EFFECT OF PLACEMENT OF ORGANIC MATTER AND UREA

ON IMMOBILIZATION OF NITROGEN

AND UPTAKE OF NITROGEN BY PLANTS

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by

JASWANT SINGH TOMAR

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ABSTRACT

The influence of soil characteristics, placement method and carbon-
aceous material upon immobilization and plant uptake of ^{15}N-labelled
urea-N was studied under laboratory, growth chamber and field condi-
tions.

In an incubation experiment, 3 to 32 ppm of added N were retained
by the soils immediately after urea was applied. Between 16 and 91 ppm
urea-N were retained by soils during the 12-week incubation period. In
10 soils, biological immobilization and/or chemical fixation was virtu-
ally completed within the first 4 weeks of incubation. In one soil there
was a continuous increase in the retention of added N during the remain-
ing 8 weeks of incubation. The rapid initial retention of added ^{15}N
was positively correlated with sand + silt content and negatively cor-
related with pH of the soil (R^2 = 0.86**). Soil organic matter (OM)
became increasingly more important in affecting the immobilization of
applied N as incubation progressed. Correlations between ^{15}N re-
tained and OM content for 4 and 8 weeks of incubation were positive,
R^2 values being 0.40* and 0.53*, respectively. After the 12 weeks of
incubation, the rentention of added N by soils was positively correlated
with OM and negatively correlated with soil pH (R^2 = 0.74**). Ten of
the 11 soils showed no or little N interchange suggesting that a signi-
ficant proportion of the applied N appeared to be truly immobilized
and/or fixed in soils of this study.

Results of the growth chamber experiments with rapeseed (Brassica
napus L.) as the test crop indicated that N uptake and dry matter yield

were higher for mixed than for point N applications where addition of high N residues resulted in appreciable N exchange and/or priming in the system. However, crop utilization of urea-N was greater in point than in mixed treatments particularly when carbonaceous residues were added and was inversely proportional to the immobilization of applied N. The losses of applied N were somewhat larger when N was added near to the soil surface than when placed otherwise. The proportion of fertilizer N found in the soil after harvest, i.e. that immobilized was particularly increased where organic residues were added to the soil and was greater for mixed than for point applied N. Residual fertilizer N found in the herbage of subsequent rapeseed crops varied from 4.2 to 12.8%. Crop recovery of immobilized fertilizer N was influenced more by organic residue placement than by the placement of fertilizer N.

Data of the field experiment conducted with barley (Hordeum vulgare L.) in lysimeters where fertilizer N removed by the above-ground portion of the crop and that remaining in the 100 cm soil depth were determined showed that N uptake and barley yield were greater from banded than from broadcast N and the differences were enhanced by adding organic matter to the soil. Recovery of fertilizer N in plant tops varied between 22.8 and 42.8% for urea surface broadcast and between 42.0 and 53.1% for urea applied in bands. Leaching losses of applied N appeared to be negligible for both methods of N application. Significantly more labelled N was found in soil from the broadcast than from the banded fertilizer (40.3 vs. 34.0% of added N) at the end of the experiment and the effect was particularly enhanced by mixing straw with the soil. Since leaching

losses were negligible and unaccountable differences probably as gaseous losses were essentially the same for broadcast and banded N applications (13 and 15%, respectively), the superiority of banding over broadcasting N was largely due to reduced immobilization of fertilizer N applied in a band.

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1. INTRODUCTION

The rapidly expanding world population has caused serious concern as to whether the basic need for food and fiber can be met. Increased N fertilization has undoubtedly contributed considerably towards crop production throughout the world. World consumption of fertilizer N was estimated to reach 45 million metric tonnes during the year 1976/77 (FAO, 1978). In Manitoba alone, consumption of fertilizer N for the years 1978 and 1979 amounted to 142,800 and 167,000 metric tonnes, respectively (Rennie et al., 1979). The relatively large consumption of N fertilizers and recent increases in energy costs have led to renewed interest in improving the efficiency of N fertilizers and especially that of urea and NH^+_4-based fertilizers which are particularly susceptible to NH_4^+ fixation/immobilization and NH_3 volatilization (Allison, 1966; Hauck, 1968; Terman, 1979).

The efficient use of N fertilizers requires a knowledge of all factors that influence the utilization of applied N by crops in the year of application and in subsequent years. The mechanisms that reduce the efficiency of fertilizer N applied to the soil include the fixation of N in soil organic and inorganic fractions, immobilization of N by soil microorganisms, gaseous losses of N through denitrification and NH_3 volatilization, and leaching. The topic of N recovery by crops has been extensively reviewed by Allison (1966) and Kundler (1970). However, if progress in the efficient use of N fertilizers is to be made, the influence of factors such as the rate of application, time of application, source of N, and methods of N placement must be thoroughly understood.

A review of the literature by Allison (1966) indicates that average crop recovery is about 50% of the N applied. Field experiments with barley in Manitoba (Soper et al., 1971; Toews and Soper, 1978) have revealed that on the average only about 50% of N added to the soil was recovered in the above-ground portion of the crop. Nitrogen carriers proved to be equally effective when they were properly worked into the soil surface before seeding. These researchers found placement of the carrier to be very important with regard to the utilization of applied N. If the N was banded with the seed, the average recovery of the N in the above-ground portion of the crop was about 60%, compared to 50% for the incorporated N, which represents a 20% increase in efficiency for the banded N placement. Other workers in Manitoba (Ridley, 1977) and Alberta (Nyborg et al., 1977) have also reported similar results. The reasons for the differences in efficiency for the two methods of placement are not well understood as, indeed, is the fate of the fertilizer N remaining in the soil, in forms unavailable to plants.

In an attempt to evaluate the effect of placement on N utilization by barley from several N sources, growth chamber experiments were conducted using ^{15}N (Powell, 1974). No differences were observed between placements for any of the carriers used. Essentially the same N uptake was observed from a point source as from a mixed throughout N treatment. The percent utilization of added N by the harvested portion of the crop varied from 36 to 42% and was roughly equal to that obtained in the field. The author postulated that the lack of a significant difference in N uptake between the two treatments may have been due to the watering practices used. The soils were watered immediately after

planting. Also, frequent watering was necessary during the period of plant growth. Under these conditions, N from the point source placement may have moved from the site of placement by diffusive and convective flow within the soil.

The lack of a proper explanation with regard to the differences in recoveries of added N for the broadcast and banded N applications led to the initiation of the present investigation. The work was undertaken to specifically study the effect of placement of organic matter and N on the utilization and immobilization of applied N and to see if immobilization of added N as affected by the method of placement could account for the observed differences in the efficiency of fertilizer N use by plants. Plant utilization of residual fertilizer N for different placement methods was also investigated. The work mainly relates to spring applied N.

2. LITERATURE REVIEW

Porter (1975) indicated that all transfers and interchanges of N occur mainly in three N pools, namely: (i) atmospheric, (ii) lithospheric (rocks and minerals), and (iii) biospheric (soil organic matter, plants, and animals). The biospheric N is believed to constitute only 0.02% of the N found in different global pools.

Nitrogen in soil is nearly all in organic forms and rarely does the plant available form exceed one percent of the total soil N at any one time. The most common forms of plant available N are NH_4^+, NO_3^- and a few simple organic compounds, particularly those containing amide and amino groups. In most soils, the amount of N that a crop receives from organic N mineralization is often far less than its requirement of N for good growth and optimum production. Application of N fertilizers is, therefore, one of the most effective means of increasing crop yields, particularly on soils in which soil organic matter has been depleted by cropping and long-term cultivation.

Most synthetic N fertilizers either contain inorganic forms of N (NH_4^+ or NO_3^-) or produce them through chemical and/or enzymatic reactions. The agricultural value of a N carrier is subject to change when placed in contact with two common variables; the soil and the crop. The soil and the added fertilizer N interact with each other chemically and biologically. For example, in the growth of any crop some residues are always returned to soil. The amount of residues returned, the chemical composition of residues, and the soil environment, all combine to determine the influence of residues on the availability of soil N as well as that of fertilizer N to the crop. Therefore, crop residues when

added to the soil are bound to affect the fertility status of our arable lands.

2.1 Soil Fertility and Organic Matter

Soil fertility refers to the status of the soil in relation to the amount and availability to plants of elements necessary for plant production (Canada Department of Agriculture, 1972). Soil fertility and productivity are commonly associated with organic matter which serves as the main reserve of plant nutrients. Soil organic matter is chiefly comprised of plant and animal residues at various stages of decomposition, cells (living and dead) and tissues of microbes, and materials synthesized by the soil population (Canada Department of Agriculture, 1972). Soil organic matter through its buffering capacity and its effect on chemical, microboiological, and physical aspects of soil characteristics, improves the availability of the nutrient elements. The role and usefulness of organic matter on soil fertility has been reviewed by several authors (Allison, 1973; Campbell et. al., 1976; Flaig et. al, 1977; Campbell, 1978; Paul and Van Veen, 1978).

2.2 Transformations of Nitrogen in Soil

The various phases of basic N transformation processes occurring in natural ecosystems are summarized by Jansson (1971). In soil, several different transformations of N may operate simultaneously all the time. Most of the N-transforming processes in the soil-plant system are biological in nature and can not be completely isolated from each other. From the viewpoint of plant production, only the resulting or net effect is the measurable parameter and has a real practical significance. However, the net changes in the system do not indicate the extent of what actually goes on in the soil. For example, the two opposite and simul-

taneously occurring phenomena of immobilization and mineralization may be vigorous and extensive and yet may have a small overall net apparent effect.

