 100 kg ha^{-1} added N compared to the 75 kg ha^{-1} added N treatments. No noticeable effect due to lodging, weed control, or disease incidence, during the growing season can account for this yield decrease.

Despite no significant differences among previous crops, where no subplot fertilizer N was added, mainplot

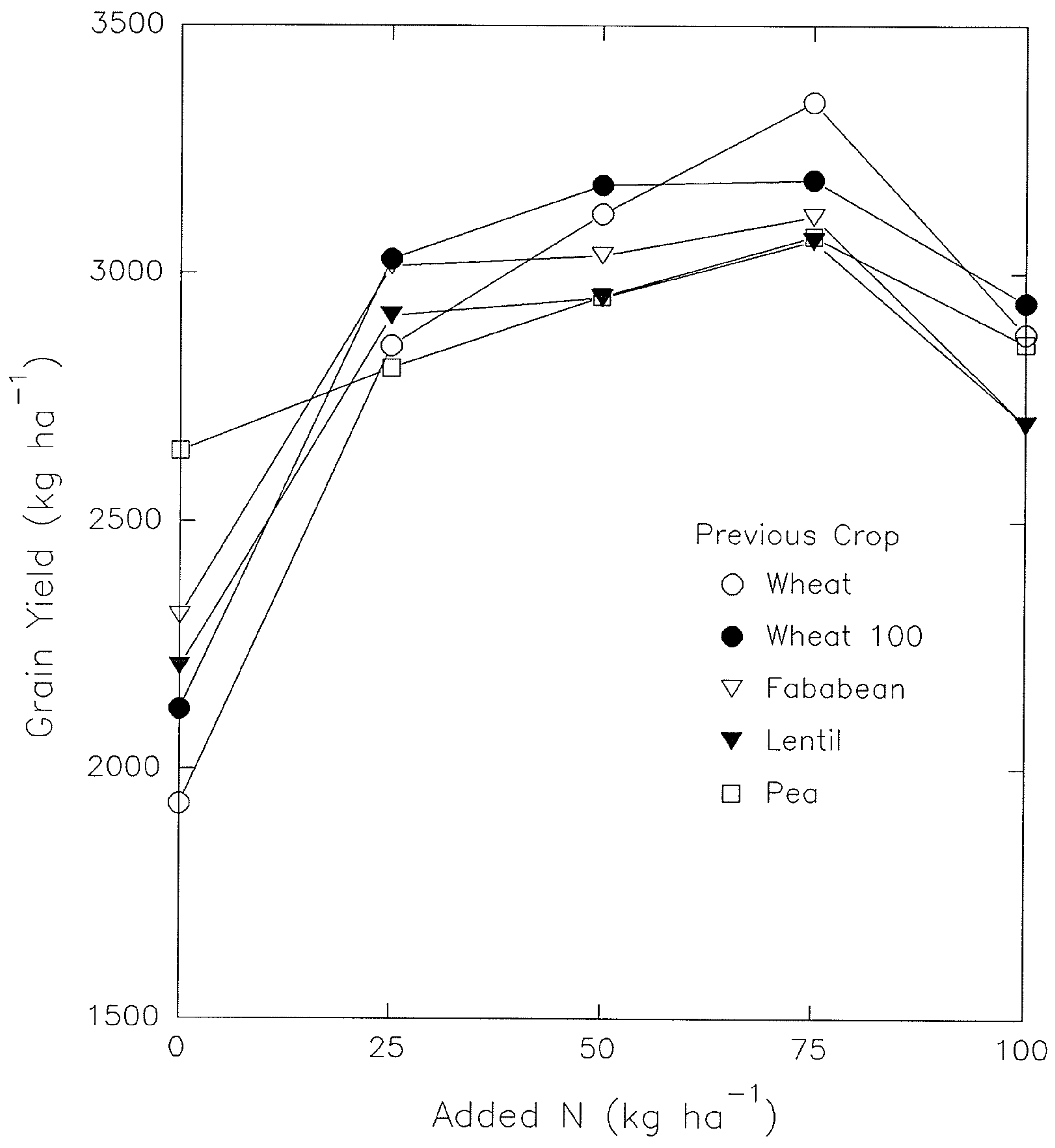

Figure 5.1. Grain yield of wheat as affected by the addition of N and previous crop at the St. Claude site

legume treatments were found to be higher than the two wheattreatments. Wheat yields, at the 25 kg ha^{-1} added N level, were similar for mainplot legume and fertilized wheat treatments, with yields ranging from 2808 to 3028 kg ha^{-1} and were found to be higher than the mainplot treatment of unfertilized wheat at 2353 kg ha^{-1}. When subplots received 50 kg added N ha^{-1} or more, there was no appreciable differences due to previous crop treatment. It appears that the addition of fertilizer N could make up for differences in grain yield due to a previous crop.

