THE UNIVERSITY OF MANITOBA

THE UTILIZATION OF NITROGEN RELEASED FROM DECOMPOSING PLANT RESIDUE BY WHEAT

By

Michelle Anne Marie Rajotte

A thesis
submitted to the Faculty of Graduate Studies
in partial fulfilment for the degree
Master of Science

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ABSTRACT

Two field experiments and a growth chamber experiment were conducted to quantitatively determine the availability of wheat plant residue N to a wheat crop, and to compare the availability of residue-N to nitrogen applied as urea. Additional objectives of the field experiments were to observe the effect of two different tillage practices on the availability of residue-N, compare the utilization of N from residues with different C:N ratios, and determine the residual effects of residue and urea N application on a wheat crop the year following the N addition.

Field experiments initiated in 1986 and 1987 used a split plot design with zero and conventional tillage treatments as the main treatments. Subtreatments consisted of residue applied at 5000 kg ha^{-1} combined with one of two urea N rates (50 and 100 kg N ha^{-1}) in such a way that only one source of N added was labelled with ^{15}N. Residue used in the 1986 field experiment had a C:N ratio = 18, while residue used in the 1987 experiment had a C:N ratio = 41.

In 1986 and 1987, the utilization by the wheat crop of residue-N at the end of the first growing season was 10% and 2.8% respectively. The average utilization of urea-N was 24% and 21% in 1986 and 1987 respectively. There were few differences found between results from the crops receiving different tillage treatments. These differences were probably due to differences in soil moisture contents and the methods used to incorporate the residue into the soil for the different tillage treatments. At the end of the first growing season in 1986, the distribution of ^{15}N-labelled residue-N within the soil showed N originating from the residue was found mainly within the top 12 cm of the soil

surface, however, some of the N had moved down through the soil. Tillage treatments did affect the distribution of residue-N in the soil. At the end of the first growing season in 1987, the distribution of residue-N within the soil showed results similar to 1986 but also indicated the addition of the urea along with the residue resulted in increased concentration of residue-N at depth between 12 to 42 cm from the soil surface. At the end of the first growing season in both 1986 and 1987, the concentration of residue-N remaining in the soil was considerably higher than that of the urea-N remaining in the soil at the end of the first growing season in 1986.

The utilization by wheat of residual urea and residue N applied the previous spring was very small, approximately 3% and 1% for the residue and urea N respectively. The distribution of residual ^{15}N-labelled residue-N within the soil at the end of the second growing season showed the concentration of residue-N was becoming uniform throughout the top 30 cm of the soil profile. The concentration of this residue-N had not greatly decreased from that found at the end of the first growing season.

Results from the growth chamber were consistently higher than those found for the 1986 field experiment employing residue of similar C:N ratio and N content. In the growth chamber, utilization of residue-N was 18% while utilization or urea-N was 27% and 41% for the 50 and 100 kg N ha^{-1} urea rate treatments respectively.

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I. INTRODUCTION

Although today's farm management systems rely heavily on commercial fertilizers to supply much of a crop's need for nitrogen, a considerable amount of N is often provided to the crop by the soil. Even though the total N content of a surface soil may be many times the amount of N the growing crop requires, only a very small portion of soil N exists in forms plants are able to utilize. In most cases, the surface layer of soil contains over 90% of its N in organic forms which are not immediately available to the plant (Stevenson, 1982). Plant available soil N is released when soil organic N is transformed into inorganic N following a complex series of reactions and transformations involving the soil microbial biomass. This release of N as organic materials are decomposed, results only as a by-product of the soil microorganisms' metabolic processes.

Plant residue added to a soil is readily acted on by the soil microorganisms and can contribute to plant available soil N. The return of crop residues to the soil has always been an important farm management practice and seems to be on the increase as farmers see a need for soil conservation and environmentally friendly alternatives to chemical fertilizers. In addition, farmers return crop residues to the soil to enhance the organic matter content, to protect the soil from erosion, and as an alternative to burning straw after harvest.

The effect of the addition of plant residue on the inorganic N status of a soil at a particular time depends on the properties of the residue added and the activity of the soil microbial community. Since N is one of the essential nutrients of plant growth, knowledge concerning the amount

of N released following decomposition of crop residues, and information documenting the subsequent reactions the released N undergoes, are important and allow for the more effective use of inorganic fertilizers.

The objective of this study was to determine what amount of the N contained in plant residue added to a soil can be utilized by a wheat crop. The residue was incorporated into the soil to simulate zero or conventional tillage and residue N uptake was monitored in the first and second years following residue addition. The ability of the crop to use the residue N was then compared to the use of inorganic N added as urea fertilizer. Finally, under field conditions in Manitoba during 1986 and 1987, the uptake by wheat of N contained in decomposing crop residue with a low C:N ratio was compared to that from residue with a higher C:N ratio.

II. LITERATURE REVIEW

The decomposition of crop residues

Returning crop residues to the soil is an important farm management practice which can benefit both the soil and subsequent crops. There are two types of crop residues which are incorporated into agricultural soils; immature plant material at the mid-season stage of growth (green manure), and mature plant material, generally the straw remaining after grain has been harvested.

The practice of green manure cropping is an alternative to summerfallow and consists of discing legume crops, such as lentils or sweet clover, into the soil when the crop reaches full bloom. Legumes are used because they form a symbiotic relationship with Rhizobium to fix atmospheric N_2, resulting in the capture of an N source otherwise unavailable for crop use. This N_2 fixing capability results in an elevated N content of the plant material. Once incorporated into the soil the green manure crop is rapidly decomposed, releasing the N contained in the residue. The practice is called a summerfallow alternative because although the inorganic N level in the soil is increased as in the case of summerfallow, the source of the N is not the native soil organic N but the N contained in the legume residue decomposing in the soil. The purpose of the green manure crop is to provide a source of inorganic N for the next crop while preserving the organic N of the soil. In addition, the residue protects the soil, otherwise left bare, from wind and water erosion (Brady, 1974).

Farmers have recently come under pressure to find environmentally friendly alternatives to the burning of straw residues. One alternative

to dealing with the large volume of straw produced as a by-product of agricultural grain production is to incorporate it into the soil. Incorporating straw will help maintain the organic matter content of the soil, improve such properties as structure and water holding capacity, and protect the soil from erosion (Troeh et al., 1980).

The degradation of plant residue, once added to the soil, can lead to the release of nutrients in forms required by plants. The path leading to the release of these nutrients is complex, involving enzymatic reactions and transformations which are mediated by the soil microbial community.

Although earthworms and other soil animals physically breakdown plant residue into particles of smaller size and help to mix the residues into the soil (Stevenson, 1986), the soil microorganisms are responsible for decomposition of plant residue in the soil. Since agricultural soils are most commonly aerobic (Paul and Clark, 1989), bacteria, actinomycetes, and fungi will all play important roles in plant residue breakdown (Stevenson, 1986).

When the breakdown of plant residue occurs, the constituents of the plant material are used as a source of nutrition by the soil microorganisms. The nutrients contained in plant material can be used in three ways. Carbohydrates (hemicellulose, cellulose, starch), organic N compounds (proteins, amino acids) and other organic compounds (lignin, hydrocarbons, organic acids) are used as energy sources. The oxidation of these organic substances releases energy used for growth (Alexander, 1977).

Some nutrients are used as acceptors for electrons released when the organic substances are oxidized to provide energy for growth. Biological

oxidation often involves dehydrogenation of the compounds being reduced. In aerobes, oxygen acts as an electron acceptor to dispose of H^+ ions by reacting with them to form water (Alexander, 1977).

Nutrients provide material for protoplasmic synthesis. In addition to C, H, and O, a microbial cell contains macronutrients such as N, P, K, S, Ca, Mg and micronutrients such as Zn, Cu, Co, Fe, Mn, and Mo (Alexander, 1977).

Although the individual constituents of plant residue are decomposed at different rates, they are intimately combined so that decomposition is not simply a step-wise process of breakdown of the less to more resistant compounds. Aerobic decomposition of plant residues is, however, composed of two distinct phases (Pinck et al., 1950; Jenkinson, 1965; Sorenson, 1966; Shields and Paul, 1973; Abd-el-malek et al., 1977; Ladd et al., 1983a). The initial phase is characterized by a rapid loss of C from easily decomposable organic substances such as sugars, starches, and amino acids (Vaughan and Ord, 1985). The amount of C used for cell synthesis will vary from 10 to 70% during this stage and depends on the nature of the soil microbial populations present (Alexander, 1977; Stevenson, 1986).

Once the readily available organic substances have been broken down, the decomposition process enters a slower phase associated with the breakdown of organic materials more resistant to microbial attack. This phase is characterized by a much slower rate of C loss which lasts for extended periods of time (Jenkinson, 1965; Shields and Paul, 1973; Jenkinson and Rayner, 1977; Ladd et al., 1983a). The primary plant constituent associated with the second slower phase is lignin. Lignin is composed of cross-linked aromatic polymers and because of its stable

structure, is resistant to microbial attack (Jenkinson, 1981). Lignin is acted on mainly by actinomycetes and fungi. A second reason for the slower phase of decomposition is that only molecules small enough to penetrate into the microbial cells can be utilized by the soil microorganisms. Enzymes excreted by the soil microorganisms break down the large molecules into smaller organic molecules, which can only then be used as a source of nutrition by the soil microorganisms. This simplification process yields energy only indirectly through the subsequent metabolism of the end products. One example of the action of microbially produced soil enzymes is the conversion of cellulose to simple sugars which are then used to provide energy for cell synthesis (Stevenson, 1986).

The breakdown of organic intermediates by all types of microorganisms and repeated recycling of the biomass C and N occur continuously throughout all phases of decomposition (Stevenson, 1986).

The extent of decomposition that has occurred at a particular point during the fast initial phase of decomposition of plant material is variable. Results from studies monitoring the temporal change in the amount of residue C remaining in the soil have indicated approximately 50% of the residue C originally contained in the residue no longer remained in the soil after four or five weeks had passed (Amato and Ladd, 1980; Ladd et al., 1981a). In contrast, results from other experiments lasting similar periods of time, measuring the loss in weight of the residue with time (Parker, 1962), or the amount of CO_2 released during decomposition (Kanamori and Yasuda, 1979), have indicated the extent of decomposition to be about half the amount reported by the other authors. The variability

is not unexpected since there are many factors which affect the ability of the microorganisms to decompose fresh plant material.

Results determined by different researchers studying the extent of decomposition of plant materials at particular points of time during the second slower phase are more comparable. Field experiments by Smith and Douglas (1968), Shields and Paul (1973), Sauerbeck and Gonzalez (1977), and Douglas et al. (1980), using wheat straw, and Jenkinson (1965) using ryegrass, have all shown that two-thirds of the plant material added was decomposed within a year. Research monitoring decomposition after four or five years has shown consistent results with approximately 80% of the plant material added to the soil being decomposed (Jenkinson, 1965; Shields and Paul, 1973; Broadbent and Nakashima, 1974; Ladd et al., 1981a).

The use of ^{15}N labelled residues has allowed direct measurement of the fate of crop residue N in a soil. Studies show that N exhibits a gradual but progressive decrease similar to that associated with the C of the material. Amato and Ladd (1980), Ladd et al. (1983a), and Azam et al. (1985), respectively reported 67%, 83%, and 89% of plant residue N remained in the soil after approximately one month. After 16 months of decomposition, Moore (1974) and Ladd et al. (1983a) determined values of 66% and 65%, respectively. By the time four or five years have passed Broadbent and Nakashima (1974), Ladd et al. (1981a), and Ladd et al. (1983a), respectively indicated that 38%, 45-50%, and 48% of the ^{15}N added initially in plant residue could remain in the soil.

The apparent relationship between C and N should not be surprising since much research has demonstrated an intimate link between these two

elements. McGill et al. (1975) reported that N transformations were highly dependent on C transformations during the decomposition of organic residue. Studies using ^{14}C and ^{15}N labelled alfalfa straw showed that the maximum rate of $^{14}CO_2$ evolution and inorganic ^{15}N accumulation occurred in the soil after exactly the same period of time (7 days), and the rates of decomposition and changes in the distribution of ^{14}C and ^{15}N residues followed similar patterns (Amato and Ladd, 1980). McGill and Cole (1981) reported that C and N are stabilized together into organic matter, and are also released together through biological mineralization. Marumoto et al. (1982) reported a significant, positive correlation between CO_2 mineralization and net N mineralization. One study, in contrast, has demonstrated the C and N contained in certain organic compounds (amino acids and nucleic acids) are processed separately by soil microorganisms. The authors concluded that the metabolism of the compounds containing covalent C-N bonds is not solely for the production of energy (Smith et al., 1989).

Factors affecting the rate of plant residue decomposition

Soil factors such as temperature, moisture, aeration, pH, as well as the amount of residue added will affect the rate of microbial degradation of plant residues added to a soil. Soil temperature can influence microbial activity by its effect on the microbial cellular components (membranes, proteins) or through its effect on the water contained in the cell (Paul and Clark, 1989). For moderate temperatures (5-30°C) an increase in temperature increases the activity of the aerobic heterotrophs in the soil (Alexander, 1977).

Soil water is very important in determining the level of activity of aerobic heterotrophs in a soil. A maximum release of nutrients from residues for a particular soil can be related to particular moisture levels (Clement and Williams, 1962), because water is required in the cell and water affects soil microorganisms indirectly by influencing the soil aeration status (Jenkinson, 1981), and the solubility of nutrient materials in the soil (Paul and Clark, 1989). Soil water can also affect the level of microbial activity in a soil through cycles of drying and rewetting (Yaacob and Blair, 1980; Marumoto et al., 1982; van Veen et al., 1984), and freezing and thawing (van Veen et al., 1984).

Soil pH affects the rate of degradation of plant residues and the formation of soil organic matter by affecting the degree of microbial metabolic activity in the soil. Fresh organic material has been shown to decompose more slowly in acid soil than in neutral soil (Jenkinson, 1977b). In soils of neutral pH, the microbial community is composed of mixed populations of microorganisms, all of which take part in the degradation of plant residues. In a soil with low pH, the microbial community is predominated by fungi and the rate of decomposition is decreased (Alexander, 1977).

Various methods have been implemented in order to determine the effect of rate of residue addition on the speed of decomposition. Results have been somewhat conflicting. While some report an increase in decomposition as rates of addition increase (Jenkinson, 1977a; Ladd et al., 1983a), others have reported no effect (Leuken et al., 1962; Jenkinson, 1965), or a decrease as rates are increased (Bartholomew, 1966; Brown and Dickey, 1970). The explanation for the increase in decomposition following the

addition of larger amounts of residue to a soil suggested by Ladd et al. (1983a) was that a soil has only a limited number of sites capable of protecting organic material therefore leaving the remainder easily accessible to the microorganisms. The suggested reason for the decrease in decomposition with increasing rate of addition of plant residue was that the microbial population may become self inhibitory when the microbial population becomes dense (Bartholomew, 1966). Jenkinson (1977a) summarizes that when residue is added in amounts relevant to the natural soil system, and when N supply is adequate, then the percentage of decomposition is independent of the amount added.

The role and function of plant residues in the formation of organic matter and release of inorganic N

The release of N within a soil occurs as soil heterotrophs decompose organic C compounds of soil organic matter to provide themselves with energy. At this time, any other nutrient, such as N, is released if not also required by the microorganisms. Most of the C and N stabilized into soil organic matter originates from plant and animal remains that were at one time added to the soil. Therefore, the primary contribution of plant residue to inorganic soil N is made indirectly through the role plant residue plays in the formation of soil organic matter.

Soil organic matter (humus) consists of nonhumic and humic substances. Nonhumic substances include biochemical compounds including the metabolites of the soil microorganisms and compounds released following decay of their cells. Humic substances include humin, relatively stable in the soil; and humic and fulvic acids, the most active fractions of soil

organic matter (Stevenson, 1982).

Humic and fulvic acids are formed from the more resistant fractions remaining after decomposition of plant residue. Humic and fulvic acids form in a process beginning with the decomposition of all plant components into monomers, metabolism of the monomers by the soil microorganisms, a subsequent increase in size of the microbial population, the recycling of the biomass C and N and the synthesis of new cells, and ending with the condensation of reactive monomers into polymers (Vaughan and Ord, 1985; Stevenson, 1986).

Nitrogen contained in humic and fulvic acids can be a significant source of inorganic soil N and is released through the functioning of the internal N cycle in the soil.

The cycling of N between inorganic and organic forms is referred to as the internal soil N cycle. The internal N cycle revolves around the organic N contained in soil organic matter and results as a consequence of the soil microorganisms breaking down organic matter as they require energy. Because most inorganic soil N is released during decomposition of soil organic matter, the soil fertility level can often be directly related to the soil organic matter content. A soil with a high amount of organic matter can support a large population of soil microorganisms. A high amount of microbial activity can lead to the release of soil nutrients as long as an energy source is present.

Mineralization and immobilization of soil N

Microorganisms contain approximately 50% C in their bodies. The process of converting the C in the organic residue to protoplasmic C is

called assimilation or immobilization. In aerobic conditions, 20-40% of the substrate C is assimilated into bacterial cells; the remaining portion is released as CO_2 or accumulates as metabolic waste products. When C is utilized by the soil microorganisms, there is an accompanying requirement for other nutrients. Of these nutrients, N is required in the largest amounts since it is necessary for the formation of many cell constituents (proteins, vitamins, nucleic acids) (Alexander, 1977).