2.2.1 Nitrogen Immobilization

The transformation of inorganic N compounds (NH_4^+, NO_2^-, and NO_3^-) into the organic forms (organic nitrogenous constituents of cells and tissues) through their assimilation by soil microorganisms is normally termed biological immobilization or more commonly immobilization of N. The other two terms used in this context are "reversion" and "tie up" and refer to the immobilization (incorporation) of fertilizer N into the microbial tissues or other products of microbial synthesis (Bartholomew, 1965; Broadbent and Nakashima, 1967). Because of the simultaneous and continuous nature of the two processes of mineralization and immobilization in soil, the occurrence of immobilization in soil was overshadowed by the more conspicuous and dominating process of mineralization. Thus, the immobilization process remained neglected for quite some time in the general realm of soil microbiology and was perhaps the last to be studied in detail (Jansson, 1971).

2.2.1.1 Factors Affecting Nitrogen Immobilization

Biological immobilization operates both in cropped and uncropped soils, with and without the addition of an energy source and can be influenced by a host of soil, environmental and management factors.

(a). Soil Organic Matter: In the absence of added source of energy, immobilization of N in soil has been found to depend on the organic matter content of the soil (Walunjkar et al., 1959). The magnitude of immobilization also varies with the state of decomposition of soil organic matter.

(b). <u>Carbon: Nitrogen Ratio of Added Residue and Composition of Residue</u>

Addition of carbonaceous residues to soil can bring changes in soil N equilibrium and hence the fertility of soil. The extent of these changes will depend upon the amount, N content, and the decomposition characteristics of residues as they control growth and propagation of microbial population in the soil. The relationship between immobilization and mineralization of N is normally a function of the C/N ratio of the material added. A large ratio is associated with net N immobilization, and a smaller ratio with net mineralization. According to Russell (1973), if the N content of a residue is less than 1.2 to 1.3%, some immobilization of N will occur during the decomposition of the residue by soil microflora. When the N content of the material exceeds 1.8%, some release of N will generally be expected during its decay. With an intermediate N content, the decomposition of the material will tend to show little or no effect on the level of mineral N in the soil. According to Harmsen and Van Schreven (1955), the critical C/N ratio and N content for mineralization-immobilization equilibrium generally lies between 20 and 25 and 1.5 and 2.0%, respectively. Black (1968) gives N value of 1.2 to 2.6%. However, these values are not constant and can show variation with changes in other factors such as temperature, moisture, and quantity and make up of added organic materials.

The ease with which residue is decomposed in the soil has a profound effect on the rapidity and extent with which added N can be assimilated by organisms in the soil. Several reports (Bartholomew, 1965; Ahmad <u>et al</u>., 1969; Agarwal <u>et al</u>., 1972) have indicated that immobilization occurred more rapidly and in greater amounts when soluble

carbohydrates rather than plant residues were added to soils. Allison and Klein (1962) noted a very rapid N immobilization during the first 7 days when $NaNO_3$ and wheat straw were added to a sandy soil which reached a maximum value (1.7% of the straw weight) after about 20 days at a diminishing rate. Winsor and Pollard (1956), on the other hand, found that when sucrose and $(NH_4)_2SO_4$ were added to the soil, the maximum N immobilization (3.7% of the sugar weight) occurred in only 2 days as compared to a period of 20 days noted with the addition of straw. Furthermore, for a given C/N ratio, both mineralization and immobilization of N decrease with increasing lignin content in the residue (Bartholomew, 1965).

(c). Temperature, Moisture, and Oxygen: Environmental factors such as temperature, moisture content, and O_2 tension in soil, can influence N immobilization by either changing the time of maximum net immobilization (Nommik, 1962) or altering the quantity of N remaining in the residue after its decomposition. In some studies, however, experimental results have not been able to provide a clearcut answer concerning the effect of temperature on the amount of net maximum immobilization as opposed to the net mineralization (Kai et al., 1969). Low temperature (Nommik, 1962) and sub-optimum moisture (Waksman and Gerretsen, 1931; Kuo, 1955) tend to slow down the biological activity of heterotrophic organisms and thus lengthen the time to reach a particular stage of decomposition. Although the optimum temperature for the immobilization of N would be expected in the mesophilic range, immobilization can continue up to

higher temperatures (thermophilic range) at a reduced rate. Immobilization is reported to cease at about 70° C (Waksman and Gerretsen, 1931; Bartholomew, 1965).

Both immobilization and mineralization rates are decreased under anaerobic conditions. The decrease is attributed to (i) the reduced decomposition rate (Karim, 1948), (ii) production of lower biomass due to decreased substrate carbon assimilation by anaerobic microorganisms as opposed to their counterparts, aerobic organisms (Alexander, 1961), and (iii) much lower N requirement of the anaerobic metabolism leading to an increased release of NH^+_4 ions than would normally be expected due to the large C/N ratio of the added organic matter.

(d). pH: Biological activity is optimum around a pH value of 7.0, the so called "physiological pH". Microflora tend to be sensitive to changes in pH and any large deviation from the optimum value is likely to change the decomposition capability of the soil population. Norman (1931) noted that decomposition under acidic conditions was slower than under neutral to alkaline conditions. The net immobilization was reported to show the same trend. Similar results on the effect of pH on immobilization have been reported by Winsor and Pollard (1956). Both the reduced availability of phosphorus and a shift in soil population from bacteria to fungi due to low pH may decrease immobilization (Winsor and Pollard, 1956).

(e). Nutrient Status: The nutrient status and the availability of nutrients necessary to proliferate the soil microorganisms play an important role in the tie up of N in the soil. Allison (1955) and Bartholomew (1965) reported that when N limited the development

of the heterotrophic microflora, an increase in mineral N resulted in a corresponding increase in net N immobilization. They also observed that a high concentration of inorganic N caused a reduction in microbial activity. In general, the amount of N immobilized increases with amount applied (Stewart et. al., 1963; Allison, 1966) and decreases with increase in N-supplying capacity of the soil (Legg and Allison, 1967). Since P and S, especially the former, along with N are required in the processes of metabolism and reproduction in an organism, a change in the status of these elements will be expected to have an important effect on the decomposition of organic fraction in the soil (Thompson and Black, 1950; Walker and Adams, 1958).

(f). Form of Nitrogen: The question whether the heterotrophs, the microbial agents largely responsible for the decomposition and immobilization, prefer the assimilation of NH_4^+-N to that of NO_3^--N, has been surrounded by speculations. The earlier tracer work by Jansson (1958) indicated that when both sources of N are present, the soil heterotrophs favor the utilization of NH_4^+-N to NO_3^--N. Energy considerations involving the conversion of NH_4^+ (reduced form) to microbial metabolites (peptides, proteins etc.) seem to support this finding. Several other reports (Stojanovic and Broadbent, 1956; Allison and Klein, 1962; Broadbent and Tyler,1962; Ahmad et al., 1972) have, however, indicated the ready utilization of NO_3^--N by soil microflora. This is particularly applicable when NO_3^-N but not the NH_4^+-N is present in the soil. Walunjkar et al. (1959), on the other hand, were of the opinion that source of N, whether NH_4^+ or NO_3-, had little to do with the process of mineralization-immobilization. In a competition for the utilization of mineral N by

heterotrophs, nitrifiers, and higher plants, the heterotrophs have been found to be the most effective competitors in meeting their demands of available N, and plants the least (Jansson, 1958).

(g). Location of Plant Residues in Soil: The rate and extent of N immobilization during the decomposition of plant residues would be affected by the placement of residues in the soil. Crop residues added to the soil surface become dehydrated and tend to decompose more slowly than those buried or incorporated into the soil (Parker, 1962; Shields and Paul, 1973). Thus, the decomposition of surface applied residues results in a slower rate of immobilization as well as mineralization as compared to mixed or deep placed residues in the soil. Burial of residues under very dry conditions (Shields and Paul, 1973) or wet and cold conditions (Kononova, 1966) tends to conserve the residues. Msumali (1977), in a recent incubation study found that mixing straw into the soil immobilized twice as much N as did placing the straw in a band for both mixed and banded N applications.

(h). Influence of Plants: The presence of living plants in soil through their addition of organic materials on one hand, and consumption of mineral N on the other, may play a key role in the interaction of various N transformations in the soil-plant system. Theron (1951) observed that the net mineralization of N was reduced where plants were grown in soils. The reduction was attributed to the presence of compounds which inhibited the mineralization of soil N. Barrow (1960), on the other hand, postulated that the reduction was due to the absorption of all the inorganic N from the soil by the continuous growth of plants resulting in a deficiency of available N for the soil microflora, with a

consequent decrease in the decomposition of soil organic matter. According to Goring and Clark (1948), a decrease in net mineralization in cropped as opposed to summerfallowed soils was due to the possible increase in immobilization of N by the rhizosphere population. Legg et al. (1971) also reported that immobilization of added N into organic forms was increased by growing oats in the greenhouses.

A more acceptable explanation for the increased immobilization of N in cropped in contrast to uncropped soils appears to be that under the influence of living plants the mineralized N is subsequently re-immobilized into microbial tissues. This is attributed to the greater number of microorganisms due to the additional sources of organic matter available in roots, sloughed off root materials, and organic substances excreted or secreted from growing plants. It is estimated that in arable soils, a yearly dry matter supply to the soil (stubble, roots, and organic debris) amounts to about 2,000 - 4,000 kg per hectare, which on the assumption that 35 kg plant dry matter is necessary for immobilization of one kg N into microbial mass, can immobilize about 60 to 110 kg N per hectare (Huntjens, 1971).

(i) Influence of Puddling and Drying of Soil: Both immobilization and mineralization of N have been reported to increase with drying and puddling of soil (Maeda and Shiga, 1978). Both factors appear to have less effect on immobilization than on mineralization. Additional studies are needed which should include a detailed and stepwise account of N immobilization due to drying and wetting as well as freezing and thawing of soils.