Total N uptake by the wheat crop measured at the mid-heading and soft-dough harvests are reported in Tables 5.2 and 5.3 respectively. Results indicate similar trends to those already noted as measured by final grain yields. While total N uptake increased from mid-heading to soft-dough harvest, differences in N uptake due to previous crops were already noticeable at mid-heading. This indicates that for the most part the effect of the added residues on available N had already occurred. Differences in percent nitrogen accumulated in the grain of the subsequent wheat crop due to either previous crop mainplot treatments or subplot added N treatments were small. Overall all subplots %N in the wheat grain varied only 2.7 to 3.1 %N, hence any differences in total N accumulated in the grain were found to be similar to those observed in grain yield (Table 5.4).

Table 5.2. Total N uptake (kg ha^{-1}) at mid heading harvest as affected by the addition of N and previous crop at the St. Claude site

	N added kg ha^{-1}				
Previous Crop	0	25	50	75	100
wheat	52	59	80	83	93
wheat 100 N	44	65	73	91	102
fababean	61	82	80	101	114
lentil	58	74	90	96	111
pea	70	73	91	98	97

Table 5.3. Total N uptake (kg ha^{-1}) at soft-dough harvest as affected by the addition of N and previous crop at the St. Claude site

	N added kg ha^{-1}				
Previous Crop	0	25	50	75	100
wheat	58	62	89	101	111
wheat 100 N	61	81	90	100	103
fababean	67	80	91	110	111
lentil	83	93	89	109	124
pea	85	96	96	115	96

Table 5.4. Total N (kg ha^{-1}) in the grain at final harvest as affected by the addition of N and previous crop at the St. Claude site

	N added kg ha^{-1}				
Previous Crop	0	25	50	75	100
wheat	53	67	86	97	81
wheat 100 N	60	86	94	89	88
fababean	63	83	89	93	82
lentil	63	87	84	93	84
pea	77	76	87	86	81

5.3.2 Effect of Previous Annual Legumes on a Succeeding Wheat Crop at the Haywood site

Final grain yield of wheat as affected by previous crop at the Haywood site are reported in Table 5.5 and illustrated in Figure 5.2. Statistical analysis of variance indicates significant (p=0.05) differences due to mainplot previous crop treatments, significant (p=0.05) differences due to subplot added N within a mainplot, and no significant interaction between mainplot and subplot effects. Use of Duncan's Multiple Range test for comparing means indicates that response in grain yield by wheat did not differ significantly amongst the legume mainplot treatments and amongst the two wheat mainplot treatments. It was found

Table 5.5. Grain yield (kg ha^{-1}) as affected by the addition of N and previous crop at the Haywood site

	N added kg ha^{-1}					
Previous Crop	0	25	50	75	100	Mainplot
wheat	1554	2308	2317	2639	2841	B[1]
wheat 100 N	1224	2009	2362	2486	2617	B
fababean	1865	2856	3055	3391	3033	A
lentil	2153	2553	3291	3266	3152	A
pea	2042	2739	3064	3277	3316	A
subplot	c[2]	b	a	a	a	

[1] Means of previous crop followed by same uppercase letter within the same rate of added N are not significantly different at p=0.05 (Duncan's Multiple Range Test).

[2] Means of added N followed by same lowercase letter within a previous crop are not significantly different at p=0.05 (Duncan's Multiple Range Test).