The extent to which the soil microorganisms can use the C in the plant residue may depend on the level of nutrients, particularly N, provided in the newly incorporated material, as well as that in the soil environment. The release of organic N to mineral forms and the assimilation and transformation of mineral N into organic forms are termed mineralization and immobilization, respectively. Because mineralization and immobilization occur simultaneously but in opposing directions, a net effect is evident. If the N contained in the residue undergoing decomposition does not meet the N requirement of the microorganisms for metabolization of the residue, then the N of the soil is used as a source of nutrition. If the soil is unable to provide adequate N, then microbial activity may be restricted. If the N contained in the material is in excess of that required, then inorganic N will be liberated. In most cases for an unamended soil, net mineralization will be most common (Agarwal et al., 1972; Broadbent and Nakashima, 1974; Abd-el-malek et al., 1977). Upon the addition of any C and/or N containing compound to the soil, the balance of the two processes may shift and a change in the net effect may occur.

In the soil system there exists an energy-nutrient (E-N) relationship

that will ensure a maximum level of microbial activity, and the E-N ratio of the material added affects the extent and rate of decomposition (Stevenson, 1982). There are several indicators of the E-N status of compounds. The two most widely used are the % total N and the C:N ratio. The C:N ratio equals the percent by weight of organic C of the material divided by the percent by weight of total N in the material. A C:N ratio greater than 30 results in net immobilization of N, a C:N ratio of 25-30 does not effect the ongoing balance, and a C:N ratio of less than 25 results in net mineralization of N (Allison and Klein, 1962; Jenkinson, 1981). With respect to % total N, the critical level to maintain the ongoing balance of mineralization and immobilization, has been determined to be in the 1 to 1.5% N range (Broadbent and Norman, 1946; Pinck et al, 1947; Pinck et al., 1950; Allison, 1966).

Not only is the N content of the plant residue important when considering whether mineralization or immobilization of N will result, but also the ability of the microorganisms to decompose the material and utilize the energy contained in it. The use of the C:N ratio or the % total N to predict what effect plant residue will have on the soil N status should be limited to materials known to have relatively low lignin contents since high amounts of lignin slow decomposition and therefore affect the N requirement of the soil microorganisms. This was demonstrated in a study (Wallace and Smith, 1954) using orange and avocado leaves. Even though both leaves contained approximately 2% N, the recovery of N from the orange leaves was approximately five times greater than that from the avocado leaves. This was attributed to the fact that the avocado leaves contained four times more lignin than the orange

leaves.

Many studies have demonstrated that the addition of plant material of low N content (high C:N ratio) results in rapid and immediate net immobilization of N (Allison and Klein, 1962; Broadbent and Nakashima, 1967; Brown and Dickey, 1970; Chae and Tabatabai, 1986; Jawson and Elliot, 1986). This period of immobilization may last for days, weeks, or months depending on the properties of the material added, and the soil. Tracer studies have made it possible to determine that the origin of the immobilized N is either the plant material itself (Amato and Ladd, 1980), native soil N (Chae and Tabatabai, 1986), or inorganic N provided as fertilizer (Broadbent and Tyler, 1962). In contrast, the incorporation of residue of a higher N content (lower C:N ratio) is believed to result in the net mineralization of N soon after the residue is added (Pinck et al., 1947; Till et al., 1982; Chae and Tabatabai, 1986). A net release of N does not mean that immobilization is not also occurring. An experiment using corn leaves (2.98% N) showed that even though net mineralization occurred throughout the course of the study, a significant amount of N was also being immobilized (Stojanovic and Broadbent, 1956). It is necessary to remember that by monitoring the inorganic soil N level, only the net effect of residue addition is determined. A soil vigorously mineralizing N may also be vigorously immobilizing N.

The requirement by the soil microorganisms for inorganic N, as the C containing compounds are oxidized, depends on several factors including the composition of the material added, the size and type of microbial population present, and the soil chemical and physical environment. Consequently, much of the research carried out has provided different

values for mineralization or immobilization of N upon the addition of plant material to a soil.

The potential of the soil microbial community to mineralize N will influence the degree to which residue addition will affect the soil inorganic N level. For example, the addition of residues that should promote immobilization, to a soil with a high N mineralization potential, may only cause in a small decrease in the available N content of the soil. If the same material is added to a soil with a low N mineralization potential, a more drastic effect on the soil available N content may be realized (Agarwal et al., 1972).

Studies have shown that when determining whether plant material will mineralize or immobilize N, the period of time in which the results are noted can be important (Parker et al, 1957; Parker, 1962; Douglas et al., 1980). In these experiments, net immobilization preceded the net mineralization that resulted at the end of the experiments.

It has been demonstrated that location of plant residue on or in a soil has a significant effect on decomposition and the potential for the residue to mineralize or immobilize N. An incubation experiment by Parker et al. (1957) showed that subsurface placement of residue resulted in more rapid decomposition and a more rapid loss of residue N than that of surface placement.

Brown and Dickey (1970) investigated the decomposition of wheat straw for three sites of placement in a soil under field conditions. The percentage loss by weight after 18 months exposure at one site was approximately 22%, 31%, and 93% for the above soil, on soil surface, and buried treatments, respectively. Results from a second site followed a

similar pattern. The N contents of the straw were monitored to determine whether the straw was causing immobilization or mineralization of soil N. For the above and on soil treatments, N percentage of the wheat straw residue remained near the initial content for the first 12 months of the study. For the buried soil treatment, the N percentage increased with time. The amount of immobilization that occurred within a one month period was greatest in that between the second and third months.

Douglas et al. (1980) reported results similar to Brown and Dickey (1970). After 26 months of exposure in the field, average residue losses were 25%, 31%, and 85% by weight for placements above, on, and incorporated in the soil, respectively. They also demonstrated that decomposition of the above and on surface residue was nearly constant and was not affected by seasonal changes in precipitation, humidity, or air temperature, whereas, for buried straw, decomposition was affected to some extent by low soil moisture or low soil temperature.

In the same study, the effect of the residue on soil inorganic N was studied by monitoring the net change in the total N content of straw placed either above, on, or in the soil. For each placement, straws of three differing N contents were used (0.78% N, 0.49% N, and 0.19% N). Although N was immobilized for the two straws lowest in N during a period of several months midway through the study, all three buried straw treatments showed a net negative change in total N content by the end of the three year study. Net mineralization equalling approximately 17, 11, and 2 kg N ha^{-1} had occurred. For the above and on surface residue treatments, a net negative change in total N indicated mineralization equalling 6 and 4 kg N ha^{-1} for the straws with the two higher N contents.

The straw with the lowest N content caused immobilization of 4 kg N ha^{-1}.

Plant residue as a source of N

Most of the N contained in crop residues undergoing decomposition is first assimilated into the microbial biomass (Amato and Ladd, 1980). Many studies have been carried out in attempts to determine what portion of the N immobilized by the soil microorganisms will subsequently be released as mineral N. Most have concluded the remineralization of the immobilized N occurs very slowly and that only a very small portion will be released, at least in the short term (Stewart et al., 1963; Stojanovic and Broadbent, 1965; Broadbent and Nakashima, 1965; Broadbent and Nakashima, 1967; Ladd et al. 1977). For example, results from a greenhouse experiment using ^{15}N as a tracer (Broadbent and Tyler, 1962) showed that true biological turnover, the remineralization of the same molecule of N that had previously been immobilized, was non-existent in an 11.5 week study period.

In the long term, the remineralization of immobilized N may make a significant contribution to the inorganic N of the soil. Allison and Klein (1962) and Marumoto et al. (1982) suggest that approximately one-third of immobilized N is not tied up as long or as tenaciously as some experiments have shown.

Once N added to a soil in the form of plant residues is first immobilized, its fate is the same as any other N entering the soil. A portion of it may be released as mineral N which in turn may be taken up by a growing crop, utilized by subsequent generations of microorganisms, lost to the soil environment, or stabilized into organic compounds.

Only a limited number of studies have attempted to determine the availability to plants of N released following the decomposition of crop residues added to a soil. Many of these demonstrate that direct uptake of N added in crop residues is relatively low and that residue N contributes only slightly to total plant N uptake.

Field studies using residues of lower N contents show the lowest uptake of residue N. Research by Fribourg and Bartholomew (1956) showed that for soybean residue (0.96% N) added alone, there was virtually no uptake by corn until into the second growing season when uptake was estimated to be only two percent of soybean N added originally. Myers and Paul (1971) showed an uptake of 5.8% of oat straw N (1.07% N) by wheat plants after the first crop year, and an additional 3.5% during the second crop year. Research by Norman et al., (1980) showed rice grown under flood conditions, was able to take up 3%, 11%, and 37% of rice (0.68% N), soybean (2.6% N), and wheat (1.18% N) residue N respectively. However, both the soybean and rice residues were incorporated seven months prior to the seeding of the rice crop, while the wheat residue was incorporated the same day seeding occurred. Frederickson et al. (1982) showed an uptake of 7.8% to 11.4% of wheat straw N (1.20% N) by wheat after one cropping season, an average of 4.8% of total plant N uptake. Wagger et al. (1985) found a winter wheat crop could take up 10.3% and 1.6% of sorghum residue N (C:N = 38) and wheat residue N (C:N = 116) respectively on a soil with a sandy loam texture. Uptake by the winter wheat crop grown on a silty loam soil was 5.9% and 1.1% of the sorghum residue N (C:N =26) and wheat residue N (C:N = 96) respectively.

The addition of residues with lower C:N ratios results in a greater

uptake of residue N, however, the contribution to total plant N remains low. This was demonstrated in a field experiment where uptake of legume N (C:N = 15, 2.66% N) by wheat was investigated (Ladd et al., 1981b). After a total of fifteen months of decomposition, uptake of legume N amounted to 10.9%, 13.8%, and 17.3% in three different soils, a contribution on average of only 8% to total plant N. A similar field experiment (Ladd et al., 1983a) showed an uptake of legume N (C:N = 11) by a first crop of wheat to be as high as 27.8% and 20.2% for two different soils. The contribution to total plant N in this case was 6.1% and 10.8% for the two soils. Further research on one of the two soils studied, determined a second wheat crop was able to recover an additional 4.8% of the N applied in the residue 25 months earlier. Results within the range of the earlier experiments were reported by Varco et al. (1989). Recovery of N added in legume residue (3.76% N) by corn during the first year cropping season averaged 32% and 20% for conventional and no till treatments, respectively. Recovery at the end of a second cropping season amounted to 7% and 3% for the two respective tillage treatments.

Although recoveries of residue N over several months or after one cropping season seem to be somewhat variable depending on the experimental conditions, determinations of residue N uptake over much shorter terms can be extremely variable. Variability in many cases can be attributed to the particular parameters of the experiment. As already discussed, characteristics of the residue added as well as those of the soil receiving the addition can strongly influence decomposition, immobilization, mineralization, and subsequently the availability of the N contained in the residue.

Results of a five week pot experiment showed a 4.86% uptake of legume N (C:N = 19, 2.15% N) by maize (Azam et al., 1985). This residue was added at a relatively high rate equivalent to approximately 20 t ha^{-1}. In contrast, results from a twelve week glasshouse experiment showed a recovery of 55.5% of Siratro (Macroptillium atropurpureum) residue N (C:N = 16, 2.61% N) by Rhodes grass (Yaacob and Blair, 1980). In this case, the soil used was collected from pots that had grown six previous Siratro crops and received organic residue returns from each crop. In addition, the soil was subjected to wetting and drying cycles during the course of the study.

Research by Norman and Werkman (1943) showed that soybeans were able to take up 26.5% of soybean residue N (2.15% N) in eleven weeks, while Till et al. (1982) reported an uptake of 32% of N contained in white clover tops (C:N = 12, 2.94% N) by oats in ten weeks.

Thus, it seems, the availability of residue N may depend on a number of factors; one of the most important of which is the C:N ratio (or N content) of the organic material added.

III. MATERIALS AND METHODS

Two lysimeter experiments, and a growth chamber experiment, were initiated to determine the availability of N in plant residue to a growing crop. All experiments used wheat (Triticum aestivum var. Columbus) as the test crop. The sites for lysimeter experiment #1 (soil #1) and lysimeter experiment #2 (soil #2), were located on NE 22-8-7-W1, north of St. Claude, MB, on a Willowcrest (Gleyed Orthic Black) fine sandy loam soil. The growth chamber experiment was conducted using a Willowcrest (Gleyed Orthic Black) fine sandy loam soil (soil #3), collected from a site near the lysimeter experiments. The characteristics of the soils used are reported in Table 1. The pH values were determined with a glass electrode (soil:water ratio, 1:1) on <2 mm air-dry soil (McLean, 1982). Organic C was determined by a dichromate oxidation method (Mebius, 1960) and total N was determined by macro-Kjeldahl method, with a pretreatment to include NO_3 (Bremner, 1965b). Nitrate-N was determined by the phenoldisulfonic acid method (Bremner, 1965a); P was extracted using 0.5M $NaHCO_3$ (pH = 8.5) and phosphate determined by a colorimetric

Table 1. Chemical properties of the experimental soil.†

Soil No.*	pH	Organic C	Total N	NO_3-N	P	K	SO_4
		%		$\mu g\ g^{-1}$			
1	7.5	2.3	0.19	9.1	7.7	308	3.2
2	7.3	2.4	0.20	3.7	7.9	247	2.8
3	7.3	2.6	0.21	5.2	7.7	198	3.3

† Analyses were done on surface samples of soil (0-15 cm).
* Willowcrest fine sandy loam

method using acid molybdate-ascorbic acid reduction method (Olsen and Sommers, 1982); exchangeable K was extracted using 1.0 N NH_4OAc and analyzed with an atomic absorption spectrophotometer (Isaac and Kerber, 1980); and sulfate was determined by a turbidimetric method (Hamm et al., 1973).

Lysimeter Experiment #1 (1986)

The experiment was arranged in a split-plot design (Little and Hills, 1978) with three replicates. Two tillage methods, conventional or zero-till, were the main treatments. The tillage methods were simulated by manually mixing the soils to different depths. The subtreatments, which consisted of nine treatments of various rates and sources of N (Table 2), were arranged in a randomized complete block (Little and Hills, 1978). The sources of N were fertilizer (urea) and wheat plant residue.

To determine the partitioning of N from the different sources, to the wheat crop and to that remaining in the soil, fertilizer or wheat plant residue labelled with ^{15}N, was applied. The unlabelled residue treatments were chosen to match the labelled residue treatments in crop growth stage and N content (labelled straw, C:N ratio = 18; unlabelled straw, C:N ratio = 17).

In order to obtain labelled wheat plant residue for the experiment, wheat was grown in the growth chamber, in a Willowcrest fine sandy loam collected from the same site as the lysimeter experiments. Potassium nitrate enriched with ^{15}N at 51%, was supplied to the wheat to ensure adequate enrichment of the residue. The above-ground portions of the plants were harvested at inflorescence (60 days after seeding), oven-dried

(60°C), and ground to pass a 2 mm screen. Since this labelled residue was very highly enriched with ^{15}N (approximately 20% ^{15}N excess), it was first diluted with unlabelled residue of the same crop, growth stage, and total N content, before being applied as treatments in the lysimeter experiment.

The open-ended polyvinyl chloride lysimeters used in this experiment were 40 cm in length, with a cross-sectional area of 490 cm^2. Each lysimeter was pressed into the soil with a front-end loader until only the top 5 cm remained above ground. All visible native residue was removed from the soil surface in each lysimeter.

The two main treatments were simulated conventional or zero-till. For the conventional tillage treatment, the surface 10 cm of soil were removed from the lysimeter, thoroughly mixed, and then placed back into the lysimeter. For the zero-till treatment, only the top 3 cm of soil were removed, manually mixed, and returned to the lysimeter.

The nine subtreatments consisted of various rates and sources of N (Table 2). The rates of urea applied were at the soil test recommendation (100 kg N ha^{-1}) and one-half the soil test recommendation (50 kg N ha^{-1}). The residue was applied at a rate of 5000 kg ha^{-1}, which represents a rate approximating that left in an actual field situation (Shields and Paul, 1973; Douglas et al., 1980). Since the residue contained 3.0 % N, this was equivalent to adding 150 kg N ha^{-1}.

For the N fertilizer subtreatments, a syringe and injection needle were used to apply the appropriate amount of urea-N solution in a single point source into the soil in the lysimeter to a depth 9.0 cm. To ensure even distribution of the fertilizer, a 490 cm^2 template, with 10 sites for injection, was used. For the residue subtreatments, appropriate amounts

Table 2. Description of rate and label of N treatments for lysimeter experiment #1 (1986).

Treatment No.	Rate of N application	
	Urea	Wheat plant residue
	------- kg N ha^{-1} -------	
1	0	0
2	50*	0
3	100*	0
4	0	150
5	50*	150
6	100*	150
7	0	150*
8	50	150*
9	100	150*

* labelled with ^{15}N.

of residue were incorporated into the soil during the manual mixing of the soil for the tillage main treatments. After the application of all treatments, the surface soil of each lysimeter received a nutrient suspension containing $CaH_4(PO_4)_2 \cdot H_2O$, K_2SO_4, and KCl, for a resulting concentration of 50 kg P ha^{-1}, 200 kg K ha^{-1}, and 30 kg S ha^{-1}.