2.2.1.2 <u>Availability of Immobilized Fertilizer Nitrogen</u>:

Research results (Bartholomew, 1965, Allison, 1966) indicate that about 25 to 60% of applied N remains immobilized in the soil. The release of this immobilized N is associated with the stability of microbial tissues and their metabolic and related products into which the added N has been incorporated. The increased stability (or decreased mineralization) of immobilized N can be attributed either to its biological reversion (Broadbent and Tyler, 1962; Broadbent and Nakashima, 1967) or to the non-enzymatic fixation into soil constituents involving NH_4^+, and NH_3 incorporation into compounds which become less susceptible to biological and chemical degradation with time (Nommik, 1965). The immobilized N may resist mineralization for rather long periods of time. From long-term pot experiments, performed with ^{15}N-labelled N fertilizers, the biological half-life of immobilized ^{15}N has been estimated in the range of 40 - 50 years (Jansson, 1971). The half-life of the live biomass fraction of the residual fertilizer N (amount of added ^{15}N remaining in the soil) has been given 2.4 years in the field (Juma and Paul, 1979). The half-life for the non-living mineralizable-N pool fraction was shown to be 7.7 years by these workers (Juma and Paul, 1979).

In a 6-year pot experiment, a net mineralization of about 3.0 to 4.7% per year of biologically immobilized N was reported by Jansson (1963). The amount of immobilized N released to the crop was estimated to amount to 10-15 kg N per hectare per year in many arable soils of temperate regions and was assumed to be the same as in the long-term pot experiments (Jansson, 1971). Juma and Paul (1979) indicated that after

one growing season, less than one percent of the ^{15}N remaining in the soil was present in the non-exchangeable and inorganic pools in the field. Tracer work also indicates that plant uptake of immobilized fertilizer N is generally less than the total amount of labelled N which may mineralize from the immobilized fertilizer N (Jansson, 1958; McGill et al., 1974) Losses of N from soils may account for this difference. Generally speaking, crop recovery of immobilized N in the greenhouse is about 1 to 4%, of the amount applied, whereas, the figure varies from zero to 50% under field condition (White et al., 1958).

From a practical point of view, the turnover process (mineralization-immobilization) is important. In the dryland agriculture of the Canadian prairies some residues are usually returned to the soil. The amount and N content of residues returned influence the supply of soil available N. Crop residues, with N content above about 1.6-1.7% N may supply nitrogen to plants following their addition to the soil. Crop residues such as corn stover and cereal straws (N content<1.6%) temporarily tie up N during their decomposition in soil, after which the immobilized N together with the original N in the residue is mineralized. Any management or cultural practice which influences the production, composition of crop residues or conditions of decomposition, will also affect the tie up and release of N.

2.2.2. Dynamics of Mineralization-Immobilization

Much of the classical work on N mineralization-immobilization (net N transformations and factors affecting them, as discussed earlier) can be found in the works of Jansson (1958) and Bartholomew (1965) (see also McGill, 1969 and Msumali, 1977). Investigations on the mechanisms and

quantifications of N transfers involving the complex inter-relationships between inorganic and organic constituents of the soil are, however, relatively new. To better understand the disposition of N in the soil and the N-supplying power of our soils, knowledge of N turnover processes is necessary.

2.2.2.1 Nitrogen Turnover: The biological N transformations (heterotrophic N cycle, especially), including synthesis, accumulation, humification, and degradation of microbial metabolites and other synthetic products of microbial and plant origin following the decomposition and utilization of added plant residues and soil organic carbon and N, in relation to their direction and quantification, may be referred to as N turnover. Turnover is also defined as the flux of organic N going through the organic matter, as modified by the mineral N pool (Hauck and Bremner, 1976).

Awareness of the significance of the turnover can be traced to the observation that results obtained by the two methods of calculating the recovery of fertilizer N, i.e.; the direct ^{15}N method which determines the amount of labelled fertilizer N removed by the crop, and the difference method which measures the difference in the amounts of N taken up by plants from the fertilized and unfertilized soils, are seldom the same. The indirect or difference method generally overestimates N recovery in the harvested crop, and the extent of overestimation is enhanced by adding an energy source to the soil. This disturbing and not so-well understood observation has largely contributed to the initiation of much of the current research pertaining to the quantification of N-transformation in the soil-plant system. The research results seem to

suggest that both the immobilization-mineralization turnover (N interchange) and priming effect (stimulation in soil N mineralization) help to explain the observed difference between the two recovery values indicated above.

The background information about the early concepts on the dynamics of organic matter/organic N can be found in the works of Jansson (1958, 1971) and Jenkinson (1966a, b). For more recent details on the subject, the reader is directed to the following works (McGill, 1971; Shields et al. 1973, McGill et al., 1973; McGill et al., 1974; Hauck and Bremner, 1976; Paul and McGill, 1977; Campbell, 1978; Paul and Van Veen, 1978).

The first detailed experimental study on the topic of turnover was performed by Jansson (1958). Using cross-wise tagging and mathematical expressions developed by Kirkham and Bartholomew (1954, 1955), Jansson (1958) theorized the existence of an active and a passive phase within the internal cycle of soil N. He indicated 10 to 15% of the total soil N to be in the active phase - a readily mineralizable N pool consisting of the living and freshly decomposed organic material in the soil.

The preferential utilization of NH_4^+-N over NO_3^--N by heterotrophic soil flora seems to suggest that the NH_4^+-N rather than the NO_3^-N constitutes the main pathway of mineralization-immobilization turnover cycle in the soil. The consequences of this relationship are that under the conditions of net mineralization (a common situation in most of normal agricultural soils), the NO_3^- pool does not form

the main component of the turnover process and, also, inorganic N may be released (nitrification) from the N cycle. On the other hand, the NO^-_3-N can always be utilized by heterotrophs under conditions of net immobilization and in that case, NO^-_3-N will be withdrawn into the turnover cycle. However, plants are normally the largest regular consumers of this NO^-_3-N from the soil.

After the inorganic N is incorporated into organic residues, some portion of this freshly immobilized N may remineralize and some may transform into increasingly stable compounds forming an integaral part of the soil N (Broadbent and Nakashima, 1965; Allen et al., 1973) The turnover rates of organic N in arable soils have generally been estimated in the range of 2 to 5% per year (Bartholomew, 1965). The stability of the nitrogenous compounds is largely based on the biological function and chemical composition of the metabolites produced and their susceptibility to decomposition. The stabilization of immobilized N in soil involves several biotic and abiotic interactions within soil, the mechanisms of which are not completely understood. On the basis of their biological stability, Jenkinson (1971) proposed the division of various organic fractions in the soil as follows: (i) fresh and partially decomposed residues (ii) residual lignins (iii) materials containing microbial cells and secondary products of microbial synthesis (iv) inorganic-organic colloidal complexes, and (v) stabilized humic substances. The use of ^{15}N has indicated that after the added N is incorporated into relatively stable organic substances, it is more active biologically than the native soil N (humic N) (Broadbent and

Nakashima, 1967; Legg et al., 1971).

In recent years, applications of a variety of tracer techniques (e.g. multiple labelling using ^{14}C and ^{15}N) and fractionation methods have greatly enhanced our understanding of C and N flow in the soil under laboratory and field conditions (Jenkinson, 1971; Greenland 1971; McGill, 1971; McGill et al., 1974; Paul and Van Veen, 1978). Several mathematical models have been developed to define and simulate the changes in the soil organic matter and its C and N components (Jenkinson, 1966a; McGill, 1971; McGill et al., 1974; Paul and Van Veen, 1978). For further details on this subject, the review by Campbell (1978) is worth mentioning.

Among the various fractions of organic materials, amino acids and amino sugars have been found to be the main constituents which are involved in the turnover process of the soil (Cheng and Kurtz, 1963; Chu and Knowles, 1966; Freney and Simpson, 1969; McGill et al., 1973). Cheng and Kurtz (1963) and Chu and Knowles (1966) observed that when tagged N and C were added to the soil, most of the immobilized N was present in the amino acid fraction of the organic matter. Similar results were reported by Tusneem and Patrick (1971). McGill et al. (1973), using ^{14}C-acetate and $^{15}NH_4$-N, found a highly significant correlation between C and N turnover indicating a strong interdependence of C and N components of organic matter in the turnover processes in the soil. The main products of microbial synthesis in this study were carbohydrates, amino sugars, and amino acids. Interestingly, C and N present as amino acid fractions appeared to be more resistant to microbial degradation than those present as carbohydrates or amino

sugars. About 50% of the amino acid-N was found to be associated with the non-organic soil colloidal fraction with a diameter of ≤ 0.04 um. The distribution of microbial cells and metabolic products containing recently immobilized ^{15}N in silt-size fractions has also been reported in a recent study by Ladd and Amato (1980).

2.2.2.2. Priming Effect: The variations in the rate of mineralization of biomass C and N after addition of energy material and mineral N to the soil is termed as priming effect or priming action (Jansson, 1971). Depending upon whether the additions of extraneous materials stimulates or retards soil N mineralization, the priming effect can be positive or negative. Both C and N balances of soil are known to be influenced by the priming action of carbonaceous and nitrogeneous compounds added to soil (Mortensen, 1963; Jenkinson, 1966a,b).

An increase in soil N mineralization with a concomitant increase in plant uptake of soil N (Sapozhnikov et al., 1968; Westerman and Kurtz, 1973) following addition of fertilizer N to soils has been observed under greenhouse and field conditions (Broadbent and Nakashima, 1971; Westerman and Kurtz, 1973; Westerman and Tucker, 1974). A reduction in the mineralization of soil N (negative priming) after addition of N fertilizer, particularly in the presence of high concentration of NH^+_4 compounds, was reported by Gadet and Saubies (1966) and Westerman and Tucker (1974).