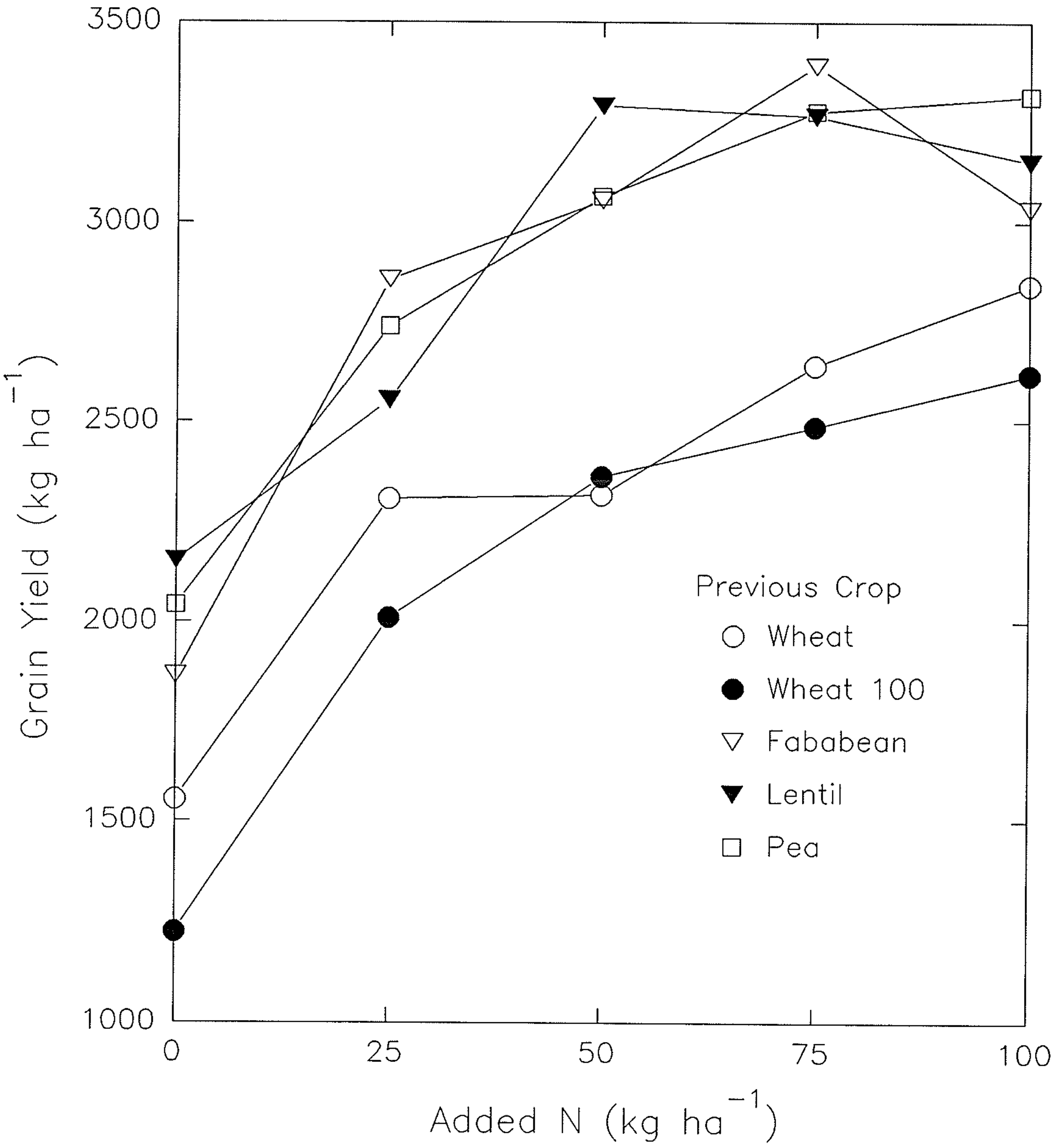

Figure 5.2. Grain yield of wheat as affected by the addition of N and previous crop at the Haywood site

that the grain yield as affected by previous legume crops to be significantly ($p=0.05$) higher than that following the two wheat crops. Similar to results at St.Claude no significant ($p=0.05$) response in wheat yield to added N above 50 kg ha^{-1}. was found.

Wheat following wheat required 75 kg ha^{-1} of fertilizer N to give a yield similar to that requiring 25 kg ha^{-1} following a legume. Since grain yields of wheat following a legume remained higher than those following wheat over all levels of added N, it would appear that there was a beneficial effect due to the previous crop of legumes which could not be overcome by adding fertilizer N. Recent work evaluating N contribution of alfalfa to a succeeding corn crop by Baldock et al. (1981) and Bruulsema and Christie (1987) concluded that a portion of the contribution could not be related to N.

Total N uptake by the wheat crop measured at the mid-heading and soft-dough harvests are reported in Table 5.6 and 5.7 respectively. Results indicate similar trends to that already noted as measured by final grain yields. Similar to St.Claude, the effect of previous crop on total N uptake were observed at mid-heading indicating that differences in available N due to added crop residues had already occurred. Differences in percent nitrogen accumulated in the grain of succeeding wheat crop due to either previous crop mainplot treatments or subplot added N treatments were small. Overall all subplots %N in the wheat grain varied from 2.3 to 2.6 %N, hence any differences in total N accumulated in the grain would be similar to those observed in grain yield (Table 5.8).