Each lysimeter received 20 seeds of wheat, planted to a depth of 5 cm, and was covered with a plastic lid until the plants emerged. The plant population within each lysimeter was thinned to ten.

Guard rows of wheat were sown around the lysimeters to ensure a crop canopy. Weed control was maintained by hand weeding throughout the growing season. Weed residue was returned to the appropriate lysimeter.

Plant samples were collected twice during the growing season, six weeks (approximately 75% of the plants were at the heading stage) and 14 weeks (maturity) after emergence. At each harvest, the entire above-ground portions of five plants were removed from each lysimeter. The

samples were placed in cloth drying bags and allowed to air dry until constant weight was achieved (about three weeks). Samples were weighed for dry matter determination. Final harvest samples were separated into seed and straw components in order to determine grain and straw yield. All samples were ground to pass a 2 mm screen. The dry material was analyzed for total N (Nelson and Sommers, 1973) and for isotope-ratio analysis of ^{15}N (Bremner, 1965b), modified to use H_2SO_4 in place of H_3BO_3.

At final harvest, soil samples were collected near the perimeter inside each lysimeter. For each lysimeter, two cores were taken at 0-5, 5-10, 10-15, 15-20, 20-35, and 35-50 cm depths. The soil samples were combined for each depth increment, air-dried, and analyzed for total N and for isotope-ratio analysis of ^{15}N (Bremner, 1965b), modified to use H_2SO_4 in place of H_3BO_3. The soil samples from each lysimeter were also combined for the top three depth increments (0 - 15 cm) and analyzed for inorganic N (Keeney and Nelson, 1982).

Lysimeter Experiment #1 (1987)

The lysimeter experiment was repeated at the same site during the summer of 1987, to determine the effects of residual N from the treatments of the previous year on wheat growth.

The experiment was conducted as described for the lysimeter experiment #1 (1986), however, the lysimeters did not receive any additional N or S. Plant samples were collected only once, 13 weeks (maturity) after emergence. The plant samples were handled as described for the samples collected for the second harvest of lysimeter experiment #1 (1986). The dry material was analyzed for total N (Nelson and Sommers, 1973) and for

isotope-ratio analysis of ^{15}N (Bremner, 1965b), modified to use H_2SO_4 in place of H_3BO_3.

Soil samples from lysimeters receiving labelled residue (treatment numbers 7, 8, and 9) were collected near the perimeter inside each lysimeter. For each lysimeter, two cores were taken at 0-10, 10-20, and 20-35 cm depths. The soil samples were combined for each depth increment, air-dried, and analyzed for total N and for isotope-ratio analysis of ^{15}N (Bremner, 1965b), modified to use H_2SO_4 in place of H_3BO_3.

Lysimeter Experiment #2 (1987)

The second lysimeter experiment was located adjacent to the site of lysimeter experiment #1 and was also arranged in a split-plot design (Little and Hills, 1978) with three replicates. Two tillage methods, simulated conventional or zero-till, were the main treatments. The subtreatments, which consisted of nine treatments of various rates and sources of N (Table 3), were arranged in a randomized complete block (Little and Hills, 1978). The sources of N were fertilizer (urea) and wheat plant residue.

Lysimeter experiment #2 was conducted as described for lysimeter experiment #1 (1986). The only difference between the two experiments was in the C:N ratio of the plant residue added (labelled straw C:N ratio = 41; unlabelled straw C:N ratio = 42). The residue contained 1.2 % N, which was equivalent to adding 60 kg N ha^{-1}, when added at the rate of 5000 kg ha^{-1}.

The sampling dates of the two harvests occurred at the same physiological stage of growth as in the lysimeter experiment #1 (1986), at

Table 3. Description of rate and label of N treatments for the lysimeter experiment #2 (1987).

Treatment No.	Rate of N application	
	Urea	Wheat plant residue
	------- kg N ha^{-1} -------	
1	0	0
2	50*	0
3	100*	0
4	0	60
5	50*	60
6	100*	60
7	0	60*
8	50	60*
9	100	60*

* labelled with ^{15}N.

seven and 12 weeks after emergence. The plant samples were handled as described for lysimeter experiment #1 (1986). The dry material was analyzed for total N (Nelson and Sommers, 1973) and for isotope-ratio analysis of ^{15}N (Bremner, 1965b), modified to use H_2SO_4 in place of H_3BO_3.

The soil samples, which were collected as described in lysimeter experiment #1 (1986), but only from lysimeters of treatment numbers 7, 8, and 9 were analyzed for total N and for isotope-ratio analysis of ^{15}N (Bremner, 1965b), modified to use H_2SO_4 in place of H_3BO_3. The soil samples from each lysimeter were also combined for the top three depth increments (0 - 15 cm) and analyzed for inorganic N (Keeney and Nelson, 1982).

Growth Chamber Experiment

The experiment was arranged in a completely randomized design with three replicates (Little and Hills, 1978). The 15 treatments consisted of various rates and sources of N (Table 4). The sources of N were

fertilizer (urea) and wheat or alfalfa plant residue. The rates of urea applied were at the field soil test recommendation (100 kg N ha^{-1}) and one-half the soil test recommendation (50 kg N ha^{-1}).

To determine the partitioning of N from the different sources, to the wheat crop and to that remaining in the soil, fertilizer or residue labelled with ^{15}N were applied. The unlabelled residue treatments were chosen to match the labelled residue treatment in crop growth stage and N content (labelled alfalfa, C:N ratio = 15 and 3.2 % N; unlabelled alfalfa, C:N ratio = 17 and 3.2 % N; unlabelled wheat C:N ratio = 17 and 2.9 % N; labelled wheat, C:N ratio = 17 and 3.2 % N). The plant residue was added at a rate of 5000 kg ha^{-1} which resulted in the application of residue N in the amounts shown in Table 4.

The soil used (Table 1) was air-dried, ground, and sieved (<2 mm) to remove as much native straw as possible. Samples of air-dried soil (2.5 kg) were placed in 6 L pots and treated with sufficient water to bring the soil to field capacity. An additional 2.5 kg of soil was thoroughly mixed with the appropriate straw treatment and added to the soil in the pot. A 40 mL suspension containing $CaH_4(PO_4)_2 \cdot H_2O$, K_2SO_4, and KCl (50 kg P ha^{-1}, 200 kg K ha^{-1}, and 30 kg S ha^{-1}) was applied to the soil surface, followed by sufficient water to bring the total 5 kg of soil to field capacity.

For the N fertilizer treatments, the appropriate amount of urea-N solution was injected into the soil in the pot, to a depth of 6.5 cm. To ensure even distribution of the fertilizer, a 330 cm^2 template, with 10 sites for injection, was used.

Eight wheat seeds per pot were planted to a depth of 2.5 cm. After emergence, the pots were thinned to four plants per pot. After 12 days on

Table 4. Description of rate and label of N treatments for the growth chamber experiment.

Treatment No.	Residue	Rate of N application	
		Urea	Residue
		----- kg N ha^{-1} -----	
1	None	0	0
2	None	50*	0
3	None	100*	0
4	Wheat	0	152
5	Wheat	50*	152
6	Wheat	100*	152
7	Alfalfa	0	166
8	Alfalfa	50*	166
9	Alfalfa	100*	166
10	Wheat	0	163*
11	Wheat	50	163*
12	Wheat	100	163*
13	Alfalfa	0	168*
14	Alfalfa	50	168*
15	Alfalfa	100	168*

* labelled with ^{15}N.

a growth bench, the pots were placed in a growth chamber. Within two days most seedlings had died, probably due to root rot. Therefore it was necessary to reseed all pots at the same rate, thinning the pots to four plants after emergence. After replanting, all pots were placed in a growth chamber that was maintained at a 14 hour (20°C, 60% R.H.) - 10 hour (15°C, 80% R.H.) day-night cycle. The light source consisted of Sylvannia cool-white florescent, supplemented with 10% incandescent light. Photosynthetically active radiation was measured at 555 μmol photon m^{-2} s^{-1}. The pots were maintained at two-thirds to three-quarters field capacity (by weight) by adding water to the soil surface as required. Pots were not maintained at full field capacity because it appeared that this would have resulted in saturated soil moisture conditions for much of

the growing period.

Ten days after reseeding, a 40 mL solution containing $CuSO_4$ and $ZnSO_4$ (10 kg Cu ha^{-1} and 16 kg Zn ha^{-1}) was applied to the soil surface of each pot.

The plants were harvested when the wheat reached the inflorescence stage (10 weeks after emergence). The above-ground portions were oven-dried at 60°C until constant weight was achieved, weighed for dry matter determination, and then ground to pass a 2 mm screen. The dry, ground material was analyzed for total N (Nelson and Sommers, 1973) and for isotope-ratio analysis of ^{15}N (Bremner, 1965b), modified to use H_2SO_4 in place of H_3BO_3.

After harvest, the soil was air-dried in the pots, removed, thoroughly mixed, and sieved (<2 mm) removing all visible root material. Soil samples from each pot were analyzed for total N and for isotope-ratio analysis.

IV. RESULTS AND DISCUSSION

Lysimeter experiment #1 (1986)

The effects of fertilizer application on growth of the wheat crop were first observed at the tillering stage. The wheat plants in the lysimeters receiving the 100 kg N ha^{-1} urea rate (treatments 3, 6, and 9) produced more tillers and heads than the plants in lysimeters receiving either the 0 or 50 kg N ha^{-1} urea rates (treatments 1, 2, 4, 5, 7, and 8). There were no visible differences in growth between the crop in lysimeters with different tillage or residue treatments throughout the course of the experiment.

For all lysimeter experiments, statistical significance was determined using the Duncan Multiple Range Test at the 95% confidence level where analysis of variance indicated the presence of significant differences. Statistical analyses for all experiments are shown in Appendix A.

Dry matter yield and total plant N uptake for the first harvest are shown in Table 5. Yield was not significantly affected by either tillage or residue application. Nitrogen uptake showed no significant effect of tillage. However, the average total N uptake for all treatments with plant residue (treatments 4 to 9) was significantly greater than the average total N uptake for all treatments having no plant residue added (treatments 1 to 3). This statistical significance of residue over all fertilizer rates may be attributed to the very large effect residue addition had on total N uptake where there was no fertilizer added. Comparison of treatment 1 (no residue, no urea) with treatments 4 and 7 (residue, no urea) shows the addition of residue alone largely increased yield and total N uptake. The increase was equivalent to approximately

Table 5. The effect of urea and residue N addition on dry matter yield and total N uptake by wheat for Lysimeter Experiment #1 (1986)-Harvest 1.

Trt. No.	N applied		Dry Matter Yield		Total N Uptake	
	Fert.	Residue	Z†	C†	Z	C
	-- kg N ha^{-1}--		---- g pot^{-1}----		-- mg pot^{-1}--	
1	0	0	6.49	6.69	110	112
2	50*	0	12.42	12.71	230	220
3	100*	0	16.16	15.22	303	288
4	0	150	9.00	11.11	161	195
5	50*	150	14.08	11.89	260	266
6	100*	150	14.51	13.16	299	280
7	0	150*	9.76	9.95	179	184
8	50	150*	15.44	12.44	308	259
9	100	150*	14.96	13.65	324	291

† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

51% for yield and 62% for total N uptake. Comparison of treatments 2 and 3 (no residue) with treatments 5, 6, 8, and 9 (residue) shows only a slight effect of residue on yield and total N uptake at the 50 kg N ha^{-1} urea rate and no effect of residue at the 100 kg N ha^{-1} rate.

All treatments demonstrated a significant increase in dry matter yield and total N uptake as the amount of N added as urea was increased from 0 to 50 to 100 kg ha^{-1}. The most extreme example of this was the doubling of yield and N uptake where no straw was added and the rate of urea-N was increased from 0 to 50 kg N ha^{-1}.

The contribution of each N source (urea or residue) to the percent and amount of N contained in the crop as well as the percent of each N source utilized by the crop is shown in Table 6.

In all the following tables, PNDFL was defined to be the percent of plant N derived from the labelled source. However, in subsequent discussion, if the source of the label was urea it will be designated as PNDFF, and if the source of label was straw residue it will be designated as PNDFS. Similar abbreviations will be used for NDFL.

The percent of wheat N derived from the straw (PNDFS) was the only variable affected by tillage. The PNDFS was significantly greater under conventional than zero tillage. This could be due to the addition and mixing of the residue with a greater volume of soil in the conventional tillage situation. A similar response to tillage was demonstrated by the amount of N derived from the residue (NDFS) although the differences were not significant. The percent utilization of residue-N by wheat was, however, not affected by tillage treatment.

The addition of residue had no effect on either the percent of plant

Table 6. Percent and amount of wheat N derived from labelled urea and residue and utilization of urea and residue N by wheat for Lysimeter Experiment #1 (1986) - Harvest 1.

Trt. No.	N applied		PNDFL‡		NDFL§		ULS¶	
	Fert.	Residue	Z†	C†	Z	C	Z	C
	-- kg N ha^{-1}--		----- % -----		-- mg pot^{-1}--		----- % -----	
2	50*	0	22.3	23.3	51	50	20.4	19.9
3	100*	0	39.4	40.4	118	116	24.2	23.8
5	50*	150	23.5	20.9	58	55	23.2	22.2
6	100*	150	41.5	37.3	123	105	25.3	21.5
7	0	150*	22.5	26.9	41	49	5.4	6.5
8	50	150*	16.2	20.8	50	53	6.6	7.1
9	100	150*	15.4	20.2	50	58	6.6	7.8

‡ PNDFL - percent nitrogen derived from labelled source
§ NDFL - amount of nitrogen derived from labelled source
¶ ULS - utilization of labelled source
† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

N derived from the urea (PNDFF), the amount of N derived from the urea (NDFF), or the percent utilization of fertilizer N.

Both PNDFF and NDFF showed a significant increase as the rate of urea-N was increased from 50 to 100 kg ha^{-1}. Consequently, the PNDFS for treatments 8 and 9 (urea, residue) were significantly less than the PNDFS for treatment 7 (no urea, residue) due to a dilution effect. Increasing the urea rate affected the actual amount of N derived from the residue (NDFS) in an opposite way. The NDFS for treatments 8 and 9 (urea, residue) were significantly greater than the NDFS for treatment 7 (no urea, residue). It is possible that the addition of urea stimulated growth and improved the ability of the crop to take up residue-N. This is further supported by the significant increase in percent utilization of both fertilizer and residue-N as the urea rate was increased from 50 to 100 kg N ha^{-1}. It is also possible that the addition of urea promoted mineralization of residue-N resulting in an increased uptake of residue-N.

The amount of urea-N utilized by the crop at the first harvest (ULS of Table 6) was approximately 22% and the utilization of fertilizer N from the treatment with the least amount of N added (treatment 2) was significantly less than that of the other treatments receiving larger amounts of additional N (treatments 3, 5, and 6). Specifically, the addition of residue at the 50 kg N ha^{-1} urea rate caused a significant increase in fertilizer N utilization. The positive effect of residue on fertilizer N utilization was not present at the 100 kg N ha^{-1} urea rate.

The contribution from the soil to total plant N ranged from approximately 76% for treatments 2 and 7; to 60% for treatment 3, 5, and 8; and to 43% for treatments 6 and 9.

The data indicate approximately six percent of the residue-N had been taken up by the crop at the time of first harvest and that the residue provided approximately one-fifth of the total plant N.

Finally, comparison of the NDFF for treatments 2 and 5 (50 kg N ha^{-1} urea) and NDFS for treatments 7, 8, and 9 (150 kg N ha^{-1} residue) indicates the crop derived approximately equal amounts of N from the 50 kg N ha^{-1} urea treatment (54 mg) and the 150 kg N ha^{-1} residue treatment (50 mg). This suggests that at the time of the first harvest, the relative availability of the N to the crop from this residue with a low C:N ratio was only one-third of that of the fertilizer N.

Table 7 shows total dry matter yield and total plant N uptake for the second harvest (maturity). Neither yield nor N uptake were significantly affected by tillage. Both the average yield and average total N uptake for all treatments with plant residue added (treatments 4 to 9) were significantly greater than the average yield and average total N uptake for all treatments having no plant residue added (treatments 1 to 3). This statistical significance of residue over all fertilizer rates is most apparent when yield and total N uptake of treatments 1 and 2 are compared to yield and total N uptake of treatments 4 and 5, and, 7 and 8. Comparison of treatment 3 (no residue, 100 kg N ha^{-1} urea) with treatments 6 and 9 (residue, 100 kg N ha^{-1} urea), shows no positive effect of residue on either yield or N uptake. This suggests the application of urea at the 100 kg N ha^{-1} rate provided adequate N nutrition to the crop and the application of additional N was not necessary for optimal growth.

All treatments demonstrated a significant increase in dry matter yield and total plant N uptake as the amount of N added as urea increased from

Table 7. The effect of N urea and residue N addition on dry matter yield and total N uptake by wheat for Lysimeter Experiment #1 (1986)-Harvest 2.