The question, whether or not the priming action leads to a net reduction in the soil organic N content, does not seem to have an un-equivocal answer. Jansson (1971) takes the view that observations of this kind might be related to the experimental error and, therefore,

need careful analysis of data. Another question, whether the stimulation in soil N mineralization is due to priming or N turnover (mineralization-immobilization turnover), is equally intriguing and calls for a careful interpretation of the experimental results. According to Jansson (1958), the apparent increase in the mineralization of soil N due to added N is a feature of mineralization-immobilization turnover (N interchange between added and soil N or a dilution of the labelled inorganic N pool) which is further associated with the microbial activity in the soil. This explanation has been supported by several other investigators (Stewart et al., 1963; Nommik, 1968). However, this explanation has been disputed by Broadbent (1965) and Broadbent and Nakashima (1971) who believe priming to be real and attribute it to factors such as salt effect (osmosis) and pH changes following fertilizer N additions to soils. Other investigators including Legg and Stanford (1967), Westerman and Kurtz (1973), and Westerman and Tucker (1974) also consider the priming action of fertilizer N to be a real phenomenon which they relate to the stimulated microbial activity resulting from the addition of NH^+_4-salts, decreased immmobilization, and increased mineralization in the rhizosphere.

Laura (1974, 1975), on the other hand, disagrees with most of the above explanations for the priming effect of added fertilizer N and suggests that priming in soil is due to chemical processes involving the reaction of H^+ ions in the soil. According to this protolytic theory put forward by Laura (1975), portons released from NH_4^+- containing fertilizer chemically react with nitrogenous organic bases in soil and catalyze the liberation of N from these bases (eq. 1).

$$RNH_2 + NH_4^+ \longrightarrow RNH_3^+ + NH_3 \qquad (1)$$
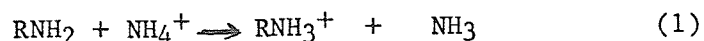
In conclusion, none of the above explanations for the observed priming action of added fertilizers appears to be completely acceptable. The effect, whether real or apparent, probably arises from a combination of more than one chemical and biological N transformation occurring in the soil-plant system. Also, this effect may have, in part, been coined from the difficulty in interpretations of a variety of tracer data encountered in studies carried out under varied experimental conditions.

2.2.3 Fixation of Ammonia in Soils

Ammonia or NH_4^+-N, unlike NO_3^--N, can be retained in soils either by fixation in non-exchangeable form within lattice structures of some clay minerals or by a chemical interaction between HN_3 and organic fractions of the soil. Such interactions of NH_3 and NH_4^+ with soil components reduce their susceptibility for biological transformations and hence their availability to plants and microorganisms. Both NH_3 and NH_4^+ fixation have been reviewed by Nommik (1965). Since different chemical species and mechanisms are involved in these N-transforming processes, their discussions will be considered separately.

2.2.3.1. Fixation by Clay Minerals: Experimental results indicate that non-exchangeable NH_4^+ which does not include fixation by organic matter constitutes 1 to 10% of the total N in surface soil and up to about 50% in sub-soils (Williams, 1967). McBeth (1917) appears to be the first to have observed that when NH_4^+-N was added to soil, it could not be completely recovered by extraction with acid or by alkaline distillation. The unrecovered portion of added N was suspected to be

retained in unavailable form by the soil. The mechanisms of NH_4^{4-} retention by the soil are now well understood.

The NH_4^+ fixation-defixation relationships in a soil system can be represented by the following dynamic equilibria among various forms of NH_4^+-N:

$$(NH_4^+)_s \rightleftharpoons (NH_4^+)_e \rightleftharpoons (NH_4^+)_f \qquad (2)$$
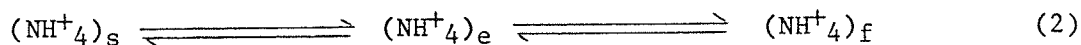
where, s, e, and f subscripts represent soil solution, exchangeable, and fixed forms of NH_4^+, repsectively. Both Freundlich and Langmuir kinetic relationships have been applied to the study of NH_4^+ fixation in the soil. Fixation of NH_4^+ in soils is believed to be strongly selective (Beckett and Nafaday, 1967).

The NH_4^+ fixation in soils is a relatively rapid process and quite large amounts of the applied NH_4^+-N can be clay-fixed within days after NH_4^+ fertilization. An incubation study by Kowalenko and Cameron (1976) showed that approximately one-half of the added NH_4^+ (0-1000 ppm N) was fixed in a surface clay loam soil within 2 days after $(NH_4)_2SO_4$ was applied to the soil. Similar findings were reported in another incubation study by Sowden (1976). In two subsequent field experiments Kowalenko (1978) and Kowalenko and Cameron (1978), also found that about 34 to 60% of the added NH_4^+-N (150 kg N/ha) was fixed immediately upon application. They, however, contrary to the general consensus, noted that a large proportion (71-96%) of the recently fixed NH_4^+-N was released to barley over the growth period of about 90 days.

The rigidly trapped NH_4^+ may be slowly released to higher plants and microorganisms. The difficulty in release of the fixed

NH^+_4-N has been attributed to a possible change in geometry of the fixing medium upon chemical fixation as well as the irreversibility of the exchange reaction. Fixation of NH_4^+ by clay minerals does not appear to have a significant effect on the efficiency of fertilizer N utilizaiton in Western Canada (Penny and Henry, 1976). Fixation of N as NH_4^+ may help conserve N in the soil.

2.2.3.2 <u>Fixation by Organic Matter</u>: The NH_3 which is released from NH^+_4-compounds added to soils or used as a fertilizer, can react with soil organic matter to form compounds which resist decomposition. The reaction of free NH_3 with the organic fractions of soil is referred to as the fixation of NH_3 by organic matter. According to Broadbent <u>et al</u>., (1961) and Nommik and Nilsson (1963a, 1963b), the fraction of added NH_4^+ which is retained by the soil organic matter after intensive extraction and leaching with acid or neutral salt solution is also termed as fixed NH_3. The early literature on the subject has been reviewed by Mortland (1958).

The exact mechanism which might be involved in NH_3 retention by the organic fractions of soil is still obscure. Condensation of NH_3 with phenolic constituents resulting in the formation of quinoneimines has been proposed (Jansson, 1960; Broadbent <u>et al</u>., 1961). The presence of O_2 and high pH (>7) appear to accelerate the reaction (Mattson and Koutler-Anderson, 1943). Broadbent <u>et al</u>., (1961) and Nommik and Nilsson (1963) also indicated that the extent of NH_3 fixation by soils was strongly dependent on the pH of the medium. Using ^{15}N recovery data, these workers showed that at pH less than 7, fixation was insignificant and increased linearly with pH above the neutral point.

Fixation of NH_3 in organic soils was found to be positively correlated with the carbon content of the soil (Burge and Broadbent, 1961). Similar results were reported by other workers (Sohn and Peech, 1958; Mendez, 1963). Other possible reactions responsible for NH_3 fixation in soils have been discussed in detail by Mortland and Wolcott (1965).

The agronomic significance of NH_3 fixation in soils depends upon soil environments. In organic soils with a high fixing capacity, it could be uneconomic to use ammonia-yielding N fertilizers such as urea. In normal mineral soils, fixation of NH_3 may not be a serious problem. It is also quite likely that fixation of NH_3 in such soils may be compensated, at least in part, by increased soil N mineralization due to increased soil pH resulting from NH_3 application.

2.3 Crop Recovery of Applied Nitrogen

Most of the early work on N balance studies in the soil-plant system, including laboratory, greenhouse, lysimeter, and field experiments, has been reviewed by Allison (1955, 1966). Some of the results of his reviews are shown in Table 1. Use of ^{15}N-labelled fertilizers has allowed direct measurements of fertilizer N in the harvested crop and in soil.

Since the last review on the subject was done by Allison (1966), there have been other accounts of research dealing with the recovery of ^{15}N-labelled fertilizers by the crop and the degree of retention of added N by the soil (Kundler, 1970; Badzhov and Ikonomova, 1971; Bartholomew, 1971; Hauck, 1971; Zamyatina, 1971). Some of the results of these accounts are given in Table 2.

Much of the current research concerning the fate of applied N seeks

Table 1. Nitrogen recoveries (crop plus soil) in pot experiments using ^{15}N-tagged nitrogen. (Allison, 1966).

Investigator	N source	N recovery (%)
MacVicar et al. (1951)	$(NH_4)_2SO_4$	85-97
Wallace and Smith (1954)	Orange leaves	60-96
	Orange roots	84-87
	Avocado leaves	94-100
Walker et al. (1956)	KNO_3	66-71
	$(NH_4)_2SO_4$	70-75
Tyler and Broadbent (1958)	NH_4NO_3	88-94
	$(NH_4)_2SO_4$	95-98
	NH_4OH	81-84
Legg and Allison (1959)	$NaNO_3$	91-98
	$(NH_4)2SO4$	90-100
Cady and Bartholomew (1960a)	$(NH_4)_2SO_4$	74-83
Dilz and Woldendorp (1960)	KNO_3	60-89
Turtschin et al. (1961)	$(NH_4)_2SO_4$	66-89
Legg (1962)	$NaNO_3$	90
Broadbent and Tyler (1962)	KNO_3 (cropped)	65-79
	KNO_3 (uncropped)	53-62
	$(NH_4)_2SO_4$ (cropped)	68-80
	$(NH_4)_2SO_4$ (uncropped)	56-72
Martin et al. (1963)	NH_4NO_3	94
Jansson (1963)	$NaNO_3$	86-90
	$(NH_4)_2SO_4$	90-92
Dinchev (1964)	$(NH_4)_2SO_4$	72-81
Broadbent and Nakashima (1965)	$(NH_4)_2SO_4$	61-79

Table 2. Relative recovery of tracer nitrogen by plants under greenhouse and field situations (Bartholomew, 1971).