Table 5.6. Total N uptake (kg ha^{-1}) at mid heading harvest as affected by the addition of N and previous crop at the Haywood site

	N added kg ha^{-1}				
Previous Crop	0	25	50	75	100
wheat	31	39	49	65	65
wheat 100 N	37	46	56	58	68
fababean	48	61	62	81	87
lentil	49	71	89	83	75
pea	39	51	71	64	92

Table 5.7. Total N uptake (kg ha^{-1}) at soft-dough harvest as affected by the addition of N and previous crop at the Haywood site

	N added kg ha^{-1}				
Previous Crop	0	25	50	75	100
wheat	45	65	73	78	89
wheat 100 N	41	59	73	73	89
fababean	56	71	74	105	113
lentil	67	73	96	94	106
pea	49	72	89	93	99

Table 5.8. Total N (kg ha^{-1}) in the grain at final harvest as affected by the addition of N and previous crop at the Haywood site

	N added kg ha^{-1}				
Previous Crop	0	25	50	75	100
wheat	36	52	54	61	67
wheat 100 N	29	48	56	57	63
fababean	46	65	72	79	74
lentil	53	62	81	81	82
pea	51	66	75	80	85

5.3.3 Mean Effect for Three Sites

A third study, with the same treatments as the St.Claude and Haywood studies, had been conducted earlier in 1984 and 1985 by Sawatsky and Soper (1985). This study had been conducted near Morden Manitoba, on soil of the Altona series which is classified as an Orthic Black Chernozem in the Canadian system of soil classification. Results from this study are reported in Appendix 1. Final grain yield as affected by previous crops at the Morden site was found to be similar to that observed at the St.Claude and Haywood sites. Data from St.Claude, Haywood and Morden were combined to determine the mean effect due to the previous crop.

Table 5.9 reports the effect of the previous crop on mean grain yields of wheat as an average of the three sites. The yields of wheat following annual legumes are higher than those following wheat even when wheat has been previously

Table 5.9. Grain yield as affected by the addition of N and previous crop as an average of the three sites

	N added kg ha^{-1}					
Previous Crop	0	25	50	75	100	Mainplot
wheat	1824	2231	2769	2944	2900	B[1]
wheat 100 N	1863	2618	2738	2910	2826	B
fababean	2293	3000	3140	3203	3025	A
lentil	2353	2816	3143	3254	3047	A
pea	2490	2919	3023	3206	3111	A
subplot	d[2]	c	b	a	ab	

[1] Means of previous crop followed by same uppercase letter within the same rate of added N are not significantly different at p=0.05 (Duncan's Multiple Range Test).

[2] Means of added N followed by same lowercase letter within a previous crop are not significantly different at p=0.05 (Duncan's Multiple Range Test).

fertilized with adequate nitrogen. Nitrogen at 75 kg ha^{-1} was enough to overcome N deficiencies for all sequences (Figure 5.3). Statistical analysis of variance indicates significant (p=0.05) mainplot effects, significant (p=0.05) subplot effects within mainplots, and no significant (p=0.05) interaction between mainplots and subplot effects. Comparison of mean previous crop effect (Duncan's Multiple range test) shows no significant (p=0.05) difference in yield of wheat amongst the different legume crop treatments, or amongst the wheat treatments, but indicates significant (p=0.05) differences between legume treatments and wheat