Trt. No.	N applied		Dry Matter Yield		Total N Uptake	
	Fert.	Residue	Z†	C†	Z	C
	-- kg N ha^{-1}--		---- g pot^{-1}----		-- mg pot^{-1}--	
1	0	0	22.26	18.81	329	289
2	50*	0	31.44	31.14	459	431
3	100*	0	38.81	41.51	566	633
4	0	150	30.81	36.67	454	437
5	50*	150	36.67	35.17	528	533
6	100*	150	42.24	40.51	631	573
7	0	150*	27.25	32.86	411	445
8	50	150*	43.27	40.59	614	623
9	100	150*	44.51	37.36	633	547

† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

0 to 50 to 100 kg ha^{-1}. When compared to the control (treatment 1), the addition of urea at the 100 kg N ha^{-1} rate resulted in a doubling of yield and total N uptake regardless of whether residue was added.

Table 8 shows the contribution of each N source (urea or residue) to the percent and amount of N contained in the crop as well as the percent of each N source utilized by the crop. None of the variables were significantly affected by tillage or residue addition. However, as for harvest 1, the PNDFS, NDFS, and percent utilization of residue-N were larger under conventional tillage than under zero tillage.

Both the PNDFF and NDFF showed a significant increase as the rate of urea-N was increased from 50 kg N ha^{-1} to 100 kg N ha^{-1}. The increased addition of urea-N led to a significant decrease in PNDFS. In contrast to harvest 1, the addition of urea did not significantly affect NDFS although the data do show the same trend as the first harvest where the contribution of the residue-N to the crop and the percent utilization of residue-N by the crop were higher where there was fertilizer added. Again, this could probably be attributed to a cause and effect situation with the fertilizer improving growth and therefore increasing uptake and utilization of any N source present.

At the end of the growing season the average percent utilization of fertilizer N equalled 24% (ULS of Table 8). The percent utilization of fertilizer N was greatest for treatment 6 which had the highest amount of additional N added.

The contribution to total plant N from the soil increased from the time of first harvest. At second harvest, the amount of N in the crop originating from the soil ranged from approximately 88% for treatment 2

Table 8. Percent and amount of wheat N derived from labelled urea and residue and utilization of urea and residue N by wheat for Lysimeter #1 (1986) - Harvest 2.

Trt. No.	N applied		PNDFL‡		NDFL§		ULS¶	
	Fert.	Residue	Z†	C†	Z	C	Z	C
	-- kg N ha^{-1}--		----- % -----		-- mg pot^{-1}--		----- % -----	
2	50*	0	13.6	11.2	61	48	24.4	19.4
3	100*	0	21.0	21.2	118	133	24.3	27.4
5	50*	150	10.9	10.4	55	55	22.2	22.2
6	100*	150	22.0	22.9	138	130	28.5	26.7
7	0	150*	16.4	17.0	65	76	8.7	10.1
8	50	150*	12.2	13.8	74	85	9.9	11.4
9	100	150*	11.7	13.6	74	75	9.9	10.0

‡ PNDFL - percent nitrogen derived from labelled source
§ NDFL - amount of nitrogen derived from labelled source
¶ ULS - utilization of labelled source
† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

(50 kg N ha^{-1} urea, no residue); to 83% for treatment 3 (no urea, residue); to 76% for treatments 5 and 8 (50 kg N ha^{-1} urea, residue); and to 65% for treatments 6 and 9 (100 kg N ha^{-1} urea, residue).

The data indicate approximately 10% of the residue-N (15 kg N ha^{-1}) had been taken up by the crop at the end of the growing season and that the mature wheat crop derived approximately 14% of its total plant N from the plant residue added. Similar values for percent utilization of legume residue-N (11% and 10.9%) have been determined by some researchers (Norman et al., 1980; Ladd et al. 1981b) while values from 20% to 32% have been found in other studies (Ladd et al., 1983a, Varco et al. 1989).

Comparison of the total N uptake data for the two harvests of lysimeter experiment #1 (1986) (Table 5, page 32 and Table 7, page 37) shows that total plant N uptake at the time of first harvest was approximately one-half of the total plant N uptake at the time of the second harvest (i.e. the plants took up N throughout the growing season at a relatively constant rate). However, comparison of the percent utilization of fertilizer N for the two harvests (Table 6, page 34 and Table 8, page 39) shows that utilization of urea-N did not change from the time of the first to the time of the second harvest. It appears that, after the time of the first harvest, the urea-N had become unavailable to the plant. Comparison of Table 6 and Table 8 also shows the percent utilization of residue-N only slightly increased from the time of the first to second harvest. Therefore, since neither the utilization of urea-N nor residue-N increased greatly from the time of the first harvest, and since N uptake was continuous over the growing season it appears that during the period from six weeks to 14 weeks after emergence, the only

available source of N to the crop was the native soil N.

Analysis of the grain and straw components of the mature plant (harvest 2) showed, for all treatments, approximately 35-40% of the urea-N or residue-N taken up by the crop was found in the straw; the remaining 60-65% of the N from either of the two sources was found in the grain (Appendix B).

The distribution of ^{15}N, originating from the ^{15}N-labelled urea, in the soil after the second harvest is presented in Figure 1. Figure 1a and 1c show that when urea was applied without residue, the N originating from the urea decreased to a depth of within 27 cm of the soil surface and then stabilized to a depth of 42 cm. Figure 1b shows a similar trend in the distribution of ^{15}N originating from the urea, however, for the zero tillage treatment the addition of residue along with the urea resulted in a zone of increased ^{15}N concentration just below the layer of soil the residue was added to. It is possible that the addition of residue to a smaller volume of soil in the zero tillage treatment stimulated the microbial activity closest to where the residue was added resulting in a greater degree of immobilization of ^{15}N urea in this zone. This immobilized N could have persisted in the soil as it continued to be recycled into microbial structures or because it was converted into components of the soil organic matter. Because the residue was applied to a much larger volume of soil in the case of the conventional tillage treatment, the effect of the residue on the immobilization of the inorganic N may not have been as pronounced. The figure for treatments of 100 kg N ha^{-1} applied with residue is not shown since the soil within several of the lysimeters of these treatments was disturbed by gophers

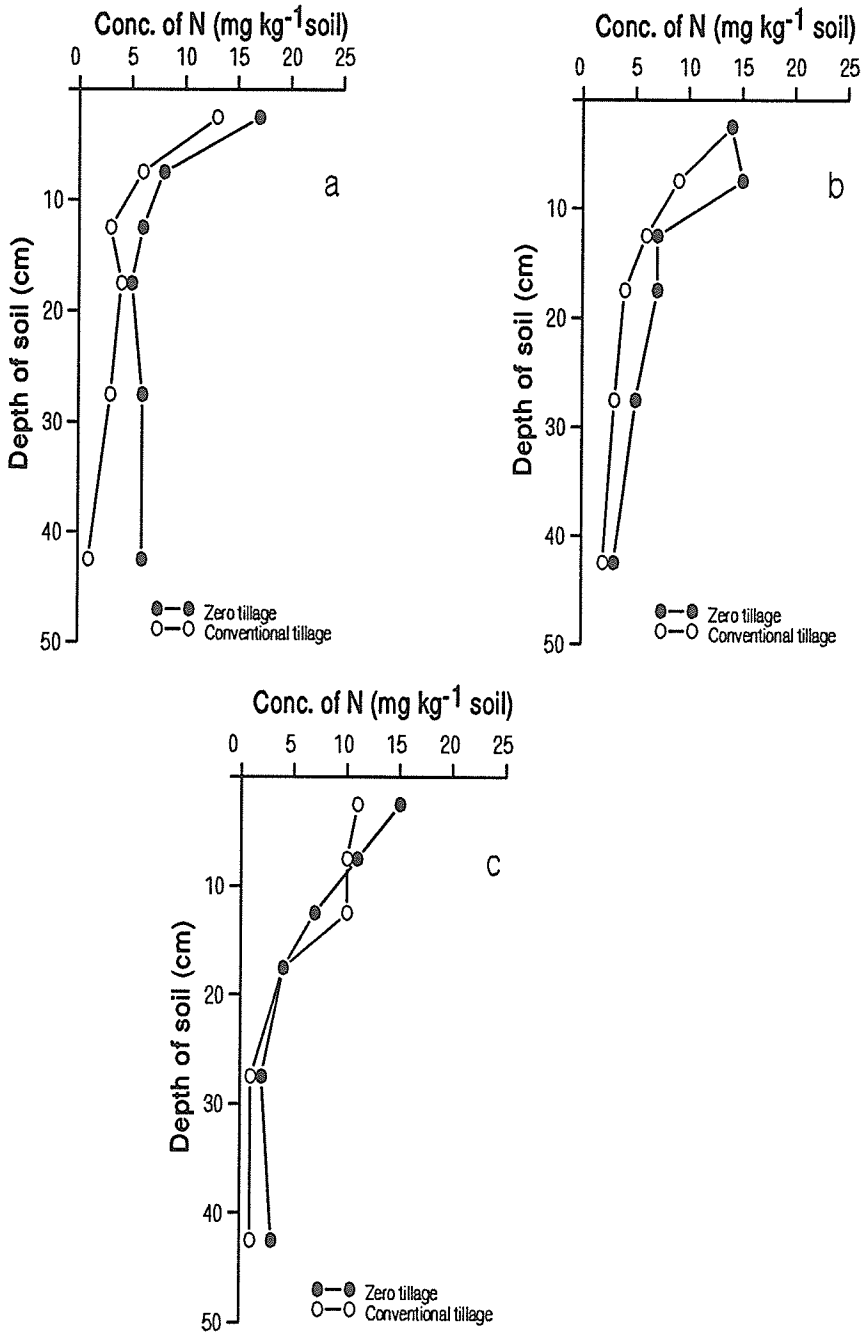

Figure 1. Distribution of spring applied ^{15}N-labelled urea-N within soil after second harvest (1986)
a) 50 kg N ha^{-1} urea
b) 50 kg N ha^{-1} urea + 150 kg N ha^{-1} residue
c) 100 kg N ha^{-1} urea

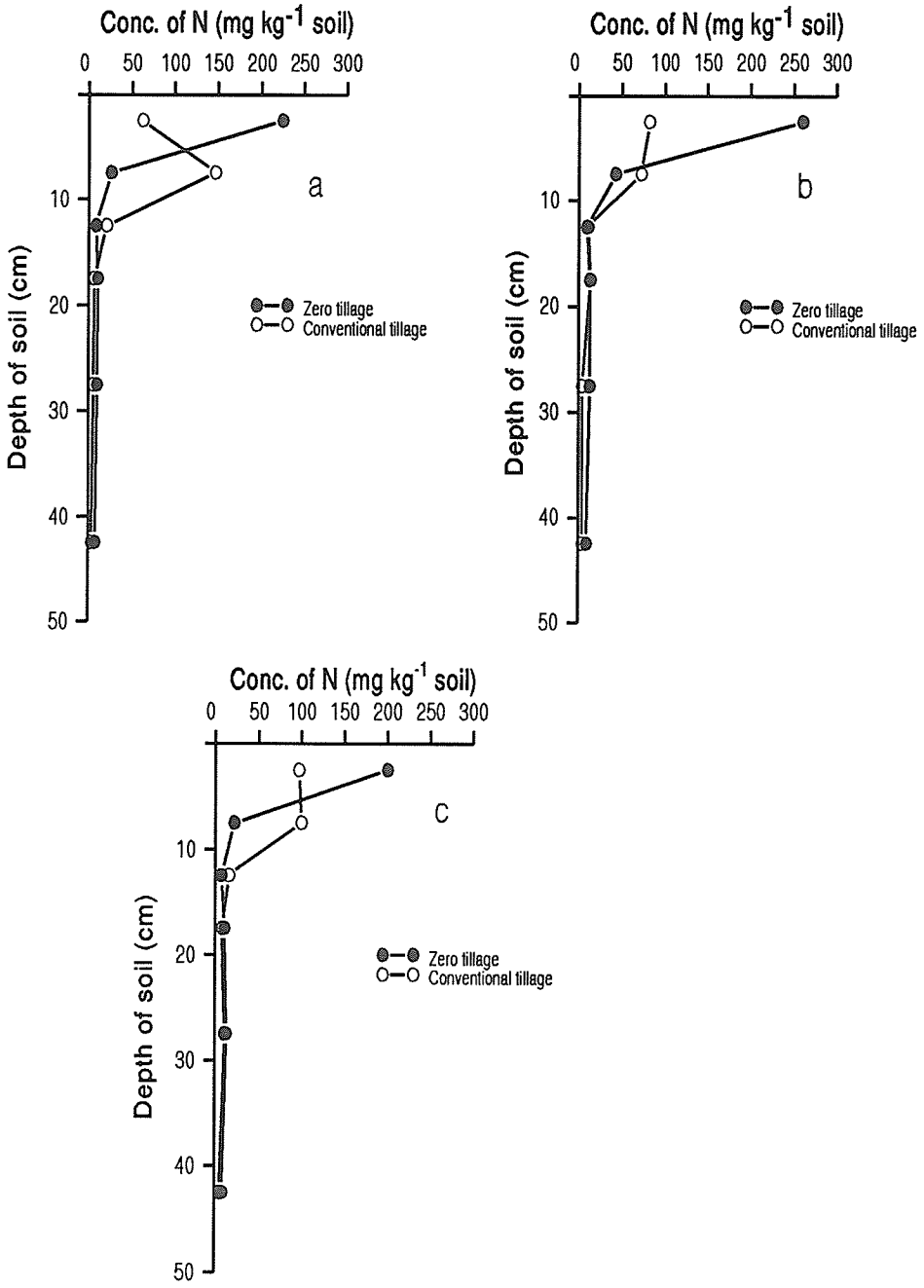

Figure 2. Distribution of ^{15}N-labelled residue-N within soil after second harvest (1986)
a) 150 kg N ha^{-1} residue
b) 150 kg N ha^{-1} residue + 50 kg N ha^{-1} urea
c) 150 kg N ha^{-1} residue + 100 kg N ha^{-1} urea.

burrowing inside them.

The distribution of N, originating from the ^{15}N-labelled residue, in the soil after the second harvest is shown in Figure 2. It appears that for the simulated zero tillage treatments, the zone of elevated ^{15}N concentration occurred within the first sampling depth (0-5 cm) while for the simulated conventional tillage treatments the zone of elevated ^{15}N concentration occurred within the top two sampling depths (0-10 cm). This is likely due to the fact that the ^{15}N labelled residue was added to the top 3 and top 10 cm of soil for zero and conventional tillage treatments respectively. Below 15 cm, the N concentration remains relatively constant and does not appear to be affected by the addition of increasing amounts of urea. The data does show that at least a portion of the N originating from the residue has moved down through the soil profile. This N could be present in organic or inorganic forms. Even accounting for the proportionally greater uptake of fertilizer N, the concentration of N in the soil originating from the residue is considerably higher than the concentration of N in the soil originating from the urea applied at the 100 kg N ha^{-1} rate. This reinforces the idea of plant residues contributing to soil organic matter and plant residue-N playing a significant role in the functioning of the soil N cycle.

Lysimeter experiment #1 (1987)

The effect of residual N originating from urea-N and residue-N applied the previous spring on dry matter yield and total plant N uptake are shown in Table 9. There were no residual effects of either urea or residue N application on yield or total N uptake for the wheat crop at the end of

Table 9. The residual effect of urea and residue N on dry matter yield and total N uptake by wheat for Lysimeter Experiment #1 (1987).

Trt. No.	N applied		Dry Matter Yield		Total N Uptake	
	Fert.	Residue	Z†	C†	Z	C
	-- kg N ha^{-1}--		---- g pot^{-1}----		-- mg pot^{-1}--	
1	0	0	24.82	18.01	356	237
2	50*	0	26.22	26.83	375	408
3	100*	0	21.42	23.82	304	342
4	0	150	23.88	20.18	339	277
5	50*	150	30.83	30.67	450	459
6	100*	150	25.07	17.80	351	238
7	0	150*	30.46	25.80	435	367
8	50	150*	33.79	28.14	455	388
9	100	150*	26.09	25.56	372	361

† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

Table 10. Total N and inorganic N contents of soil at the end of the season for Lysimeter Experiment #1 (1986).†

Treatment No.‡	Tillage	Total N	Inorganic-N§
		%	$\mu g\ g^{-1}$
1	Z	0.21	18.8
	C	0.21	19.9
2	Z	0.20	20.1
	C	0.21	15.8
3	Z	0.21	19.5
	C	0.21	20.4
4	Z	0.22	25.5
	C	0.22	21.0
5	Z	0.21	19.5
	C	0.22	18.4
6	Z	0.21	25.0
	C	0.23	23.2
7	Z	0.22	25.4
	C	0.21	17.0
8	Z	0.22	21.2
	C	0.22	21.7
9	Z	0.22	22.8
	C	0.22	22.7

† Analyses were done on surface samples of soil (0 – 15 cm).
‡ Treatment no. corresponds to the same treatments for the lysimeter experiment #1 (1986) as reported in Table 2, page 24.
§ $(NH_4 + NO_3) - N$
Z zero tillage treatment
C conventional tillage treatment

the second growing season. Soil analysis data for surface soil samples taken at the end of the first growing season are shown in Table 10. This information suggests the absence of residual effects was due to the very slight effect the application of urea and/or residue had on total soil organic N content and inorganic N concentration. The effect of tillage on yield and total N uptake was non-existent.