INVESTIGATOR	CROP	NITROGEN SOURCE AND METHOD OF APPLICATION	EXPERIMENTAL TIME (week)	% RECOVERY
		Greenhouses		
Allos and Bartholomew (1955)	Legumes	(NH4)2SO4 at weekly intervals	10	43 - 73
	Grasses	(NH4)2SO4 at weekly intervals	10	60 - 99
Bartholomew and Hiltbold (1952)	Oats	(NH4)2SO4 at planting	5 and 10	27 - 54
Broadbent and Norman (1946)	Sudan grass	Ca(NO3)2 at planting with straw	8	1 - 14
Cady and Bartholomew (1960)	Sudan grass	(NH4)2SO4 at planting with corn residue	6	50 - 71
		(NH4)2SO4 at planting without corn residue	6	23 - 50
MacVicar et al. (1951)	Oats & sudan grass	(NH4)2SO4 at planting	17	38 - 47
Norman and Kranpitz (1945)	Soybeans	NH4NO3 at intervals	10	55 - 59
	Soybeans	Ca(NO3)2 at intervals	10	74 - 100
Thornton (1946)	Soybean and Lespedeza	Ca(NO3)2 at planting	11	53 - 98
		Field		
Bartholomew et al. (1950)	Oats (top growth)	(NH4)2SO4 when grain 2-4 inches long		11 - 29
Bartholomew and Fitts (1964)	Corn (tops and roots)	KNO3 late in season	2.0, 3.5	30 - 45
Bartholomew and Fitts (1964)	Coastal Bermuda grass (tops)	KNO3 late in season	4, 5	30 - 39
Swedlund (1956)	Corn (tops)	KNO3 late in season	2	18 - 40

to explore our understanding of those mechanisms which control the forms and amounts of fertilizer N in the soil and that taken up by crop plants. The increasing concern for maximizing the efficiency of N use by plants is reflected in the increased number of tracer studies which have been designed to measure the utilization of applied N by the crop. Nevertheless, comparatively few field experiments have been reported that account for the added N in the soil-plant system. Likewise, attempts to determine N losses through leaching and volatilization have met with no or limited success under field conditions.

Most tracer and non-tracer field experiments examined by Allison (1966) have indicated recoveries of applied N between 50 and 70% in the first crop. Subsequent reviews by Kundler (1970) and Hauck (1971), where ^{15}N-labelled fertilizers had been used under different experimental conditions, have given the following recoveries of fertilizer N in the year of application: in the crop, 30 to 70% (indicating an average recovery in the above-ground portion of the crop of 50% of the N applied); in the soil, 10 to 40%; removed by leaching, from 5 to 10%; and that remained unaccounted for and presumably lost, from 10 to 30%. Field experiments conducted in Manitoba (Soper et al., 1971; Ridley, 1977) and in Saskatchewan (Myers and Paul, 1971) have also indicated similar results. For additional details on this topic, the bibliography of ^{15}N work published by Hauck and Bystrom (1970) may be consulted.

2.3.1 Processes Affecting Efficiency of Nitrogen Use

It is now generally recognized that only about 50% of N applied to soil is annually assimilated by crop plants. Nitrogen which does not

find its way into the harvested portion of the crop can be incorporated into various transformations represented in Fig. 1. For example, some part of fertilizer N can be fixed by clay minerals, some of it can be assimilated by soil microorganisms and transformed in organic compounds, and still some of it can be involved in ammonification, nitrification, and denitrification and escape the systems through leaching and gaseous losses (Fig. 1). The extent and intensity of each process will be determined by soil, climate, and management conditions as well as by the interactions of various processes within the soil-plant system.

2.3.1.1. Gaseous Losses:

(a) Ammonia Volatilization: Loss of N as NH_3 from applied N fertilizers is one of several channels which can affect the efficiency of N use by plants. The direct dissociation of NH_4^+- based fertilizers and the catalytic hydrolysis of urea produce NH_4^+-ions in soil solution. With an increase in soil pH, ionized NH_4^+ can change into nonionized NH_3 which may escape into the atmosphere as a gas from soils which have poor absorption capacity. Ammonia which is released from the soil system may also be reabsorbed by the soil and vegetation.

$$NH_4^+ + OH^- \rightleftharpoons NH_3 + H_2O \qquad\qquad (3)$$

Most of the work on NH_3 volatilization has been performed under controlled environments since this facilitates the evaluation of the parameters of interest. Research results from laboratory, greenhouse, and field experiments have indicated that surface application of urea and NH_4^+- fertilizers on neutral to alkaline soils may result in substantial N losses via NH_3 volatilization (Devine and Holmes, 1963;
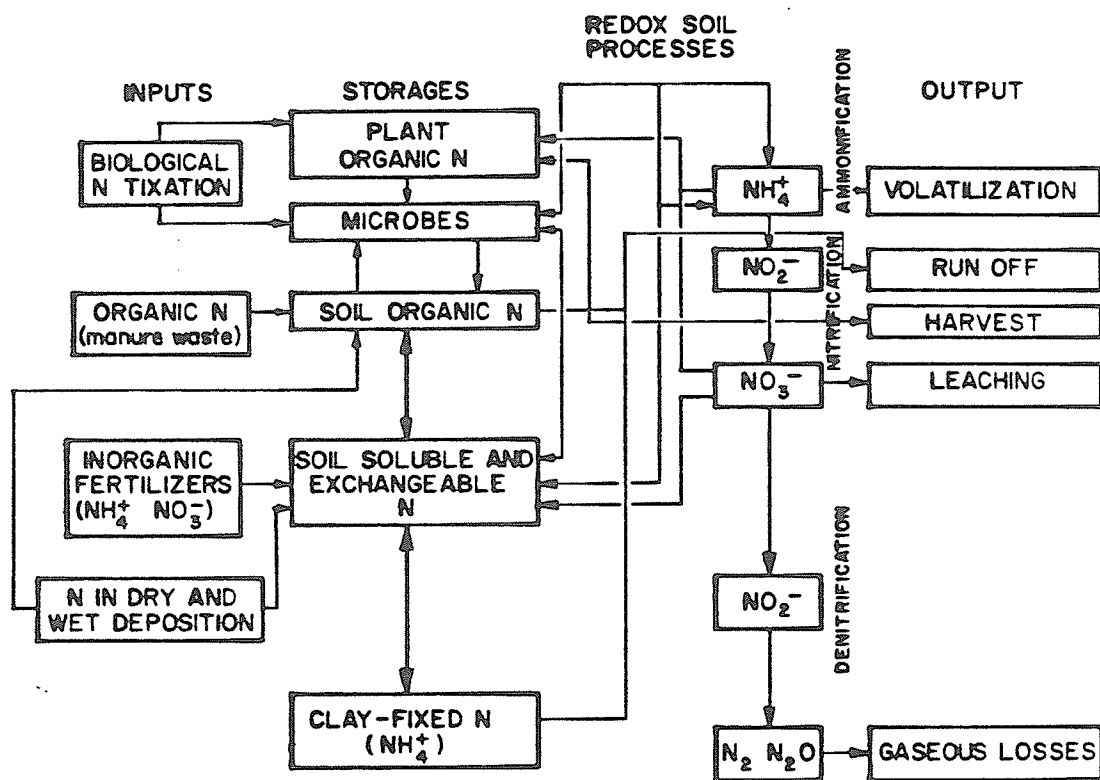
Fig. I. The basic inputs , Storages, Transfers and outputs of nitrogen in terrestrial ecosystems (from Bolin and Arrhenius, 1977).

Toews, 1971; Fenn and Escarzaga, 1976). Losses of NH_3-N from urea and other NH_4^+-N compounds can be reduced to almost zero by applying them 5 cm or deeper in acidic soils but may not be reduced to the same level by applying in alkaline soils (Van Schreven, 1950; McDowell and Smith, 1958; Toews, 1971; Ridley, 1977; Toews and Soper, 1978). Losses of NH_3 from calcareous soils decrease with an increase in solubility of the reaction products of NH_4^+-fertilizers with $CaCO_3$. For example, addition of $(HN_4)_2SO_4$ to alkaline soils will result in more loss than the addition of NH_4NO_3 (Terman and Hunt, 1964; Fenn and Kissel, 1973).

$$(NH_4)_2SO_4 + CaCO_3 \longrightarrow CaSO_4 + (NH_4)_2CO_3 \qquad (4)$$

$$2NH_4NO_3 + CaCO_3 \longrightarrow Ca(NO_3)_2 + (NH_4)_2CO_3 \qquad (5)$$
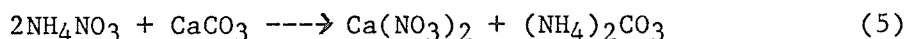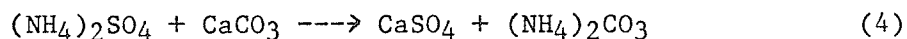
The formation of $CaSO_4$ from $(NH_4)_2SO_4$ and Ca compounds results in complete formation of $(NH_4)_2CO_3$ due to low solubility of $CaSO_4$. The ready decomposition of $(NH_4)_2CO_3$ will result in increased NH_3 losses from the system. Ammonia losses from calcareous soils also decrease with an increase in soil CEC (Fenn and Kissel, 1976; Toews and Soper, 1978).