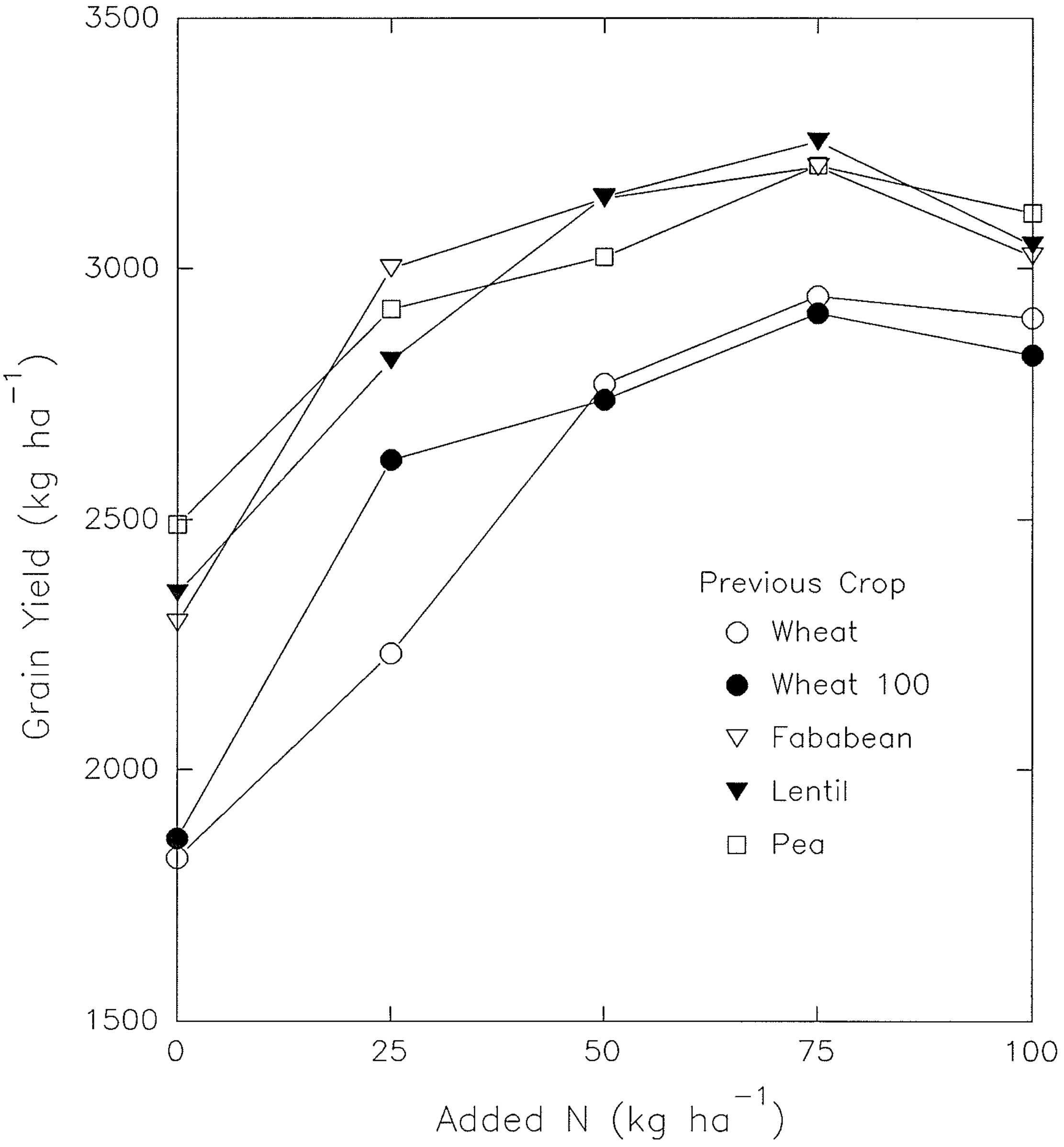

Figure 5.3. Grain yield of wheat as affected by the addition of N and previous crop (average of three sites)

treatments, over all subplot levels of added N. That is to say:

Lentil = Pea = Fababean > Wheat = Wheat with N

Since there was no significant ($p=0.05$) effects amongst legumes or amongst wheat, yields were averaged to determine the effect due to a previous annual legume crop as compared to a previous wheat crop. Mean yield of wheat ranged from 2293 to 3254 kg ha^{-1} and 1824 to 2900 kg ha^{-1} following annual legumes and wheat respectively (Figure 5.4). Results illustrated in Figure 5.4 indicate that nitrogen applied at 25 kg ha^{-1} to wheat following an annual legume gave a yield comparable to 75 kg ha^{-1} to that following wheat. This seems to confirm results of lysimeter experiments (Tables 4.5 and 4.6) that there is an approximately 50 kg saving of fertilizer N if an annual legume is in rotation. A previous annual legume crop did not eliminate the total need for additional N fertilization to reach a maximum yield of the subsequent wheat crop.

According to Figure 5.4 the initial difference in yields of a subsequent wheat crop due to a previous legume or wheat crop decreased as added fertilizer N increased. However the annual legumes had a beneficial effect on the subsequent wheat crop which could not be related to added fertilizer N. No doubt there are many reasons for this finding, none of which was assessed.