The residual effect of each N source (urea or residue) on the percent and amount of N contained in the crop, as well as the percent of each N source utilized by the crop at the end of the second growing season is shown in Table 11. Although significant differences for NDFS and utilization of residue-N did exist due to tillage, the differences are difficult to interpret. Tillage had no significant effect on any of the other variables.

The statistical analysis (Appendix A) of the data presented in Table 11 indicated significantly greater PNDFF and NDFF values for the 100 kg N ha^{-1} urea rate than the 50 kg N ha^{-1} urea rate, however, the contribution to total plant N from either of these fertilizer treatments was very low (less than 2%). The reason for the significant differences amongst urea-N rates observed for PNDFS and percent utilization of urea-N are unclear but are probably due to variations in yield.

At the end of the second growing season the crop was able to use approximately 3.4% of the N provided in the residue 16 months earlier. Although this was a relatively small amount in terms of total plant N uptake (approximately 6.4%), the utilization of residual urea-N (approximately 1.4%) was only about half the utilization of residual residue-N and the contribution of the residual urea-N to plant N was

Table 11. Percent and amount of wheat N derived from residual urea and residue N and utilization of residual urea and residue N by wheat for Lysimeter Experiment #1 (1987).

Trt. No.	N applied		PNDFL‡		NDFL§		ULS¶	
	Fert.	Residue	Z†	C†	Z	C	Z	C
	-- kg N ha^{-1}--		----- % -----		-- mg pot^{-1}--		----- % -----	
2	50*	0	1.0	1.0	4	4	1.6	1.5
3	100*	0	1.7	1.7	5	6	1.1	1.2
5	50*	150	0.9	1.1	4	5	1.6	2.1
6	100*	150	1.9	1.8	7	5	1.4	0.9
7	0	150*	6.1	6.7	25	24	3.4	3.1
8	50	150*	6.4	5.3	29	20	3.9	3.3
9	100	150*	6.8	7.2	25	26	3.4	3.4

‡ PNDFL - percent nitrogen derived from labelled source
§ NDFL - amount of nitrogen derived from labelled source
¶ ULS - utilization of labelled source
† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

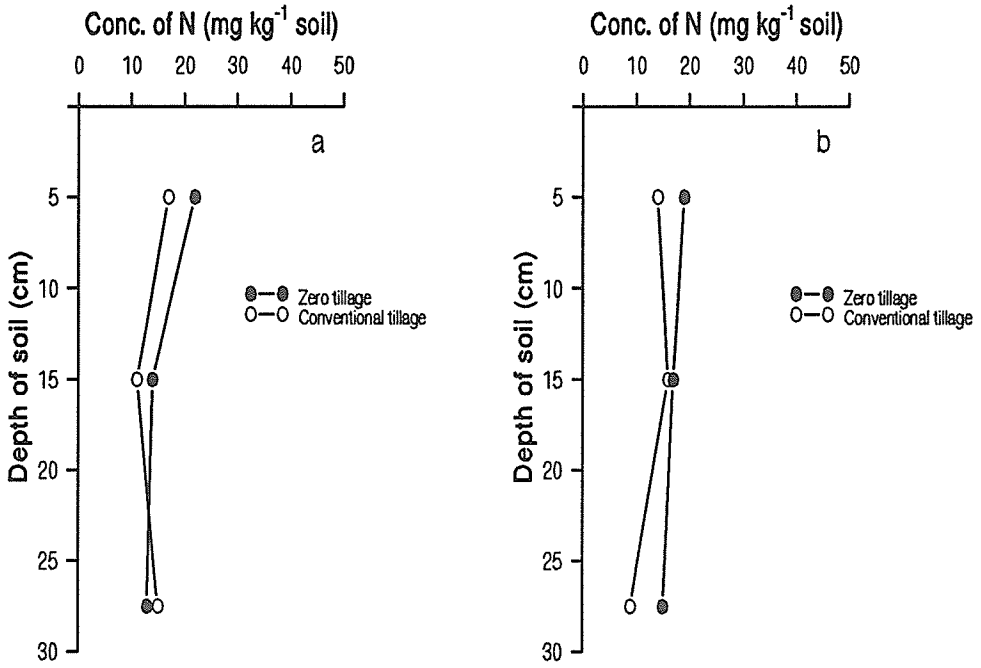

Figure 3. Distribution of residual ^{15}N-labelled residue-N within soil in 1987 after harvest (N applied in 1986)
a) 150 kg N ha^{-1} residue
b) 150 kg N ha^{-1} residue + 50 kg N ha^{-1} urea

almost negligible (approximately 1.4%).

The distribution of ^{15}N in the soil, originating from the ^{15}N-labelled residue applied 16 months earlier, is shown in Figure 3. Figures 3a and 3b show the concentration of the residue-N is becoming uniform within a depth of 30 cm of the soil surface. In both instances the concentration of N originating from the residue under zero tillage was somewhat higher than under conventional tillage. This could be due to the original manner in which the residue was added to the soil. The figures show that the zone of elevated ^{15}N concentration discovered at the end of the first growing season had almost disappeared and suggest that some of the N originating from the residue has been distributed at least within 30 cm of the soil surface. In addition, the concentrations of the N originating from the residue approximated those found at the end of the first growing season which seems to indicate that a portion of the residue-N is either continually being recycled within the microbial system or has become somewhat stabilized in the soil or both.

Lysimeter experiment #2 (1987)

The effects of fertilizer application on growth of the wheat crop were first observed at the tillering stage. The wheat plants in the lysimeters receiving the 100 kg N ha^{-1} urea rate (treatments 3, 6, and 9) produced more tillers and heads than the plants in lysimeters receiving either the 0 or 50 kg N ha^{-1} urea rates (treatments 1, 2, 4, 5, 7, and 8). There were no visible differences in growth between the crop in lysimeters with different tillage or residue treatments throughout the course of the experiment.

Table 12. The effect of urea and residue N addition on dry matter yield and total N uptake by wheat for Lysimeter Experiment #2 (1987)-Harvest 1.

Trt. No.	N applied		Dry Matter Yield		Total N Uptake	
	Fert.	Residue	Z†	C†	Z	C
	-- kg N ha^{-1}--		---- g pot^{-1}----		-- mg pot^{-1}--	
1	0	0	10.97	10.54	174	161
2	50*	0	14.70	14.46	247	221
3	100*	0	15.33	20.49	278	344
4	0	60	9.89	10.67	159	161
5	50*	60	13.30	15.33	221	226
6	100*	60	19.54	17.89	383	336
7	0	60*	6.44	8.02	107	125
8	50	60*	13.04	17.16	218	256
9	100	60*	16.44	21.08	297	333

† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

Dry matter yield and total plant N uptake for the first harvest are shown in Table 12. Neither yield nor total plant N uptake were significantly affected by tillage treatment or residue addition (see Appendix A, page 93 for statistical analysis of this experiment).

Comparison of yield and total N uptake data for treatments 1, 2, and 3 (urea, no residue) and treatments 4, 5, and 6 (urea, residue), and treatments 7, 8, and 9 (urea, residue) demonstrates the addition of residue with a relatively high C:N ratio did not appear to have negative effect. All treatments demonstrated a significant increase in dry matter yield and N uptake as the amount of N added as urea was increased from 0 to 50 to 100 kg ha^{-1}.

Table 13 shows the contribution of each N source (urea or residue) to the percent and amount of N contained in the crop as well as the percent of each N source utilized by the crop. The PNDFS and NDFS, and percent utilization of residue-N were significantly greater under zero than under conventional tillage. This is in contrast to what occurred throughout lysimeter experiment #1 (1986) where values from the conventional tillage treatment were greater than values from the zero tillage treatment. This may be attributed to the moisture conservation aspect of the zero tillage treatment and the low amount of precipitation that occurred during the first half of the 1987 growing season. An improved soil moisture content could have directly affected growth and improved uptake or indirectly affected uptake by the favourable effect on microbial activity or both.

The addition of residue had no effect on either the PNDFF, NDFF, or the utilization of fertilizer N.

The PNDFF, NDFF, and percent utilization of fertilizer N showed a

Table 13. Percent and amount of wheat N derived from labelled urea and residue and utilization of urea and residue N by wheat for Lysimeter Experiment #2 (1987) - Harvest 1.

Trt. No.	N applied		PNDFL‡		NDFL§		ULS¶	
	Fert.	Residue	Z†	C†	Z	C	Z	C
	-- kg N ha^{-1}--		----- % -----		-- mg pot^{-1}--		----- % -----	
2	50*	0	23.6	22.9	58	51	24.2	20.8
3	100*	0	37.8	36.4	105	125	20.9	25.0
5	50*	60	22.1	23.0	49	51	20.2	21.0
6	100*	60	35.1	39.3	134	133	26.6	26.5
7	0	60*	3.7	1.4	4	2	1.4	0.6
8	50	60*	3.2	1.4	7	4	2.4	1.2
9	100	60*	3.1	1.0	9	3	3.2	1.1

‡ PNDFL - percent nitrogen derived from labelled source
§ NDFL - amount of nitrogen derived from labelled source
¶ ULS - utilization of labelled source
† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

significant increase as the rate of urea-N added was increased from 50 to 100 kg ha^{-1}. In contrast to lysimeter experiment #1 (1986) data, PNDFS was not significantly affected by the addition of fertilizer though there does seem to be a trend towards a lower contribution of residue-N to total plant N as urea was added. The addition of urea significantly increased the actual amount of N in the plant contributed to by the residue (NDFS) and the utilization of the residue-N. It is possible that the addition of urea stimulated growth and improved the ability of the plant to take up the residue-N. This is further supported by the significant increase in percent utilization of both fertilizer and residue-N as the urea rate was increased from 50 to 100 kg N ha^{-1}. It is also possible that the addition of urea promoted mineralization of residue-N resulting in an increased uptake of the residue-N.

Table 13 shows that the amount of urea-N utilized by the crop at the time of the first harvest was approximately 23%. The utilization of fertilizer N from the treatment with the highest amount of additional N added (treatment 6) was significantly greater than the other treatments receiving ^{15}N-labelled urea (treatments 2, 3, and 5). The average percent utilization of urea-N compares consistently with that found at the first harvest for lysimeter experiment #1 (1986), which was 22% (Table 6, page 34).

The contribution from the soil to total plant N ranged from approximately 97% for treatment 7 (no urea, residue); to 76% for treatments 2, 5, and 8 (50 kg N ha^{-1} urea); to 61% for treatments 3, 6, and 9 (100 kg N ha^{-1} urea).

The data indicate approximately 1.7% of residue-N had been taken up by

the crop at the time of first harvest. This is only about one-quarter of the portion taken up by the crop at the same harvest for lysimeter experiment #1 (1986). The residue provided only about 2% of total plant N. This compares to 20% for the first experiment. If the utilization of N from the fertilizer for treatment 2 (50 kg N ha^{-1} urea, no residue) is compared to the utilization of N from the residue for treatment 7 (no urea, 60 kg N ha^{-1} residue) it appears that the residue was only about 4% as efficient at providing N as the urea. The residue with the lower C:N ratio applied in lysimeter experiment #1 (1986) was able to supply N at a 30% efficiency rate when compared to urea.

Table 14 shows total dry matter yield and total plant N uptake for the second harvest (maturity) of lysimeter experiment #2 (1987). Although significant differences were noted only for total N uptake, both yield and N uptake were larger under zero than under conventional tillage. Differences were most obvious at the 0 and 50 kg N ha^{-1} urea treatments. Comparison of data for treatment 2 with treatments 5 and 8, and treatment 3 with treatments 6 and 9 demonstrates total N uptake was lower where fertilizer and residue were added than where fertilizer was added alone. This may lead to the suggestion that the residue used in this experiment (C:N ratio = 41) was affecting the availability of the fertilizer N, possibly through the process of immobilization. Opposite to these results, the residue (C:N ratio = 18) had contributed positively to yield and total N uptake at the time of the second harvest for lysimeter experiment #1 (1986) indicating the mineralization of the residue-N.

All treatments demonstrated a significant increase in dry matter yield and total N uptake as the amount of N added as urea was increased. The

Table 14. The effect of N urea and residue N addition on dry matter yield and total N uptake by wheat for Lysimeter Experiment #2 (1987)-Harvest 2.

Trt. No.	N applied		Dry Matter Yield		Total N Uptake	
	Fert.	Residue	Z†	C†	Z	C
	-- kg N ha^{-1}--		---- g pot^{-1}----		-- mg pot^{-1}--	
1	0	0	21.40	15.92	299	224
2	50*	0	24.39	27.37	358	385
3	100*	0	34.95	32.66	511	475
4	0	60	18.37	14.83	267	215
5	50*	60	24.67	21.87	336	317
6	100*	60	31.26	29.12	454	433
7	0	60*	17.30	13.69	258	198
8	50	60*	27.16	18.06	390	259
9	100	60*	28.41	29.28	401	424

† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

Table 15. Percent and amount of wheat N derived from labelled urea and residue and utilization of urea and residue N by wheat for Lysimeter Experiment #2 (1987) - Harvest 2.

Trt. No.	N applied		PNDFL‡		NDFL§		ULS¶	
	Fert.	Residue	Z†	C†	Z	C	Z	C
	-- kg N ha^{-1}--		----- % -----		-- mg pot^{-1}--		----- % -----	
2	50*	0	12.9	15.2	46	58	18.7	23.4
3	100*	0	22.6	28.3	115	135	22.8	26.8
5	50*	60	13.7	13.4	46	42	18.6	17.1
6	100*	60	22.8	24.7	101	106	20.2	21.2
7	0	60*	1.2	3.4	5	7	1.7	2.3
8	50	60*	2.1	4.0	8	10	2.9	3.5
9	100	60*	1.5	3.0	6	13	2.1	4.3

‡ PNDFL - percent nitrogen derived from labelled source
§ NDFL - amount of nitrogen derived from labelled source
¶ ULS - utilization of labelled source
† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

extent of this increase was lower than in the first field experiment.

Table 15 shows the contribution of each N source (urea or residue) to the percent and amount of N contained in the crop as well as the percent of each N source utilized by the crop.

As for both harvests of lysimeter experiment #1 (1986), but in contrast to the first harvest of this experiment, a positive influence of conventional tillage on PNDFS, NDFS, and the utilization of residue-N was shown. For PNDFS the positive influence of conventional tillage was significant. By the end of the growing season, the total amount of precipitation reached that equivalent to the previous year and the moisture conservation aspect of zero tillage was obliterated. It is possible that the effect of mixing the residue with a greater volume of soil became a stronger factor in residue-N utilization.

The addition of residue was shown to significantly decrease the NDFF and the percent utilization of urea-N. Comparing values for treatments 2 and 3 (urea, no residue) with treatments 5 and 6 (urea, residue) demonstrates these decreases. It is possible that the addition of residue with a higher C:N ratio caused a reduction in the availability of inorganic N through the process of immobilization.

The PNDFF, NDFF, and the utilization of urea-N significantly increased as the rate of urea-N was doubled. As for both harvests of the first experiment, the expected decrease in PNDFS by a dilution effect and increase in NDFS and utilization of residue-N resulted as the rate of urea-N was increased from 50 to 100 kg N ha^{-1}.

At the end of the growing season the average percent utilization of fertilizer equalled nearly 21%. This is somewhat lower but does compare

with the value (24%) found for fertilizer N utilization at the end of the season in the first experiment (Table 13, page 53).

The contribution to total plant N from the soil increased from the time of first harvest. At second harvest, the amount of N in the crop originating from the soil ranged from 97% for treatment 7 (no urea) to approximately 84% for treatments 2, 5, and 8 (50 kg N ha^{-1} urea); and to 74% for treatments 3, 6, and 9 (100 kg N ha^{-1} urea).

The data indicate approximately 2.8% of the residue-N (1.7 kg N ha^{-1}) had been taken up by the crop at the end of the growing season and that the mature wheat crop derived approximately 2.6% of its total plant N from the plant residue added. Other field research has indicated values for percent utilization of N from residues of similar N content to range from 5.8% to 11.4% (Fredrickson, 1982; Wagger et al., 1985). The results of this second field experiment contrast sharply with the values determined for the second harvest of the lysimeter experiment #1 (1986) and clearly depict the effect of adding residue of high versus low C:N ratios (lysimeter experiment #1 C:N ratio = 18; lysimeter experiment #2 C:N ratio = 41). In lysimeter experiment #1 (1986), values determined at the time of second harvest for utilization of residue-N and percent of total plant N uptake contributed to by the residue were 10% and 14% respectively.

Similar to the first experiment, comparison of the total plant N uptake data for the two harvests of lysimeter experiment #2 (1987) (Table 12, page 51 and Table 14, page 56) shows that uptake of N by the wheat crop occurred over the entire growing season. However, comparison of the percent utilization of fertilizer N for the two harvests (Table 13, page 53 and Table 15, page 57) shows that utilization of urea-N did not

increase from the time of the first to the time of the second harvest. It appears that, after the time of the first harvest, the urea-N had become unavailable to the plant. Comparison of Table 13 and Table 15 also indicates the percent utilization of residue-N was slightly increased from the time of the first to second harvest. Since neither the utilization of urea-N nor residue-N increased greatly after the time of the first harvest, and since N uptake was continuous over the growing season, during the period from seven weeks to 12 weeks after emergence, the only available source of N to the crop was the native soil N. These findings are similar to those of the first lysimeter experiment.