Losses of N as NH_3 from surface-applied fertilizers decrease with increase in soil sorption capacity for NH_4^+-N (fine texture, lower pH; higher moisture content; higher organic matter content) and increase with intensity of drying conditions (lower humidity, higher temperature) (Martin and Chapman, 1951; Wahhab et al., 1957; Tripathi, 1958; Ernst and Massey, 1960). Overrein and Moe (1967) found that NH_3 volatilization loss rates from urea increased exponentially with increasing amounts of N application. Reduction in NH_3 losses from

urea has been reported by increasing the size of pellets (Watkins et al., 1972; Nommik, 1973; Nyborg et al., 1979). Hargrove et al. (1977) estimated that 3 to 55% of the added N was lost from soils in the field depending upon rates, carriers, and soils. Losses of N as NH_3 from the Canadian prairies are summarized by Rennie et al. (1976) and ranged between 1 and 46% of the N applied. Losses, however, varied greatly depending upon soil type and environmental factors.

(b) Losses of Ammonia from Urea

Losses of NH_3 from urea in soil depends upon the degree of its contact with urease for hydrolysis to $(NH_4)_2CO_3$. Surface-applied urea may, therefore, be less susceptible to initial loss through NH_3 volatilization than $(NH_4)_2SO_4$ applied to alkali soils. If rain or irrigation move surface-applied urea deep into the soil profile before its hydrolysis takes place, the loss from urea as NH_3 may be reduced considerably. Mixing urea into the soil may not, therefore, be a better placement over surface-applied urea in soils where little urease is present in the soil or urease activity is low at the soil surface. Urea hydrolysis is considerably increased with an increase in temperature (Fisher and Parks, 1958: Broadbent et al., 1958). Urease activity has also been detected at -10 C and -20 C in frozen soils (Bremner and Zantua, 1975). This was attributed to enzyme-substrate interaction in unfrozen water at the surface of soil particles. Chemical hydrolysis of urea is very slow compared to biochemical hydrolysis (Chin and Kroontje, 1963).

There must be sufficient moisture in soil to dissolve urea before its hydrolysis can take place. Differences in dissolution rates of urea are

responsible for erratic behavior of surface-applied urea. Compounds that can reduce urease activity in soils may also reduce losses of NH_3 from applied urea (Bundy and Bremner, 1973, 1974; Gould et al., 1978).

(c) Denitrification

The term denitrification refers to the microbial or chemical processes whereby NO^-_3 (or NO^-_2) are reduced to gaseous products such as N_2, N_2O, and NO and thence lost from the soil. Denitrification losses of soil and fertilizer N may be substantial under reducing conditions caused by poor drainage and can considerably influence N economy of the agricultural system. Microbiological, biochemical, and physiological features of denitrification in soils and the factors which influence denitrification (O_2 tension, substrate concentration, pH, temperature, soil, crop, rate, and form of fertilizer N) have been reviewed by several investigators (Broadbent and Clark, 1965; Campbell and Lees, 1967; Delwiche and Bryan, 1976).

Direct measurements of N loss through denitrification in the field are rare and difficult to make (Hauck and Bremner, 1976). Use of tracer N has, however, been made in direct quantitative determinations of gaseous products obtained from bio- and chemo-denitrification of fertilizer N in the laboratory and closed-system lysimeters (Hauck, 1971; Hauck and Bremner, 1976; Christianson and Cho, 1980). Results of these measurements indicated that up to 40% of the applied N can be denitrified from arable crop lands. The more common figure was estimated at 15% of the N applied. Estimates of denitrification losses from soils can also be made by following the disappearance of added labelled

NO_3^- over time under laboratory conditions.

Stanford et al. (1975), however, question the decrease in NO^-_3-N as an accurate measurement of denitrification for all soils since a significant amount of added $^{15}NO^-_3$-N was found to be assimilated by soil microorganisms (after its converion to NH^+_4-N). This observation was in agreement with the results of MacRae et al. (1968) who had found that from 8 to 41% of the added labelled NO^-_3 was transformed into organic form after 6 weeks of incubation of water-logged soils.

Recent research results from Western Canada have indicated that the utilization of spring applied N by cereal crops was greater than utilization of fall applied N (Racz, 1979; Nyborg and Leitch, 1979). Also, the amounts of fertilizer N remaining in the soil at harvest time of the first crop were greater for spring than for fall applied fertilizers. This indicates that recoveries of added N in plant plus soil were larger for the fertilizer added in the spring than that added in the fall. The higher recovery values for the spring applied N were attributed to lower denitrification losses since losses of fertilizer N due to erosion and leaching were negligible. Nitrogen balance data from Manitoba (Racz, 1979) showed that denitrification losses of spring applied N were far less than fall applied N and ranged from about 26 to 40% as compared to 50% estimated for fall applied N. Similar results have been reported by workers in Alberta (Nyborg and Leitch, 1979).

In an attempt to determine the effects of depth of soil and soil temperatures on the maximum denitrification capacities of some Alberta soils, Cho et al. (1979) concluded that from 26.0 to 74.0 kg N/ha/day could be lost from soils through denitrification under anaerobic

conditions (early spring and late fall). An incubation study by Christianson and Cho (Agronomy abstract, 1980) indicated that N loss of applied N through chemical denitrification in acidic soils under frozen conditions could be substantial and may even exceed the losses which may take place from soils during normal growing season. Quite large amounts of urea N (up to 75% of the N applied), when the fertilizer was mixed into the soil, have also been reported to be nitrified in frozen soils in Alberta (Malhi and Nyborg, 1979).

2.3.1.2 Leaching: Leaching losses of applied N are mainly due to the movement of NO_3^- beyond the rooting depth of crops. Losses of NO_3^--N via leaching may be severe on sandy and gravelly soils under conditions of excessive moisture. Most leaching losses are expected to occur during spring when crops are not growing and precipitation exceeds evapotranspiration. Loss of N through leaching is dependent on soil porosity, climatic conditions, amount and type of fertilizer, and state and type of crop. Movements of NO_3^- through the soil profile occurs mainly by convective or mass flow (Chang and Cho, 1974). Losses of NO_3^- through leaching do not appear to be significant in Manitoba (Racz, 1979). It is difficult to present average values of leaching losses with certainty. Banded fertilizer N appears to resist both leaching and denitrification

2.3.1.3 Effect of Time and Method of Application: The efficiency of fertilizer N can be influenced by methods and time of placement including split and foliar fertilization of crops. Numerous workers have evaluated the effects of time and methods of application in relation to the crop recovery and yield of applied N in greenhouses as well

as in fields. Timely application of N fertilzier is an important and well established approach to increase the efficiency of N use by plants. The practice of split or fractional application of N to supply N at stages of plant growth when it is needed or utilized most in grain production should benefit most crops under temperate as well as tropical conditions.

Williams and Smith (1954) noted that later applications of N fertilizers were more effective in increasing yield of wheat than broadcasting N before seeding. Sinha (1973) observed that the efficiency of fertilizer N use by wheat was equally productive whether the fertilizer was applied at seeding or at tillering, while it decreased considerably when applied at boot stage. He also found that two split applications of N fertilizer were better than a single or three applications. Similar results have been reported by Myers (1978) in an experiment with dryland grain sorghum (Sorghum vulgare Pers.). Serry et al. (1974), on the other hand, found that fertilizer N was utilized more efficiently when applied in three equal doses at planting, tillering, and booting than when applied in one dose at planting, or two doses, one at planting and the other at tillering.

Foliar application of urea is also practiced in many parts of the world. Urea is absorbed rather rapidly by plants and absorption is reported to be practically complete within 2 days after application (Freiberg and Payne, 1957; Impey and Jones, 1960a, b). Some workers in India found partial application of urea N through foliage more effective than application of the total amount of N through soil for rice (Oryza sativa L.) and wheat (Triticum aestivum L.) (Sahu and Lenka, 1966;

Sharma, 1970).

Several studies have indicated that spring applied N is more efficiently utilized by plants than fall applied N (Welch et al., 1966; Miller et al., 1975; Ridley, 1977; Malhi and Nyborg, 1979). Welch et al. (1966) found that fall applied N was 67% as efficient as spring applied N at all rates of fertilizer used. Malhi and Nyborg (1979) reported 29% increase in barley grain yield from spring applied compared with fall applied urea, the figures being 3250 and 2520 kg/ha, respectively. The differences in yields were attributed to denitrification of fall applied N. In Manitoba (Ridley, 1977) found that spring applied N was superior to fall applied N when efficiency of N fertilziers was determined in terms of N uptake and crop yields. Nyborg et al. (1979) also reported that fall applied urea resulted in higher yields when placed in big pellets (as nests) at a depth of 5 cm in soil than when incorporated into the soil. Similar trends in yields were observed when $(NH_4)_2SO_4$ was used as a source of N. The increase in yield from nests of urea applied in fall over that from urea incorporated in the fall were suspected to be due to slower nitrification of urea with the nests than with the incorporation.

Soil placement of N is yet another means used to increase the efficiency of fertilizer N utilization by crop plants. Four methods of N placement generally used include: broadcasting, mixing into the surface soil, side banding, and placing N with the seed (proper amount). Surface applications of urea and NH^+_4-N may result in low efficiency due to NH_3 volatilization, especially on alkaline or calcareous soils as indicated before (Martin and Chapman, 1951; Stephen and Waid, 1963).

Losses of N through NH_3 volatilization (and perhaps due to denitrification) can be reduced by soil incorporation or deep placement of fertilizer N into the soil (Meyer et al., 1961; Joint FAO/IAEA Division, 1970). Macleod et al. (1975) obtained higher yields of barley when fertilizer N was placed to the side and 5 cm below the seed, than when broadcast on the soil surface. Volatilization of NH_3 from anhydrous NH_3 can be reduced by injecting it in soil at a depth of adequate moisture supply. Placing fertilizer N as a band in the vicinity of the seed has proved a more effective method of N application than surface broadcasting or mixing N throughout the soil (Nyborg et al., 1977; Ridley, 1977). Mixing N in the soil perhaps increases the immobilization and/or fixation of N by the soil (Msumali, 1977). Field experiments conducted in Manitoba (Soper et al., 1971; Ridley, 1977; Toews and Soper, 1978) showed that efficiency of N use by plants was increased by 20% when fertilizers were banded than when incorporated or broadcast.