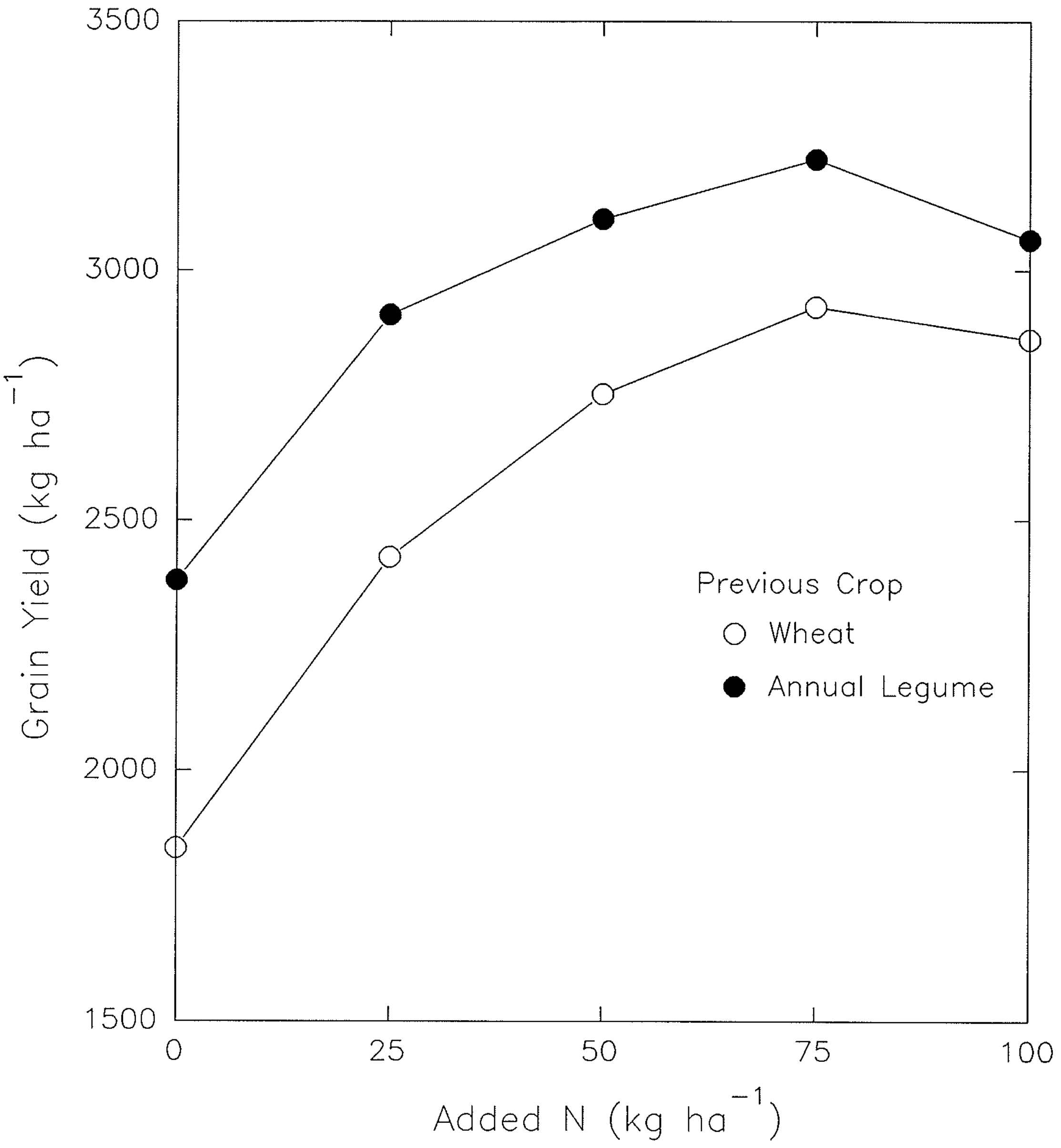

Figure 5.4. Mean grain yield of wheat as affected by addition of N and previous legume or wheat crop (an average of three sites)

It can be concluded from this study that when lentil, pea, and fababean are grown for their seed, there is little difference amongst them in their effect on the N nutrition of a subsequent wheat crop. They are however found to contribute more to N nutrition than a preceding wheat crop. This is consistent with results found in the lysimeter studies where the increase in available N following annual legumes appears to be mainly due to less immobilization of N upon decomposition of the legume residues versus wheat residue. This effect due to the annual legumes is the same regardless of their N_2 fixation capabilities.