Analysis of the grain and straw components of the mature plant (harvest 2) showed, for all treatments, approximately 30% of the urea or residue N taken up by the crop was found in the straw; the remaining 70% of the N from either of the two sources was found in the grain (Appendix B).

The distribution of N originating from the ^{15}N-labelled residue in the soil profile after the second harvest is presented in Figure 4. Similar to the figure for 1986 (Figure 2, page 43), although not as evident, the zone of elevated ^{15}N concentration occurred within the top two sampling depths (0-10 cm) for the simulated conventional tillage treatments while for the simulated zero tillage treatments the zone of elevated ^{15}N concentration occurred within the first sampling depth (0-5 cm). This is likely due to the fact that the ^{15}N labelled residue was added to the top 3 and top 10 cm of soil for zero and conventional tillage treatments respectively. The concentration of N originating from the residue was lowest at a depth of approximately 12 cm below the soil surface. After

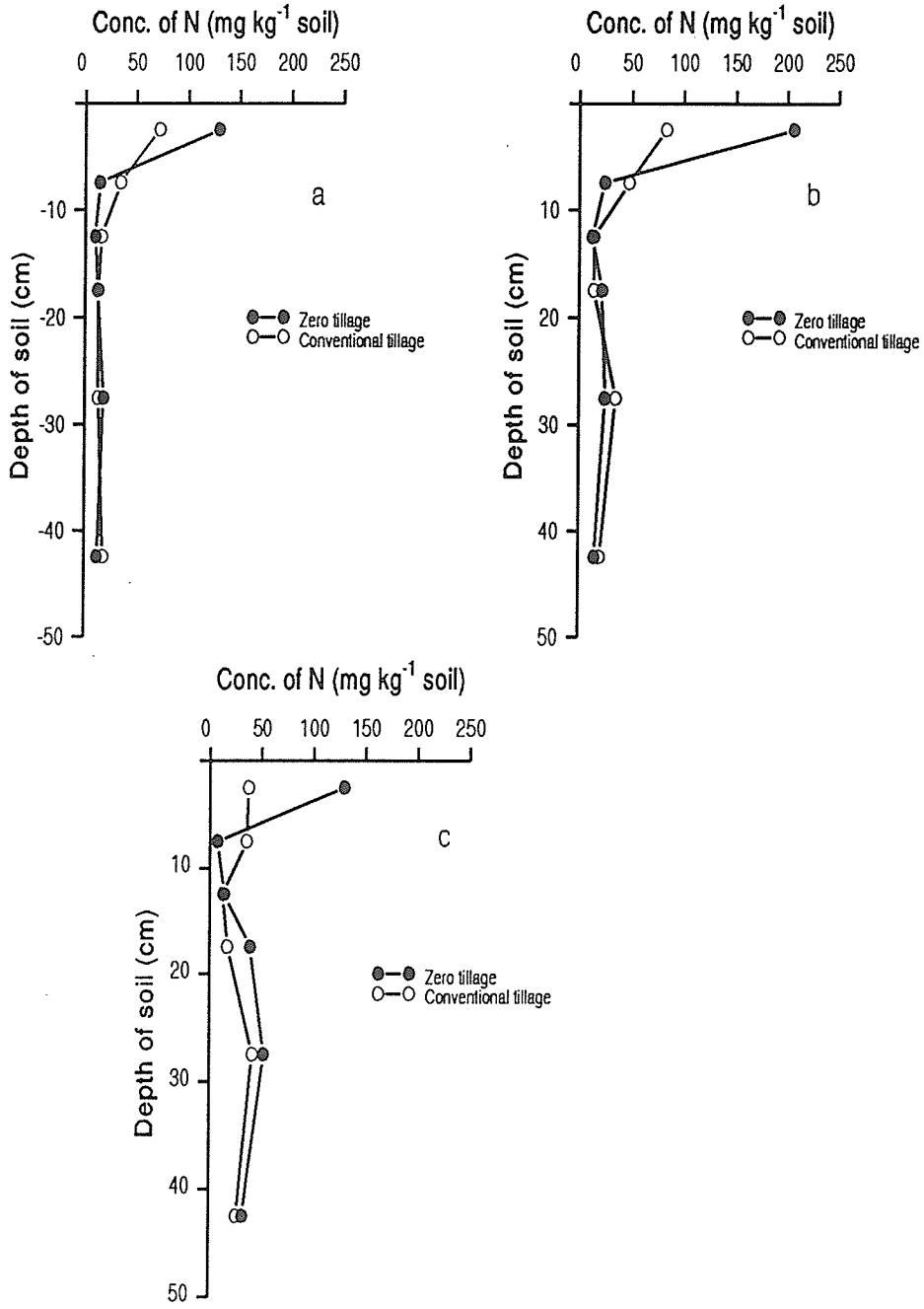

Figure 4. Distribution of ^{15}N-labelled residue-N within soil after second harvest (1987)
a) 60 kg N ha^{-1} residue
b) 60 kg N ha^{-1} residue + 50 kg N ha^{-1} urea
c) 60 kg N ha^{-1} residue + 100 kg N ha^{-1} urea.

this point, the concentration increased gradually to a soil depth of 30 cm and then stabilized to 42 cm. The figures show a very noticeable portion of the N originating from the residue had moved down through the soil profile. This N could be present in organic or inorganic forms. Figure 4 also shows that the addition of urea along with the residue resulted in a somewhat higher concentration of residue-N at depth between 12 to 42 cm from the soil surface than where residue was added alone. This effect of fertilizer on residue-N concentration in the soil at the end of the growing season was not evident in the 1986 field experiment where much more of the residue-N was utilized by the crop.

Growth chamber experiment

The effects of fertilizer application on growth of the wheat crop were first observed approximately one month after emergence. The growth of wheat in pots receiving the 100 kg N ha^{-1} urea rate was superior to the growth in pots receiving either the 0 or 50 kg N ha^{-1} urea rate. The growth of wheat plants in pots without urea-N addition was inferior to growth of all wheat plant in pots with urea-N addition. Throughout the course of the study, no visible differences in growth were observed between the crop in pots with different residue treatments.

Dry matter yield and total plant N uptake are shown in Table 16. For the growth chamber experiment, statistical significance was determined using the Duncan Multiple Range Test at the 95% confidence level where analysis of variance indicated the presence of significant differences. Statistical analyses for the growth chamber experiment are shown in Appendix A, beginning on page 101. Over all residue treatments, the yield

Table 16. The effect of fertilizer and residue N addition on dry matter yield and total N uptake by wheat for the growth chamber experiment.

Trt. No.£	N applied		Dry Matter Yield		Total N Uptake
	Fert.	Residue			
	-- kg N ha^{-1} --		---- g pot^{-1} ----		-- mg pot^{-1} --
1	0	0	25.83	a†	187
2	50*	0	31.95	bcde	256
3	100*	0	34.57	cde	381
4	0	152	28.35	ab	255
5	50*	152	31.56	bcd	341
6	100*	152	32.69	cde	445
7	0	166	31.20	bc	272
8	50*	166	35.89	de	389
9	100*	166	34.03	cde	517
10	0	163*	30.88	bc	273
11	50	163*	32.43	bcde	397
12	100	163*	34.14	cde	445
13	0	168*	33.14	cde	306
14	50	168*	33.81	cde	336
15	100	168*	36.16	e	489

£ treatment nos. 4 to 6 and 10 to 12 wheat residue added
treatment nos. 7 to 9 and 13 to 15 alfalfa residue added

† values are significantly different at $P \leq 0.05$ using the Duncan Multiple Range Test when not followed by the same letter

* labelled with ^{15}N

of wheat was significantly increased with the addition of urea. However, the yields of wheat from pots receiving the 50 or 100 kg ha^{-1} urea-N rates were not significantly different. Over all fertilizer treatments, significant differences were found between wheat yields from pots receiving different residue treatments. Yields were significantly higher where alfalfa residue was applied compared to where either wheat residue or no residue was applied. However, there were no significant differences between wheat yields of treatments with wheat residue addition or without residue addition. The wheat yield for treatment 1 (no additional N added) was significantly lower than yields for all the other treatments except treatment 4. For the labelled wheat and labelled alfalfa treatments, the addition of fertilizer did not significantly increase yield. Several other statistically significant differences were also observed, however, the differences are difficult to interpret because the rates of residue-N addition for the residue treatments varied.

Over all residue treatments, total plant N uptake significantly increased as the urea rate was increased from 0 to 50 to 100 kg N ha^{-1}. Over all fertilizer treatments, the addition of residue significantly increased total plant N uptake.

Table 17 shows the contribution of each ^{15}N-labelled source (urea or residue) to the percent and amount of N contained in the crop as well as the percent of N from each labelled source utilized by the crop. In all the following tables, PNDFL was defined to be the percent of plant N derived from the labelled source. However, in subsequent discussion, if the source of the label was urea it will be designated as PNDFF, and if the source of label was straw residue it will be designated as PNDFS.

Table 17. Percent and amount of nitrogen derived from ^{15}N-labelled fertilizer and residue and utilization of fertilizer and residue N by wheat for the growth chamber experiment.

Trt. No.£	N applied		PNDFL‡	NDFL§	ULS¶
	Fert.	Residue			
	-- kg N ha^{-1} --		--- % ---	-- mg pot^{-1}--	--- % ---
2	50*	0	23 b†	57	29
3	100*	0	39 d	147	44
5	50*	152	13 a	45	23
6	100*	152	28 c	126	37
8	50*	166	15 a	58	30
9	100*	166	27 c	140	42
10	0	163*	27	74 a	14 a
11	50	163*	26	103 bc	20 bc
12	100	163*	24	109 bc	21 c
13	0	168*	27	82 a	16 a
14	50	168*	26	88 ab	17 ab
15	100	168*	24	116 c	22 c

£ treatment nos. 5, 6, 10, 11, 12 wheat residue added
treatment nos. 8, 9, 13, 14, 15 alfalfa residue added
‡ PNDFL - percent nitrogen derived from labelled source
§ NDFL - amount of nitrogen derived from labelled source
¶ ULS - utilization of labelled source
† values are significantly different at $P \leq 0.05$ using the Duncan Multiple Range Test when not followed by the same letter
* labelled with ^{15}N

Similar abbreviations will be used for NDFL.

Over all residue treatments, PNDFF and NDFF significantly increased as the rate of urea-N was increased from 50 to 100 kg ha^{-1} (Appendix A). Consequently, over all residue treatments, PNDFS was significantly less for the wheat crop receiving the 100 kg N ha^{-1} urea rate (treatments 12 and 15) than the value for the crop receiving the 50 kg N ha^{-1} urea rate (treatments 11 and 14) due to a dilution effect. Significant differences were not observed for PNDFS values from the wheat crop from pots receiving treatments of 0 and 50 kg N ha^{-1} urea. Increasing the urea-N rate affected the actual amount of N derived from the residue (NDFS) in an opposite way to PNDFS. The NDFS values significantly increased as the urea rate was increased from 0 to 50 to 100 kg N ha^{-1} urea. These results are similar to those found in the field experiments and could likely be attributed to the stimulated growth of wheat where higher rates of urea-N were added or the possibility that the addition of urea promoted mineralization of residue-N resulting in an increased uptake of the residue-N.

Over all fertilizer rates, PNDFF was lowered by the addition of residue indicating the residue supplied considerable amounts of N to the wheat. The NDFF also showed a negative response to residue addition, however, the value was only significantly lower when comparing the unlabelled wheat residue treatments to the treatments receiving no residue addition. This is in contrast to lysimeter experiment #1 (1986) where there was no effect of residue on the percent and amount of fertilizer N found in the crop. There were no significant differences between the sources of the residue added (ie: unlabelled wheat or unlabelled alfalfa) on PNDFF, however, NDFF values were significantly greater for the

unlabelled alfalfa than the unlabelled wheat residue.

Statistical analyses (Appendix A) indicated there were no significant differences for PNDFS and NDFF amongst the treatments when considering the interaction of straw and fertilizer and looking at values for each individual treatment. Significant differences among the values for PNDFF and NDFS were found. The PNDFF for treatments including the 50 kg N ha^{-1} rate (treatments 2, 5, and 8) were significantly less than treatments including the 100 kg N ha^{-1} rate (treatments 3, 6, and 9). The PNDFF values for treatments receiving residue addition (treatments 5, 6, 8, and 9) were significantly lower than for values for the treatments receiving the corresponding urea rate without residue (treatments 2 and 3). For the labelled wheat residue, NDFS was significantly lower at the 0 kg N ha^{-1} rate than the other two fertilizer rates, while for the labelled alfalfa residue, NDFS at the 100 kg N ha^{-1} rate was significantly higher than the NDFS at the two lower urea-N rates.

Over all residue treatments, the percent utilization of urea-N was significantly greater for the 100 kg N ha^{-1} urea rate than the 50 kg N ha^{-1} urea rate. Over all fertilizer treatments, the utilization of urea-N was significantly lower where unlabelled wheat residue was added than where unlabelled alfalfa or no residue were added. Table 17 shows the amount of urea-N utilized by the crop was approximately 27% for the 50 kg N ha^{-1} rate and 41% for the 100 kg N ha^{-1} rate. These results are higher than those found in the field, approximately 24% and 21% in the 1986 and 1987 lysimeter experiments respectively. The higher values found in the growth chamber experiment could be due to the absence of losses due to leaching or because the roots of the crop were forced to explore the entire volume

of soil in the pots or both.

Over all residue treatments, the utilization of residue-N significantly increased as urea rates were increased from 0 to 50 to 100 kg N ha^{-1}. Over all fertilizer treatments, the utilization of residue-N from the labelled alfalfa was not significantly different from the labelled wheat. For the labelled wheat residue, the utilization of residue-N was significantly lower at the 0 kg N ha^{-1} rate than the other two fertilizer rates, while for the labelled alfalfa residue, the utilization of residue-N at the 100 kg N ha^{-1} rate was significantly higher than the utilization of residue-N at the two lower urea-N rates. The data indicate approximately 18% (30 kg N ha^{-1}) of the residue-N had been taken up by the crop. This compares with approximately 10% (15 kg N ha^{-1}) from the wheat residue with a C:N ratio of 17 used in the first lysimeter experiment applied at the same rate (5000 kg ha^{-1}). In the growth chamber experiment, the wheat crop derived an average of 26% of its total plant N from the plant residue added.

The data suggest the availability of the residue-N was higher than in the growth chamber than in the field. This could probably be due to the more favourable soil moisture content maintained in the growth chamber, the subsequent effect on the rate of decomposition of the residue, and the limited volume of soil in the pots compared to the lysimeters.

Even under the conditions of this growth chamber experiment, the residue-N was approximately one-half as efficient at providing N to the crop as the urea-N.

Even though the C:N ratios and the N contents were similar, 17 and 3% respectively, total N uptake, NDFF, and utilization of urea-N were

Table 18. Recovery of ^{15}N from ^{15}N-labelled urea, and wheat and alfalfa residues, after crop harvest in the growth chamber experiment.

Trt. No.	N applied		Recovery of ^{15}N from labelled source			
	Fert.	Residue	Soil N†	Soil N	Wheat plant N	Total
	-- kg N ha^{-1} --		mg pot^{-1}	---------- % recovery ----------		
2	50*	0	40	20	29	49
3	100*	0	70	21	44	65
5	50*	152	50	26	23	49
6	100*	152	80	24	37	61
8	50*	166	50	26	30	46
9	100*	166	70	21	42	63
10	0	163*	270	53	14	67
11	50	163*	220	43	20	63
12	100	163*	240	47	21	68
13	0	168*	240	46	16	62
14	50	168*	200	38	17	55
15	100	168*	240	46	22	68

† total soil N analysis included NO_3-N
* labelled with ^{15}N

significantly lower with the addition of unlabelled wheat than with the addition of unlabelled alfalfa residue. This suggests that perhaps other factors such as the composition of the residues (i.e. lignin and carbohydrate content) may have played a role in the availability and utilization of the residue-N (Herman et al., 1977; Wagger et al., 1985).

The recovery of ^{15}N from the ^{15}N-labelled urea or residues added is shown in Table 18. For pots receiving both urea and residue addition (treatments 5 to 9), about 24% of the urea-N was recovered in the soil organic N plus NO_3-N fraction of the soil. This value is somewhat lower in the absence of residue (treatments 2 and 3) where nearly 21% of the urea-N was recovered. For pots receiving residue-N addition (treatments 10 to 15), approximately 45% of the residue-N was found to remain in the organic N plus NO_3-N fraction of the soil. The total recovery of ^{15}N from the ^{15}N-labelled urea as measured by adding the amount of ^{15}N found as soil organic ^{15}N, $^{15}NO_3$-N, and plant ^{15}N was 48% at the 50 kg N ha^{-1} urea rate and 63% at the 100 kg N ha^{-1} urea rate. In contrast, other data from growth chamber experiments conducted using Manitoba soils and combinations of fertilizer and residue as N sources have shown total recoveries of fertilizer N to range from 85% to 95% (Tomar, 1981; Grenier, 1992). Although plant recovery of fertilizer N in all experiments were similar, soil N recovery of fertilizer N found by the earlier authors exceeded those found in this growth chamber experiment.