On the basis of work done in Manitoba (Soper et al., 1971; Ridley, 1977; Toews and Soper, 1978), the effect of time of application and method of placement on the average relative efficiency of N fertilizers, when the N uptake from spring broadcast treatment is given a value of 100, can be exprssed as shown in Table 3.

TABLE 3. Relative efficiency of nitrogen fertilizers as affected by
time of application and method of placement.

Time	Method	
	Broadcast	Banded
Spring	100	120
Fall	82	93

2.3.1.4 <u>Effect of Crop Residues</u>: The presence of crop residues in soil
is useful in maintaining soil organic matter and protecting soil from
erosion. On the other hand, the addition and persistence of low N
content organic residues in soils may adversely affect the utilization
of plant available N by agronomic crops. Some work in this connection
has been reported in the literature and is summarized below.

A 6-year field study conducted in Manitoba (Hedlin <u>et al</u>., 1957)
showed that incorporation of wheat residues into the soil reduced yields
in the first year after summer fallow, the reduction being even greater
in the second year after fallow. The depressing effects caused by de-
composing crop residues were alleviated when N and P were added to the
soil. Increased yields were reported when the stubble was burnt or the
clover residues were ploughed under in the fallow year. Results of
another field study by Ferguson and Gorby (1964) showed somewhat con-
trasting responses to the application of crop residues to soils. This
study indicated that incorporation of straw into the soil of fallow

fields neither induced an N deficiency nor affected mean grain yield in the succeeding cereal crop. These observations seem to suggest that relatively slow decomposition (under cool climatic condition) and high N supplying capacity of the Chernozemic soils did not favor N immobilization to the extent that it would depress yields of the crops. Ferguson (1967) also reported that long-term straw applications to soils with continuous cropping promoted a beneficial residual effect on yield of cereal crops. This yield increase was attributed to the residual mineralization of N from the large straw applications. Myers and Paul (1971) in Saskatchewan found that yield of wheat and uptake of soil and fertilizer N were not influenced by the application of straw to the soils. Significant amounts of applied N were, however, reported to be immobilized in the presence of straw in the latter study. The recovery of fertilizer N in the above-ground portion of the plants was about 25% in a coarse textured soil and about 50% in a clay soil. With added straw generally larger amounts of added N were recovered from the soil.

Results of a greenhouse study conducted by Parker et al., (1957) indicated that N uptake by crop was significantly greater where cornstalk residue was added to the soil surface than when it was worked into the soil. The incorporation of residue in the soil immobilized considerably more N than applying cornstalk residue to the soil surface. The results of a field experiment by the same authors demonstrated that surface applications of low-N residue without added N fertilizer depressed N uptake by corn and yield of corn. The adverse effects of residue on yield and N uptake were offset by adding fertilizer along with the residue.

In a pot experiment where tagged $(NH_4)_2SO_4$ was applied to sandy soils, Cady and Bartholomew (1960) reported that the addition of 5 tons per acre of corn stover did not show any appreciable effect on total percent recovery of fertilizer N. Total recoveries varied from 74 to 83 percent of the added N. Broadbent and Tyler (1962) reported a greenhouse study where tagged $(NH_4)_2SO_4$ and KNO_3 were applied to cropped and uncropped sandy loam with and without the addition of straw. Where straw was added, total percent recoveries of added N were higher in both cropped and uncropped soils with both N fertilizers. Total percentage recoveries ranged from 65 to 80 percent and from 53 to 72 percent of the added N for cropped and uncropped soils, respectively.

In a long-term greenhouse experiment, Broadbent and Nakashima (1965) found that addition of straw resulted in slightly lower total percent recoveries of tagged N compared to that obtained in no straw treatments. The total recovery values of applied N varied between 61 and 79 percent. Terman and Brown (1968) carried out a greenhouse study where the effect of carbonaceous residue on the uptake of fertilizer and soil N by ryegrass (Lolium multiflarum Lam.) was studied. Total recoveries of labelled fertilizer N varied between 87 and 97 percent for silty clay and between 90 and 96 percent for fine sandy loam. Total recoveries of applied N were slightly less where residue was added than without it. Addition of residue resulted in significantly greater amounts of fertilizer N remaining in the soil. Yield of dry matter of six clippings were lower with than without added residue.

Results of a field study conducted by Myers and Paul (1971) showed total recoveries of applied N ranged from 64 to 66 percent in coarse

textured soil and 75 to 84 percent in clay soil. Addition of straw did not influence the recoveries of fertilizer N significantly, although straw treated plots showed higher recovery values in the clay soil. Literature reviewed indicates that addition of straw generally results in higher total recoveries both in cropped and uncropped soils (Allison, 1966; Legg, 1969).

The literature reviewed indicated that considerable work has been carried out on the effect of carbonaceous residues on the immobilization of added N in the soil. However, studies concerning the effect of immobilization on the efficiency of fertilizer N utilization by the crop are almost nonexistent. This is particulary true in Western Canada where general values on immobilization of applied N are very limited (Nyborg, 1979; Racz, 1979). In the world literature the low recovery of applied N by plants has mainly been written off as gaseous losses either through NH_3 volatilization or via denitrifaction. Furthermore, immobilization of fertilizer N does not appear to have been ever related either to the low recovery of applied N or to the differences in the utilization of applied N from different methods of application. The work reported here was an attempt to answer, at least in part, some of these questions.

3. MATERIALS AND METHODS

The present investigation consisted of one laboratory incubation study, two growth chamber experiments, including main and residual effects, and one field experiment.

3.1 Soil Description

3.1.1 Laboratory Study

Soil samples used in the incubation study were taken from several locations within the Winnipeg Region of South Central Manitoba, approximately 50° latitude, 97° West longitude (Fig. 2). Selection of sampling sites was made on the basis of soil properties and description provided in the Winnipeg Region Study Area (Michalyna et al., 1975). The area is characterized by low relief and the elevation ranges from about 220 to 330 m above the sea level. The topography is smooth and level to very undulating. The climate of this region is characterized as dominantly subhumid, cool, continental with high summer and lower winter temperatures than the world average for the same latitude. The mean annual temperature and precipitation for the Winnipeg area are 2.3C and 533.6 mm, respectively (30 years results 1941-1970).

Soils of the study area are dominantly Chernozemic (Black and Dark Gray) and Gleysolic, developed on lacustrine, coarse to fine textured deposits and thin lacustrine deposits over glacial till. The general description of the area of sampling and soils had been given by Michalyna et al. (1975) and is summarized below.

Soil samples were taken from the surface horizons from cultivated fields for 9 series and from a native site for the Beaverdam series.
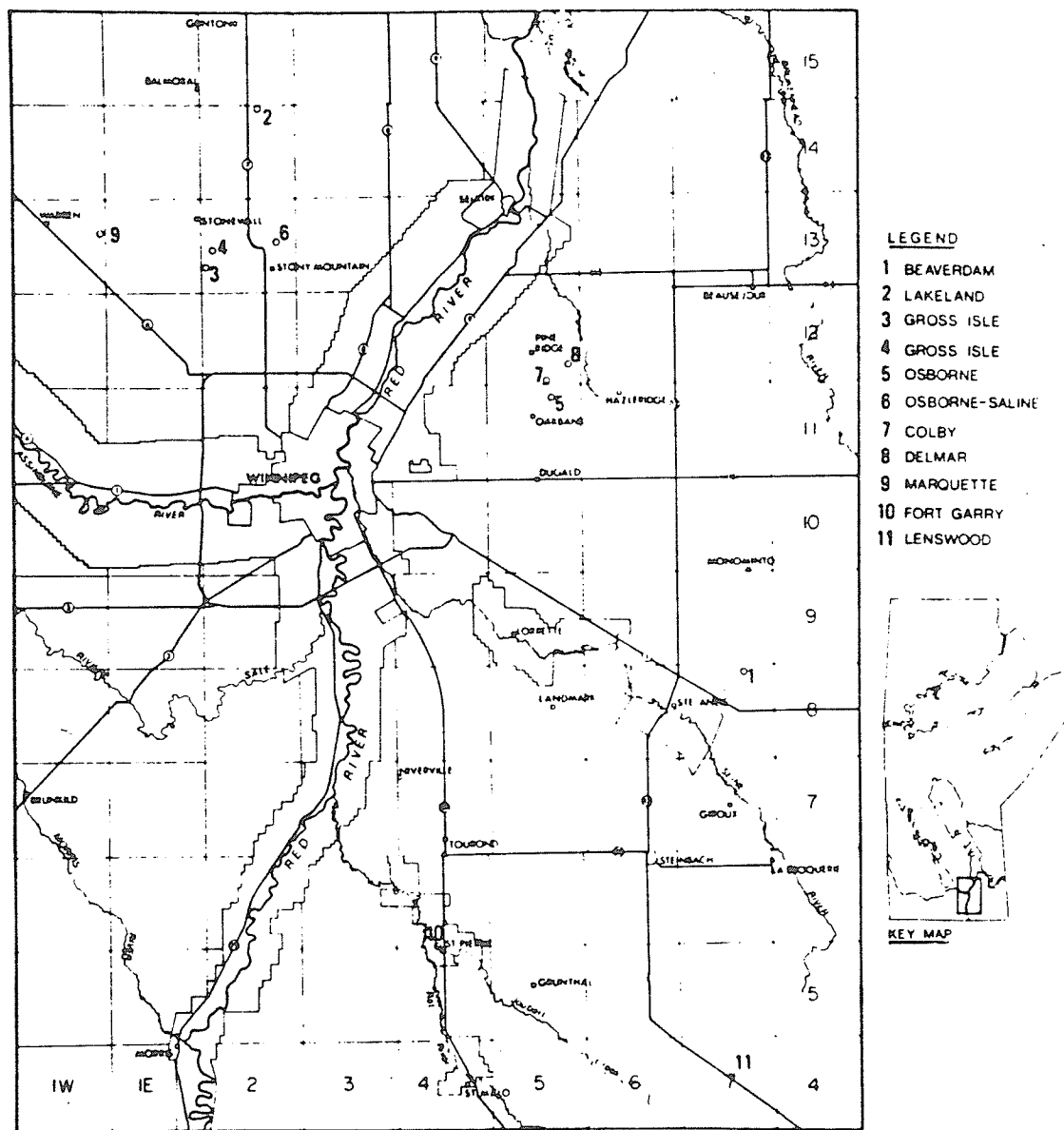
Figure 2. Soil Sampling Sites (o), Winnipeg Region, Manitoba, Canada.