5.3.4 Effect of a Preceding Annual Legume Crop on Soil Nitrate-N Levels

In addition to studying the effect of annual legumes on the N status of soil, this study affords the opportunity to consider the validity of the soil nitrate test to predict nitrogen fertilizer requirements, given various types of crop residue. It was observed in the previous Morden study site (Appendix Table 1a) that the type of crop residue did not affect the soil nitrate test, but that wheat yields in the following year and the amount of nitrogen fertilizer needed for maximum yield were significantly altered. Soil analyses taken at St.Claude (Table 5.10) reveal that there was no significant ($p=0.05$) differences in soil nitrate-N to 60 cm at any given sampling time. Soil nitrate-N levels in the spring following annual legume crops tended to be higher than those of wheat but this was not found to be statistically significant. Fertilizer recommendations based on these data would not be different among the legumes and the wheat at any time sampled. Soil analyses taken at Haywood (Table 5.11) showed similar results to that at St.Claude. With the exception of Wheat May 85 and Wheat fertilized October 85 samples there were no significant ($p=0.05$) differences in soil nitrate-N between legumes and wheat at any given sampling time.

It is evident from the yield data (Table 5.9) that fertilizer N recommendations based on the nitrate test would not need adjustment for previous crops as 75 kg ha^{-1} added fertilizer N provided maximum yields in all cropping sequences. Adjustments in fertilizer recommendations could be made if a particular target yield was desired. The fact that there was little difference in spring soil nitrate-N levels, and the N nutrition of the wheat was affected prior to mid heading harvest, would suggest that immobilization of available soil N by the decomposing crop residues began sometime during this period. This would further suggest that when annual legumes are used as green manure crops in mid summer, soil nitrate tests taken that late fall or early spring of the following year should be able to measure part of the effect due to previous residue addition.

Table 5.10. Soil nitrate -N (kg ha^{-1}), sampled to a depth of 60 cm, as affected by previous crop at the St. Claude site (1985-1986)

	Sampling date			
Previous crop	May 85	Sept 85	Oct 85	May 86
wheat	50	40	51	31
wheat 100 N	57	37	54	25
fababean	57	33	40	36
lentil	53	41	48	38
pea	61	34	54	31

Table 5.11. Soil nitrate -N (kg ha^{-1}), sampled to a depth of 60 cm, as affected by previous crop at the Haywood site (1985-1986)

	Sampling date			
Previous crop	May 85	Sept 85	Oct 85	May 86
wheat	15*	32	25	19
wheat 100 N	20	35	17*	25
fababean	24	37	22	26
lentil	26	41	33	29
pea	29	37	28	27

*Indicates significantly lower within sampling date at $p=0.05$.

6. Summary and Conclusions

Annual legumes such as lentil, pea, and fababean are grown as alternative crops in rotation with cereals and oilseeds in western Canada. This project focused on investigating the effects of these annual legumes as compared to wheat on the nitrogen status of soil and the nitrogen nutrition of subsequent crops. Studies evaluating these effects were conducted in a growth chamber, field lysimeters and in the field.

The effect of added crop residues on available soil N is a function of their yield and N contents. Results from the growth chamber study indicate a linear relationship between the amount of available N released or immobilized and the N content of added crop residue, over the residue nitrogen content range of 0.5 to 3.1 %N. It can be concluded from this study that if the nitrogen content of the added residue is greater than 1.5 %N there will be a net mineralization of N upon decomposition; and conversely if the nitrogen content of the added residue is less than 1.5 %N there will be a net immobilization of available nitrogen. This critical N content value of 1.5 %N is in agreement with values reported in the literature (Christensen 1985; Haynes 1986; Smith and Peterson 1982). It is also evident from the data that the N released from the high N content residues is similar in availability to N from $(NH_4)_2SO_4$. Percent utilization of nitrogen derived from residues (NdfR) expressed as a percentage of the N released ranged from 70 to 81% for the residues containing 2.1 or more %N. This result is similar to percent utilization of NdfR observed in other studies (Bruulsema and Christie 1987; Wagger 1985).

The results of the first wheat crop in the growth chamber study help to explain the effects of added crop residues on the N status of the soil. The data suggest that any residue added to the soil, will decompose in the short term to form a new humus containing the same amount of N (15 kg N per Mg of original residue) regardless of initial N content. In the long term all added crop residues will increase the soil organic N pool to the same degree and act the same after initial decomposition. This effect of added residues has been observed in other studies (Christensen 1985; Smith and Peckenpaugh 1986) and is supported by data from the second growth chamber wheat crop. Yield and N accumulation for the second wheat crop indicate little difference among those treatments receiving added residue; all were higher than the unamended checks. It can be concluded from the second wheat crop results that when N is not limiting decomposition, added residues increase the organic N pool to about the same size regardless of initial N content and will act similarly during further decomposition.