The total recovery of residue-N was 66% for the labelled wheat and 62% for the labelled alfalfa. Apparently, significant portions of both residue-N and urea-N were lost, possibly through the processes of volatilization and denitrification.

V. SUMMARY AND CONCLUSION

Field studies undertaken to determine the availability of N from plant residues added to a soil to a wheat crop indicated that a relatively small amount of residue-N was utilized by the crop. The amount of residue-N taken up by the crop largely depended on the C:N ratio or N content of the residue added. In the 1986 field experiment, the wheat crop used approximately 10% of the N added in the residue. This residue, applied at 5000 kg ha^{-1}, contained approximately 3% N and had a C:N ratio of 18. In the 1987 field experiment, the wheat crop utilized only 1.7% of the residue-N added. This residue was applied at the same rate as that in 1986 but contained 1.2% N and had a C:N ratio of 41. In the same field experiments, the average utilization by the wheat crops of urea applied at rates of 50 and 100 kg N ha^{-1} was 24% and 21% in 1986 and 1987 respectively.

The field studies demonstrated only a very minor number of differences between results for the different tillage treatments. These differences could probably be attributed to differences in soil moisture content and the methods used to incorporate the residue in the soil.

Distribution of spring applied urea-N within the soil at the end of the first growing season showed N originating from the urea-N was found mainly within the top 27 cm of the soil surface and could possibly have been influenced by residue addition. In 1986, the distribution of residue-N within the soil at the end of the first growing season showed N originating from the residue was found mainly within the top 12 cm of the soil surface and was influenced by the tillage treatments and associated zone of residue application. By the end of the first growing season some

residue-N had become distributed down through the soil profile. In 1987, the distribution of residue-N within the soil at the end of the first growing season showed results similar to 1986 but also indicated the addition of urea along with the residue resulted in a somewhat higher concentration of residue-N at depth between 12 to 42 cm from the soil surface than where residue was added alone. At the end of the first growing season in both 1986 and 1987, the concentration of residue-N remaining in the soil was considerably higher than that of the urea-N remaining in the soil at the end of the first growing season 1986.

The 1987 field study undertaken to determine the utilization of residual urea and residue N by a wheat crop found the utilization of N from the N sources applied the previous spring was very small, approximately 3% and 1% for the residue and urea N respectively. However, the amount of N provided to the wheat crop by the residual residue-N was six times that of the residual urea-N. The distribution of residual residue-N within the soil at the end of the second growing season showed the concentration of residue-N was becoming uniform throughout the top 30 cm of the soil profile. The concentration of this residue-N had not greatly decreased from that found at the end of the first growing season and seems to suggest that some portion of residue-N was continually being recycled within the microbial system or had become somewhat stabilized in the soil or both.

Results from the growth chamber experiment were consistently higher than those found for the 1986 field experiment employing residue of similar C:N ratio and N content. In the growth chamber, utilization of the residues added was approximately 18% while utilization of urea-N was

27% and 41% for the 50 kg N ha^{-1} and 100 kg N ha^{-1} urea rate treatments respectively. The higher values could probably be attributed to the more favourable soil moisture content found in the growth chamber. After harvest, approximately 38% of the residue-N (235 mg pot^{-1}) and 23% of the urea-N (45 to 75 mg pot^{-1}) remained in the soil. For the 50 and 100 kg N ha^{-1} urea rate treatments, 52% and 37% of the N respectively was not recovered in either the soil or wheat crop, for the residue-N approximately 36% was not recovered.

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APPENDIX A

The statistical analyses for the observations of the lysimeter and growth chamber experiments presented in the Results and Discussion section are reported in this appendix.

Analysis of Variance Procedures
Lysimeter Experiment #1 (1986) - Harvest 1

Table A1. Effect of tillage, residue, and fertilizer treatment on dry matter yield of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	530.40	25.26	5.77	.0001
Error	32	140.05	4.38		
Corrected Total	53	670.45			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	10.90	1.25	.3014
Fert	2	325.28	37.16	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	5.99	0.20	.7011

Duncan Multiple Range Test for variable dry matter yield
Factor: Fert $DMRT_{p=.05} = 1.492$

Fert	Mean	Grouping
100	14.611	a
50	13.162	b
0	8.833	c

Table A2. Effect of tillage, residue, and fertilizer treatment on total N uptake of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	266224.93	12677.38	7.16	.0001
Error	32	56686.35	1771.45		
Corrected Total	53	322911.28			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	20895.99	5.90	.0066
Fert	2	188165.26	53.11	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	1041.92	0.07	.8189

Duncan Multiple Range Test for variable total N uptake

Factor: Residue
$DMRT_{p=.05} = 30.02$

Residue	Mean	Grouping
LA	257.40	a
UL	243.41	a
NO	210.47	b

Factor: Fert
$DMRT_{p=.05} = 30.02$

Fert	Mean	Grouping
100	297.27	a
50	257.12	b
0	156.89	c

Table A3. Effect of tillage, residue, and fertilizer treatment on the percent of wheat plant N derived from the urea (PNDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	14330.90	682.42	101.65	.0001
Error	32	214.83	6.71		
Corrected Total	53	14545.73			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	1.42	0.11	.9000
Fert	2	14170.89	1055.41	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	21.51	0.86	.4522

Duncan Multiple Range Test for variable PNDFF
Factor: Fert $DMRT_{p=.05} = 1.848$

Fert	Mean	Grouping
100	39.566	a
50	22.397	b
0	0.000	c

Table A4. Effect of tillage, residue, and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the urea (NDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	121709.54	5795.69	57.68	.0001
Error	32	3215.52	100.48		
Corrected Total	53	124925.06			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	15.92	0.08	.9240
Fert	2	118947.98	591.87	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	350.98	0.53	.5439

Duncan Multiple Range Test for variable NDFF
Factor: Fert $DMRT_{p=.05} = 7.151$

Fert	Mean	Grouping
100	114.909	a
50	54.406	b
0	0.000	c

Table A5. Effect of tillage and fertilizer treatment on the percent of plant N derived from the residue (PNDFS)

Source	DF	SS	MS	F-value	Pr>F
Model	21	5521.62	262.93	111.00	.0001
Error	32	75.80	2.36		
Corrected Total	53	5597.42			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	228.91	48.32	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	124.82	752.31	.0013

Duncan Multiple Range Test for variable PNDFS

Factor: Tillage $DMRT_{p=.05} = 0.477$

Tillage	Mean	Grouping
Conv	15.059	a
Zero	12.018	b

Factor: Fert $DMRT_{p=.05} = 1.098$

Fert	Mean	Grouping
0	16.437	a
50	12.329	b
100	11.849	b

Table A6. Effect of tillage and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the urea (NDFS).

Source	DF	SS	MS	F-value	Pr>F
Model	21	31563.58	1503.03	37.38	.0001
Error	32	1286.72	40.21		
Corrected Total	53	32850.30			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	351.21	4.37	.0210

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	275.00	2.23	.2738

Duncan Multiple Range Test for variable NDFS

Factor: Fert $DMRT_{p=.05} = 4.523$

Fert	Mean	Grouping
100	35.876	a
50	34.249	a
0	29.839	b

Table A7. Effect of tillage, residue, and fertilizer treatment on the percent utilization of urea-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	6402.75	304.89	48.09	.0001
Error	32	202.89	6.34		
Corrected Total	53	6605.64			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	4.98	0.39	.6782
Fert	2	6222.81	490.73	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	19.00	0.39	.5972

Duncan Multiple Range Test for variable percent utilization of urea-N
Factor: Fert $DMRT_{p=.05} = 1.796$

Fert	Mean	Grouping
100	23.594	a
50	21.850	b
0	0.000	c

Table A8. Effect of tillage and fertilizer treatment on the percent utilization of residue-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	562.67	26.79	37.30	.0001
Error	32	22.98	0.71		
Corrected Total	53	585.65			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	6.26	4.36	.0212

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	4.91	2.23	.2740

Duncan Multiple Range Test for variable percent utilization of residue-N
Factor: Fert $DMRT_{p=.05} = 0.605$

Fert	Mean	Grouping
100	4.791	a
50	4.571	a
0	3.984	b

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Table A9. Effect of tillage, residue, and fertilizer treatment on dry matter yield of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	2983.13	142.05	9.26	.0001
Error	32	490.90	15.34		
Corrected Total	53	3474.03			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	476.81	15.54	.0001
Fert	2	1781.79	58.07	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	13.78	0.19	.7044

Duncan Multiple Range Test for variable dry matter yield

Factor: Residue
$DMRT_{p=.05} = 2.794$

Residue	Mean	Grouping
LA	37.641	a
UL	35.938	a
NO	30.661	b

Factor: Fert
$DMRT_{p=.05} = 2.794$

Fert	Mean	Grouping
100	40.822	a
50	36.379	b
0	27.038	c

Table A10. Effect of tillage, residue, and fertilizer treatment on total N uptake of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	623265.06	29679.29	9.07	.0001
Error	32	104662.15	3270.69		
Corrected Total	53	727927.21			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	89010.04	13.61	.0001
Fert	2	385704.48	58.96	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	2103.13	0.15	.7383

Duncan Multiple Range Test for variable total N uptake

Factor: Residue
$DMRT_{p=.05} = 40.80$

Straw	Mean	Grouping
LA	545.28	a
UL	525.89	a
NO	451.11	b

Factor: Fert
$DMRT_{p=.05} = 40.80$

Fert	Mean	Grouping
100	596.89	a
50	531.33	b
0	394.06	c

Table A11. Effect of tillage, residue, and fertilizer treatment on the percent of wheat plant N derived from the urea (PNDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	4430.43	210.97	57.73	.0001
Error	32	116.93	3.65		
Corrected Total	53	4547.36			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	0.21	0.03	.9717
Fert	2	4353.86	595.74	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	0.23	0.04	.8576

Duncan Multiple Range Test for variable PNDFF
Factor: Fert $DMRT_{p=.05} = 1.364$

Fert	Mean	Grouping
100	21.993	a
50	11.241	b
0	0.000	c

Table A12. Effect of tillage, residue, and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the urea (NDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	158419.88	7543.80	115.61	.0001
Error	32	2088.07	65.25		
Corrected Total	53	160507.95			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	113.38	0.87	.4291
Fert	2	157000.02	1203.02	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	36.56	0.74	.4816

Duncan Multiple Range Test for variable NDFF
Factor: Fert $DMRT_{p=.05} = 5.762$

Fert	Mean	Grouping
100	131.492	a
50	54.991	b
0	0.000	c

Table A13. Effect of tillage and fertilizer treatment on the percent of plant N derived from the residue (PNDFS)

Source	DF	SS	MS	F-value	Pr>F
Model	21	2585.28	123.11	33.92	.0001
Error	32	116.13	3.63		
Corrected Total	53	2701.41			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	81.05	11.17	.0002

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	11.74	1.15	.3954

Duncan Multiple Range Test for variable PNDFS

Factor: Fert $DMRT_{p=.05} = 1.359$

Fert	Mean	Grouping
0	11.147	a
50	8.677	b
100	8.436	c

Table A14. Effect of tillage and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the residue (NDFS).

Source	DF	SS	MS	F-value	Pr>F
Model	21	68720.79	3272.42	34.75	.0001
Error	32	3013.25	94.16		
Corrected Total	53	71734.04			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	339.18	1.80	.1815

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	336.00	6.61	.1239

Table A15. Effect of tillage, residue, and fertilizer treatment on the percent utilization of urea-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	7559.85	359.99	74.18	.0001
Error	32	155.30	4.85		
Corrected Total	53	7715.15			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	5.48	0.56	.5744
Fert	2	7445.41	767.08	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	5.18	0.57	.5275

Duncan Multiple Range Test for variable percent utilization of urea-N
Factor: Fert $DMRT_{p=.05} = 1.571$

Fert	Mean	Grouping
100	27.001	a
50	22.084	b
0	0.000	c

Table A16. Effect of tillage and fertilizer treatment on the percent utilization of residue-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	1225.10	58.34	34.69	.0001
Error	32	53.82	1.68		
Corrected Total	53	1278.92			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	6.05	1.80	.1819

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	6.00	6.54	.1249

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Table A17. Effect of tillage, residue, and fertilizer treatment on dry matter yield of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	1340.82	63.85	1.49	.1492
Error	32	1367.40	42.73		
Corrected Total	53	2708.22			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	222.83	2.61	.0893
Fert	2	411.97	4.82	.0148

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	110.37	1.45	.3517

Duncan Multiple Range Test for variable dry matter yield
Factor: Fert $DMRT_{p=.05} = 4.663$

Fert	Mean	Grouping
50	29.414	a
0	23.857	b
100	23.294	b

Table A18. Effect of tillage, residue, and fertilizer treatment on total N uptake of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	335183.33	15961.11	1.48	.1540
Error	32	344602.37	10768.82		
Corrected Total	53	679785.70			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	34287.26	1.59	.2192
Fert	2	99342.37	4.61	.0174

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	21760.30	0.89	.4448

Duncan Multiple Range Test for variable total N uptake
Factor: Fert $DMRT_{p=.05} = 74.027$

Fert	Mean	Grouping
50	422.44	a
0	335.22	b
100	328.11	b

Table A19. Effect of tillage, residue, and fertilizer treatment on the percent of wheat plant N derived from the urea (PNDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	30.62	1.46	42.74	.0001
Error	32	1.09	0.03		
Corrected Total	53	31.71			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	0.03	0.45	.6419
Fert	2	29.93	438.68	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	0.01	0.02	.9071

Duncan Multiple Range Test for variable PNDFF
Factor: Fert $DMRT_{p=.05} = .132$

Fert	Mean	Grouping
100	1.821	a
50	0.992	b
0	0.000	c

Table A20. Effect of tillage, residue, and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the urea (NDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	393.54	18.74	5.37	.0001
Error	32	111.70	3.49		
Corrected Total	53	505.24			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	1.16	0.17	.8475
Fert	2	315.93	45.25	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	0.44	0.09	.7976

Duncan Multiple Range Test for variable NDFF
Factor: Fert $DMRT_{p=.05} = 1.333$

Fert	Mean	Grouping
100	5.654	a
50	4.356	b
0	0.000	c

Table A21. Effect of tillage and fertilizer treatment on the percent of plant N derived from the residue (PNDFS)

Source	DF	SS	MS	F-value	Pr>F
Model	21	512.87	24.42	62.88	.0001
Error	32	12.43	0.39		
Corrected Total	53	525.30			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	5.52	7.11	.0028

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	0.01	0.02	.9066

Duncan Multiple Range Test for variable PNDFS
Factor: Fert $DMRT_{p=.05} = 0.444$

Fert	Mean	Grouping
100	4.670	a
0	4.246	b
50	3.888	b

Table A22. Effect of tillage and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the residue (NDFS).

Source	DF	SS	MS	F-value	Pr>F
Model	21	7723.68	367.79	28.52	.0001
Error	32	412.68	12.90		
Corrected Total	53	8136.36			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	6.23	0.24	.7867

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	68.59	30.13	.0316

Duncan Multiple Range Test for variable NDFS
Factor: Tillage $DMRT_{p=.05} = 1.767$

Tillage	Mean	Grouping
Zero	17.743	a
Conv	15.489	b

Table A23. Effect of tillage, residue, and fertilizer treatment on the percent utilization of urea-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	35.25	1.68	4.73	.0001
Error	32	11.36	0.36		
Corrected Total	53	46.61			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	28.57	40.24	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	0.01	0.01	.9518

Duncan Multiple Range Test for variable percent utilization of urea-N
Factor: Fert $DMRT_{p=.05} = 0.425$

Fert	Mean	Grouping
50	1.751	a
100	1.163	b
0	0.000	c

Table A24. Effect of tillage and fertilizer treatment on the percent utilization of residue-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	137.76	6.56	28.35	.0001
Error	32	7.40	0.23		
Corrected Total	53	145.16			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	0.11	0.25	.7831

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	1.22	29.92	.0318

Duncan Multiple Range Test for variable percent utilization of residue-N
Factor: Tillage $DMRT_{p=.05} = 0.236$

Tillage	Mean	Grouping
Zero	2.370	a
Conv	2.069	b

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Table A25. Effect of tillage, residue, and fertilizer treatment on dry matter yield of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	926.82	44.13	7.12	.0001
Error	32	198.45	6.20		
Corrected Total	53	1125.27			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	6.37	0.51	.6032
Fert	2	741.82	59.81	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	42.67	4.77	.1607

Duncan Multiple Range Test for variable dry matter yield
Factor: Fert $DMRT_{p=.05} = 1.776$

Fert	Mean	Grouping
100	18.462	a
50	14.663	b
0	9.422	c

Table A26. Effect of tillage, residue, and fertilizer treatment on total N uptake of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	347206.83	16533.66	9.28	.0001
Error	32	57030.15	1782.19		
Corrected Total	53	404236.98			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	5713.81	1.60	.2170
Fert	2	294623.81	82.66	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	1057.80	2.35	.2647

Duncan Multiple Range Test for variable total N uptake
Factor: Fert $DMRT_{p=.05} = 30.11$

Fert	Mean	Grouping
100	328.56	a
50	231.72	b
0	147.78	c

Table A27. Effect of tillage, residue, and fertilizer treatment on the percent of wheat plant N derived from the urea (PNDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	12726.55	606.03	53.18	.0001
Error	32	364.67	11.40		
Corrected Total	53	13091.22			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	0.45	0.02	.9805
Fert	2	12646.54	554.87	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	11.66	1.82	.3093

Duncan Multiple Range Test for variable PNDFF

Factor: Fert $DMRT_{p=.05} = 2.408$

Fert	Mean	Grouping
100	37.169	a
50	22.792	b
0	0.000	c

Table A28. Effect of tillage, residue, and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the urea (NDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	159875.29	7613.11	27.08	.0001
Error	32	8994.73	281.08		
Corrected Total	53	168870.02			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	588.13	1.05	.3630
Fert	2	155610.85	276.80	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	35.67	1.51	.3444

Duncan Multiple Range Test for variable NDFF

Factor: Fert $DMRT_{p=.05} = 11.960$

Fert	Mean	Grouping
100	130.564	a
50	51.782	b
0	0.000	c

Table A29. Effect of tillage and fertilizer treatment on the percent of plant N derived from the residue (PNDFS)

Source	DF	SS	MS	F-value	Pr>F
Model	21	105.46	5.02	26.02	.0001
Error	32	6.18	0.19		
Corrected Total	53	111.64			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	1.00	2.60	.0900

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	25.79	51.64	.0188

Duncan Multiple Range Test for variable PNDFS
Factor: Tillage
$DMRT_{p=.05} = 0.823$

Tillage	Mean	Grouping
Zero	2.213	a
Conv	0.830	b

Table A30. Effect of tillage and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the urea (NDFS).