An important factor affecting the nitrogen status of soil is the amount and composition of organic residues added annually. Minimal data exist regarding the amounts of residue added to the soil via a legume crop root system. It is generally considered that a legume does not require fertilizer N and will add fixed atmospheric N to the soil. However when annual legumes are grown for their grain yield most of the fixed N will be removed in the seed and only that portion of the N remaining in the straw and roots will be returned to the soil. Studies were conducted in lysimeters in order to quantify the amounts and composition of residues as well as N_2 fixation by lentil, pea and fababean under Manitoba conditions.

Results from both lysimeter experiments showed that there is an appreciable amount of dry matter produced as roots by the legume crops. The roots of the legumes at the mid pod harvest contained from 16 to 54% percent as much N as that accumulated in the shoots. Dinitrogen fixation was highest for fababean and lowest for lentil. With the exception of fababean in 1987, N removed as seed was higher than that produced by dinitrogen fixation. This means that the soil had a net loss in total nitrogen. From these data, and using equation 3.1 derived from the growth chamber study an attempt was made to predict the amount of N which would be released from each crop. Predictions from both lysimeter experiments indicated that at the mid-pod harvest, considerable amounts of N would have been returned to the soil. As a green manure, the amount of N released would have ranged from 39 to 128 kg N ha^{-1}, this released N would substantially reduce the need for N fertilizer to a subsequent non-legume crop. When grown for their seed yield, these annual legumes would have either released or tied up only small amounts of N. Whereas mature wheat residue would have tied up 57-58 kg N ha^{-1}. The predicted results further imply that non-legumes would have require 59 kg ha^{-1} less fertilizer N following annual legume stubble than following wheat stubble. It is apparent that when these annual legumes are grown for their seed, regardless of their dinitrogen fixation capability, there will be little difference between them in their effect on the available N status of soil in the next year.

In Manitoba, soil N tests based on soil nitrate-N do not make allowances for the effects of annual legume stubble fields. Field studies at three sites were conducted to evaluate the effect on a crop of wheat grown an annual legume stubble such as lentil, pea and fababean as compared to wheat stubble. Results averaged over the three sites support the predicted effect in the lysimeter studies. Wheat yields following annual legume stubble were found to be higher than those following wheat stubble even when wheat had been previously fertilized with adequate nitrogen. There was little difference in the effect amongst the three legumes. Averaged wheat yields ranged from 2293 to 3254 kg ha^{-1} and 1824 to 2900 kg ha^{-1} following annual legume crops as compared to those following wheat respectively. Results indicated that fertilizer nitrogen applied at 25 kg ha^{-1} to wheat following an annual legume gave a yield comparable to 75 kg ha^{-1} applied to wheat following wheat. It should be noted that in the field study the initial difference in yields of a subsequent wheat crop due to a previous crops decreased as added fertilizer increased. However the annual legumes had a beneficial effect on the subsequent wheat yield which could not be related to added fertilizer N. No doubt there are many reasons for this finding, none of which was assessed.

It can be concluded from this field study that when lentil, pea and fababean are grown for their seed yield there is little difference amongst them in their effect on the N nutrition of a subsequent wheat crop. This is consistent with results predicted in the lysimeter studies where, the increase in available N following annual legumes appears to be mainly due to less immobilization of N upon decomposition of the legume residues versus the wheat residues.

The field study also offered the opportunity to study the effect of previous crops on the validity of the soil nitrate-N test to predict the nitrogen fertilizer requirements. Soil nitrate-N levels in the spring following annual legumes tended to be higher than those following wheat but this was found not to be statistically significantly. Fertilizer recommendations based on these results would not be different between the legumes and the wheat at any time sampled. While wheat yields were significantly affected by the previous crop it is evident from the yield data that fertilizer N recommendations based on the nitrate test would not need adjustment for maximum wheat yield. Fertilizer N added at 75 kg ha^{-1} provided maximum yields in all cropping sequences. Adjustments in fertilizer recommendations could be made if a particular target yield was desired.

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Appendix 1. Grain yield (kg ha^{-1}) as affected by the addition of N and previous crop at the Morden site

	N added kg ha^{-1}				
Previous Crop	0	25	50	75	100
wheat	1989	2030	2870	2845	2980
wheat 100 N	2245	2818	2675	3055	2920
fababean	2705	3130	3330	3105	3348
lentil	2700	2980	3188	3430	3291
pea	2785	3210	3053	3270	3158