Source	DF	SS	MS	F-value	Pr>F
Model	21	495.93	23.61	22.86	.0001
Error	32	33.06	1.03		
Corrected Total	53	528.99			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	48.54	23.49	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	83.38	30.78	.0310

Duncan Multiple Range Test for variable NDFS

Factor: Tillage
$DMRT_{p=.05} = 1.927$

Tillage	Mean	Grouping
Zero	4.306	a
Conv	1.875	b

Factor: Fert
$DMRT_{p=.05} = 0.725$

Fert	Mean	Grouping
100	4.132	a
50	3.369	b
0	1.851	c

Table A31. Effect of tillage, residue, and fertilizer treatment on the percent utilization of urea-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	6826.34	325.06	20.72	.0001
Error	32	501.97	15.69		
Corrected Total	53	7328.31			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	6.22	0.20	.8211
Fert	2	6665.26	212.45	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	0.83	0.22	.6877

Duncan Multiple Range Test for variable percent utilization of urea-N
Factor: Fert $DMRT_{p=.05} = 2.825$

Fert	Mean	Grouping
100	25.462	a
50	21.049	b
0	0.000	c

Table A32. Effect of tillage and fertilizer treatment on the percent utilization of residue-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	59.03	2.81	22.85	.0001
Error	32	3.94	0.12		
Corrected Total	53	62.97			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	5.77	23.46	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	9.93	30.77	.0310

Duncan Multiple Range Test for variable percent utilization of residue-N

Factor: Tillage
$DMRT_{p=.05} = 0.665$

Tillage	Mean	Grouping
Zero	1.504	a
Conv	1.347	b

Factor: Fert
$DMRT_{p=.05} = 0.250$

Fert	Mean	Grouping
100	1.426	a
50	1.162	b
0	0.639	c

Analysis of Variance Procedures
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Table A33. Effect of tillage, residue, and fertilizer treatment on dry matter yield of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	2186.56	104.12	4.81	.0001
Error	32	692.65	21.64		
Corrected Total	53	2879.22			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	138.73	3.20	.0539
Fert	2	1770.73	40.90	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	105.09	15.50	.0589

Duncan Multiple Range Test for variable dry matter yield
Factor: Fert $DMRT_{p=.05} = 3.319$

Fert	Mean	Grouping
100	30.947	a
50	23.919	b
0	16.921	c

Table A34. Effect of tillage, residue, and fertilizer treatment on total N uptake of wheat.

Source	DF	SS	MS	F-value	Pr>F
Model	21	466535.92	22215.99	4.71	.0001
Error	32	150991.41	4718.48		
Corrected Total	53	617527.33			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	27386.11	2.90	.0695
Fert	2	383982.11	40.69	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	19570.07	29.90	.0319

Duncan Multiple Range Test for variable total N uptake

Factor: Tillage
$DMRT_{p=.05} = 29.961$

Tillage	Mean	Grouping
Zero	363.815	a
Conv	325.741	b

Factor: Fert
$DMRT_{p=.05} = 49.00$

Fert	Mean	Grouping
100	449.94	a
50	340.89	b
0	243.50	c

Table A35. Effect of tillage, residue, and fertilizer treatment on the percent of wheat plant N derived from the urea (PNDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	5428.35	258.49	104.04	.0001
Error	32	79.50	2.48		
Corrected Total	53	5507.85			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	6.54	1.32	.2822
Fert	2	5342.79	1075.23	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	20.40	44.06	.0220

Duncan Multiple Range Test for variable PNDFF

Factor: Tillage

$DMRT_{p=.05} = 0.797$

Tillage	Mean	Grouping
Conv	13.283	a
Zero	12.054	b

Factor: Fert

$DMRT_{p=.05} = 1.124$

Fert	Mean	Grouping
100	24.298	a
50	13.707	b
0	0.000	c

Table A36. Effect of tillage, residue, and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the urea (NDFF).

Source	DF	SS	MS	F-value	Pr>F
Model	21	114478.37	5451.35	31.32	.0001
Error	32	5570.32	174.07		
Corrected Total	53	120048.69			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	1180.61	3.39	.0462
Fert	2	110883.53	318.50	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	185.63	1.30	.3727

Duncan Multiple Range Test for variable NDFF

Factor: Residue

$DMRT_{p=.05} = 9.412$

Residue	Mean	Grouping
NO	58.947	a
UL	49.028	b

Factor: Fert

$DMRT_{p=.05} = 9.412$

Fert	Mean	Grouping
100	110.532	a
50	46.471	b
0	0.000	c

Table A37. Effect of tillage and fertilizer treatment on the percent of plant N derived from the residue (PNDFS)

Source	DF	SS	MS	F-value	Pr>F
Model	21	111.71	5.32	45.89	.0001
Error	32	3.71	0.12		
Corrected Total	53	115.42			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	2.57	11.09	.0002

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	15.38	29.31	.0325

Duncan Multiple Range Test for variable PNDFF

Factor: Tillage $DMRT_{p=.05} = 0.848$

Tillage	Mean	Grouping
Conv	2.288	a
Zero	1.221	b

Factor: Fert $DMRT_{p=.05} = 0.243$

Fert	Mean	Grouping
50	2.026	a
100	1.747	b
0	1.491	c

Table A38. Effect of tillage and fertilizer treatment on the amount of wheat plant N (mg pot^{-1}) derived from the residue (NDFS).

Source	DF	SS	MS	F-value	Pr>F
Model	21	1048.78	49.94	28.10	.0001
Error	32	56.88	1.78		
Corrected Total	53	1105.66			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	66.11	18.60	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	69.59	13.26	.0678

Duncan Multiple Range Test for variable dry matter yield

Factor: Fert $DMRT_{p=.05} = 0.951$

Fert	Mean	Grouping
100	6.187	a
50	6.170	a
0	3.831	b

Table A39. Effect of tillage, residue, and fertilizer treatment on the percent utilization of urea-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	13246.38	630.78	27.74	.0001
Error	32	727.72	22.74		
Corrected Total	53	13974.10			

Source	DF	ANOVA SS	F-value	Pr>F
Residue	2	260.21	5.72	.0075
Fert	2	11829.67	260.09	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	14.80	0.53	.5410

Duncan Multiple Range Test for variable percent utilization of urea-N

Factor: Residue $DMRT_{p=.05} = 2.402$

Residue	Mean	Grouping
NO	15.274	a
UL	12.753	b

Factor: Fert $DMRT_{p=.05} = 2.402$

Fert	Mean	Grouping
100	21.888	a
50	18.891	b
0	0.000	c

Table A40. Effect of tillage and fertilizer treatment on the percent utilization of residue-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Model	21	124.66	5.93	28.09	.0001
Error	32	6.76	0.21		
Corrected Total	53	131.42			

Source	DF	ANOVA SS	F-value	Pr>F
Fert	2	7.89	18.68	.0001

Test of hypothesis using the ANOVA MS Block x Tillage as an error term

Source	DF	ANOVA SS	F-value	Pr>F
Tillage	1	8.27	13.29	.0677

Duncan Multiple Range Test for variable percent utilization of residue-N

Factor: Fert $DMRT_{p=.05} = 0.328$

Fert	Mean	Grouping
100	2.132	a
50	2.128	a
0	1.319	b

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Table A37. Effect of fertilizer treatment and residue addition on dry matter yield of wheat.

Source	DF	SS	MS	F-value	Pr>F
Fert	2	158.17	79.08	27.32	.0001
Residue	4	94.77	23.69	8.18	.0001
Residue x Fert	8	57.29	7.16	2.47	.0344
Error	30	86.84	2.89		
Total	44	397.07			

Duncan Multiple Range Test for variable dry matter yield

Factor: Fert
$DMRT_{p=.05}$ = 1.269

Fert	Mean	Grouping
100	34.318	a
50	33.129	a
0	29.882	b

Factor: Residue
$DMRT_{p=.05}$ = 1.638

Fert	Mean	Grouping
LA	34.369	a
UA	33.706	a
LW	31.485	bc
UW	30.869	bc
NO	30.786	c

Table A38. Effect of fertilizer treatment and residue addition on total N uptake of wheat.

Source	DF	SS	MS	F-value	Pr>F
Fert	2	291809.51	145904.75	149.23	.0001
Residue	4	77711.65	19427.91	19.87	.0001
Residue x Fert	8	15091.66	1886.46	1.93	.0921
Error	30	29332.10	977.74		
Total	44	413944.92			

Duncan Multiple Range Test for variable total N uptake

Factor: Fert
$DMRT_{p=.05}$ = 23.32

Fert	Mean	Grouping
100	455.31	a
50	343.91	b
0	258.64	c

Factor: Residue
$DMRT_{p=.05}$ = 30.10

Fert	Mean	Grouping
UA	392.66	a
LA	377.04	ab
LW	371.44	ab
UW	347.13	b
NO	274.83	c

percent of plant N derived from the urea (PNDFF)

Source	DF	SS	MS	F-value	Pr>F
Fert	2	6687.69	3343.84	1359.83	.0001
Residue	4	310.00	77.50	31.52	.0001
Residue x Fert	8	175.51	21.94	8.92	.0001
Error	30	73.77	2.46		
Total	44	7246.97			

Duncan Multiple Range Test for variable PNDFF

Factor: Fert — $DMRT_{p=.05} = 1.17$

Fert	Mean	Grouping
100	29.85	a
50	15.65	b
0	0.00	c

Factor: Residue — $DMRT_{p=.05} = 1.51$

Fert	Mean	Grouping
NO	20.41	a
UA	13.98	b
UW	13.73	b

Table A40. Effect of fertilizer treatment and residue addition on the amount of plant N (mg pot^{-1}) derived from the urea (NDFF)

Source	DF	SS	MS	F-value	Pr>F
Fert	2	140304.13	70152.06	1218.90	.0001
Residue	4	1103.59	275.90	4.79	.0041
Residue x Fert	8	627.89	78.49	1.36	.2521
Error	30	1726.60	57.55		
Total	44	143762.21			

Duncan Multiple Range Test for variable NDFF

Factor: Fert — $DMRT_{p=.05} = 5.66$

Fert	Mean	Grouping
100	135.62	a
50	52.45	b
0	0.00	c

Factor: Residue — $DMRT_{p=.05} = 7.30$

Fert	Mean	Grouping
NO	68.17	a
UA	65.93	a
UW	56.71	b

Table A41. Effect of fertilizer treatment and residue addition on the percent of plant N derived from the residue (PNDFS)

Source	DF	SS	MS	F-value	Pr>F
Fert	2	45.35	22.67	13.11	.0001
Residue	4	4767.99	1191.99	689.28	.0001
Residue x Fert	8	13.77	1.72	0.99	.4598
Error	30	51.88	1.73		
Total	44	4878.99			

Duncan Multiple Range Test for variable PNDFS

Factor: Fert
$DMRT_{p=.05}$ = 0.98

Fert	Mean	Grouping
0	21.63	a
50	20.90	a
100	19.23	b

Factor: Residue
$DMRT_{p=.05}$ = 1.51

Fert	Mean	Grouping
LW	25.89	a
LA	25.57	a
NO	0.00	b

Table A42. Effect of fertilizer treatment and residue addition on the amount of plant N (mg pot^{-1}) derived from the residue (NDFS)

Source	DF	SS	MS	F-value	Pr>F
Fert	2	5591.98	2795.99	41.34	.0001
Residue	4	65244.76	16311.19	241.16	.0001
Residue x Fert	8	2368.52	296.06	4.38	.0014
Error	30	2029.09	67.64		
Total	44	75234.35			

Duncan Multiple Range Test for variable NDFS

Factor: Fert
$DMRT_{p=.05}$ = 6.13

Fert	Mean	Grouping
100	89.66	a
50	76.43	b
0	62.36	c

Factor: Residue
$DMRT_{p=.05}$ = 7.30

Fert	Mean	Grouping
LW	95.21	a
LA	95.17	a
NO	0.00	b

Table A43. Effect of fertilizer treatment and residue addition on the percent utilization of urea-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Fert	2	12642.11	6321.06	790.34	.0001
Residue	4	173.06	43.26	5.41	.0021
Residue x Fert	8	100.44	12.55	1.57	.1758
Error	30	239.94	7.99		
Total	44	13155.55			

Duncan Multiple Range Test for variable percent utilization of urea-N

Factor: Fert
$DMRT_{p=.05} = 2.11$

Fert	Mean	Grouping
100	40.36	a
50	26.69	b
0	0.00	c

Factor: Residue
$DMRT_{p=.05} = 1.51$

Fert	Mean	Grouping
NO	24.36	a
UA	23.73	a
UW	20.02	b

Table A44. Effect of fertilizer treatment and residue addition on the percent utilization of residue-N by wheat

Source	DF	SS	MS	F-value	Pr>F
Fert	2	212.70	106.35	40.72	.0001
Residue	4	2482.44	620.61	237.65	.0001
Residue x Fert	8	90.22	11.28	4.32	.0015
Error	30	78.34	2.61		
Total	44	2863.70			

Duncan Multiple Range Test for variable percent utilization of residue-N

Factor: Fert
$DMRT_{p=.05} = 1.20$

Fert	Mean	Grouping
100	17.47	a
50	14.92	b
0	12.15	c

Factor: Residue
$DMRT_{p=.05} = 1.56$

Fert	Mean	Grouping
LW	18.82	a
LA	18.30	a
NO	0.00	b

APPENDIX B

The partitioning of urea or residue N in grain and straw components of wheat for the lysimeter experiments presented in the Results and Discussion section are reported this appendix.

Table B1. Partitioning of urea or residue N in grain and straw components of wheat for Lysimeter #1 (1986).

Trt. No.	Treatment		NDFL[§]						PNDFL[‡]			
	Fert.	Residue	Straw		Grain		Total		Straw		Grain	
			Z[†]	C[†]	Z	C	Z	C	Z	C	Z	C
	kg N ha^{-1}		mg pot^{-1}						%			
2	50*	0	21	21	40	28	61	49	34	57	66	43
3	100*	0	50	52	68	61	118	113	42	46	58	54
5	50*	150	19	19	36	36	55	55	35	35	65	65
6	100*	150	48	44	91	86	139	130	35	34	65	66
7	0	150*	26	32	39	44	65	76	40	42	60	58
8	50	150*	26	31	48	54	74	85	35	37	65	63
9	100	150*	28	22	45	53	73	75	38	29	62	71

§ NDFL - amount of nitrogen derived from labelled source
‡ PNDFL - percent of nitrogen derived from labelled source
† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N

Table B2. Partitioning of urea or residue N in grain and straw components of wheat for Lysimeter #2 (1987).

Trt. No.	Treatment		NDFL[§]						PNDFL[‡]			
	Fert.	Residue	Straw		Grain		Total		Straw		Grain	
			Z[†]	C[†]	Z	C	Z	C	Z	C	Z	C
	kg N ha^{-1}		mg pot^{-1}						%			
2	50*	0	15	16	31	42	46	58	33	28	67	72
3	100*	0	32	42	84	93	116	135	28	31	72	69
5	50*	60	12	15	33	27	45	42	27	36	73	64
6	100*	60	30	31	71	74	101	105	30	30	70	70
7	0	60*	2	2	3	5	5	7	40	29	60	71
8	50	60*	2	3	6	7	8	10	25	30	75	70
9	100	60*	2	3	4	9	6	12	33	25	67	75

§ NDFL - amount of nitrogen derived from labelled source
‡ PNDFL - percent of nitrogen derived from labelled source
† Z and C - zero and conventional tillage treatments respectively
* labelled with ^{15}N