Analytical data for these soils are given in Tables 4 and 5.

3.1.1.1. <u>Beaverdam Series</u>: Gleyed Dark Grey, imperfectly drained, developed on moderately to strongly calcareous outwash and beach deposits over extremely calcareous loamy till.

3.1.1.2. <u>Colby Series</u>: Gleyed Carbonated Rego Black, imperfectly drained, developed on thin moderately to strongly calcareous coarse textured lacustrine deposits over extremely calcareous loamy till.

3.1.1.3. <u>Delmar Series</u>: Carbonated Rego Humic Gleysol, poorly drained, developed on moderately to strongly calcareous moderately coarse to medium textured sediments over moderately to strongly calcareous lacustrine clay.

3.1.1.4. <u>Fort Garry Series</u>: Calcareous Black, well to moderately well drained, developed on thin mantle of lacustrine clay over strongly calcareous silty sediments. Silty sediments are variable in thickness and underlain by lacustrine clay.

3.1.1.5 <u>Gross Isle Series</u>: Calcareous Black, imperfectly drained, developed on a thin mantle of moderately calcareous lacustrine clay over loamy extremely calcareous till or a mixture of clay and extremely calcareous loamy till.

3.1.1.6 <u>Lakeland Series</u>: Gleyed Carbonated Rego Black, imperfectly drained, developed on strongly to very strongly calcareous dominantly moderately fine textured lacustrine deposits.

3.1.1.7. <u>Lenswood Series</u>: Gleyed Carbonated Rego Black, imperfectly drained, developed on moderately to strongly calcareous sandy outwash and lacustrine deposits.

3.1.1.8. <u>Marquette Series</u>: Gleyed Rego Black, imperfectly drained,

Table 4. Mechanical analysis of soil samples used.

Soil Series	VCS	CS	MS	FS	VFS	Total Sand	Si	C	Texture
						------- percent -------			
Colby	-	-	1	36	57	94	1	5	VFS
Osborne-Saline	-	-	-	-	-	9	33	58	C
Gross Isle 1	2	2	3	5	9	21	19	60	C
Delmar	2	2	3	16	30	53	11	36	SC-SCL
Gross Isle 2	1	1	3	4	6	15	18	67	C
Lakeland	-	-	1	8	12	21	43	36	CL
Marquette	-	2	2	4	5	13	24	63	C
Fort Garry	-	1	3	3	5	12	33	55	C
Beaverdam	7	10	32	21	3	73	14	13	SL
Lenswood	4	17	31	20	4	76	10	14	LS
Osborne	-	2	2	8	12	24	30	46	C

Table 5. Some physical and chemical characteristics of the surface
          horizon of the soils studied.

Soil Series	cond. mmho/cm	CEC me/100g	pH	C/N ratio	CaCO$_3$ equiv. %	Total N %	OM %
Colby	0.2	8.8	7.74	11.9	1.5	0.088	1.8
Osborne-Saline	4.8	38.4	7.94	9.8	14.5	0.404	6.8
Gross Isle 1	0.3	41.0	7.60	10.3	4.8	0.360	6.4
Delmar	0.7	33.2	7.81	10.7	9.8	0.460	8.5
Gross Isle 2	0.4	46.7	7.42	10.9	0.9	0.383	7.2
Lakeland	0.3	19.2	7.96	11.8	24.6	0.202	4.1
Marquette	0.4	39.7	7.21	11.3	0.5	0.438	8.5
Fort Garry	0.3	31.6	7.45	8.4	0.3	0.345	4.9
Beaverdam	0.2	22.8	7.76	21.7	11.5	0.421	15.7
Lenswood	0.6	21.2	7.31	15.6	0.5	0.350	9.4
Osborne	0.2	47.5	6.70	10.9	0.4	0.813	15.2

developed on a thin mantle of moderately calcareous lacustrine clay over loamy extremely calcareous till or a mixture of clay and extremely calcareous loamy till.

3.1.1.9. <u>Osborne Saline Phase:</u> Rego Humic Gleysol, poorly drained, developed on moderately calcareous lacustrine clay deposits with appreciable accumulation of soluble salts.

3.1.1.10. <u>Osborne Series:</u> Rego Humic Gleysol, poorly drained, developed on moderately calcareous lacustrine clay deposits.

3.1.2. <u>Growth Chamber Experiments</u>

3.1.2.1. <u>Pine Ridge Series:</u> Grey Forested, rapidly drained, developed on slightly to moderately calcareous sandy outwash and beach deposits in South Central Manitoba (Smith <u>et al.</u>, 1964).

3.1.3 <u>Field Experiment</u>

3.1.3.1. <u>Hochfeld Series:</u> Orthic Black, well drained, developed on moderately coarse to coarse textured, moderately calcareous sandy deltaic and lacustrine sediments (Smith and Michalyna, 1973).

3.2. <u>Carbonaceous Residues</u>

The plant residues added to soils were obtained by grinding fababean (<u>Vicia faba</u> L.), barley (<u>Hordeum vulgare</u> L.) and oat (<u>Avena sativa</u> L.) plant materials to pass through a 2-mm sieve (Table 6). Barley plant residues were intended to be of low N content. However, an error occurred in the selection of barley plant material for the first growth chamber experiment and consequently, the residue with such a high N content was used in this experiment. The sugar used was a fine granulated Manitoba sucrose.

Table 6. Analysis of carbonaceous residues

Residue added	Experiment	% Total N	% Carbon	C/N Ratio
Barley	First G.C.	1.99	41.6	20.9
Fababean	First G.C.	1.97	43.0	21.8
Sucrose	First G.C.	-	42.1	-
Barley	Second G.C.	0.53	42.4	80.0
Oats	Field	0.45	41.0	91.1

3.3. Fractionation of Soil Organic Matter Into Humic Acids

The Stevenson method described by Hesse (1971) was used to fractionate and isolate the humic acid fraction from the soils.

3.3.1. Carbon and N Content

Analyses for C and N in humic acid samples were conducted using a Perkin Elmer model 240 elemental analyzer in accordance with the procedure developed by Fresh Water Institute, Fisheries and Environment Canada, Winnipeg, Manitoba (1977).

3.3.2. Ash Content

The ash content of samples of humic acid was determined by dry combustion at 700 C for 4 hours (Dormaar et al. 1970).

3.4 Analytical Methods

3.4.1. Soil Analysis

3.4.1.1. Calcium Carbonate Equivalent

Calcium carbonate equivalent ($CaCO_3$ equiv.) was estimated by the manometric method of Skinner et al., (1959).

3.4.1.2. Cation Exchange Capacity (CEC):

Cation exchange capacity was determined by the ammonium acetate (pH 7) method of Chapman (1965).

3.4.1.3. Field Capacity:

Soil samples (2 mm-size) were placed in plastic cylinders the bottoms of which were fitted with porous cloth. The surfaces of the samples were saturated with distilled water and equilibrated for 24 hours. Tops of the cylinders were kept covered with parafilm. The moist soils were then sub-sampled, oven-dried at 105 C, and the moisture content, so determined, was expressed on an oven dry soil basis.

3.4.1.4. Organic Matter:

Soil organic matter determinations were made by

the method of Walkley and Black as described by Allison (1965) using a Radiometer Titrator II.

3.4.1.5. pH: pH determinations were made using an Orion Research Model 801/Digital pH ionalyzer equipped with a combination electrode. pH was measured in 0.01 M $CaCl_2$ (soil:solution ratio of 1:2) by the method described by Peech (1965).

3.4.1.6. Soluble Salt Content: The conductivity measurements were made on aqueous saturation extracts of samples using the method outlined by Bower and Wilcox (1965).

3.4.1.7. Texture: Particle size anlaysis on all samples was performed by the standard Pipette method (Kilmer and Alexander, 1949) after the required pretreatment of soils.

3.4.1.8. Ammonium Nitrogen (NH_4^+-N): Ammonium nitrogen concentrations were determined on 2N KCl extracts with an Orion ammonia electrode coupled to a Fisher model 520 digital pH/ion meter. KCl extracts were obtained by filtering a 1:5 soil-KCl suspension which had been shaken for 60 minutes. In order to check the accuracy of the results obtained by the ammonia electrode, random ammonium nitrogen determinations were also performed by distillation with magnesium oxide (Bremner, 1965).

3.4.1.9. Nitrate and Nitrite Nitrogen $(NO_3^-$ and $NO_2^--N)$: Nitrate- and nitrite- N concentrations were determined on a 1:20 soil-sodium bicarbonate solution by the method of Kamphake et al. (1967) using a Technicon autoanalyzer 1. The above method was also checked on several samples by steam dstillation as described by Bremner (1965).

3.4.1.10. Total Nitrogen (N): The total N content of soils was

determined by the Kjeldahl method modified to include NO^-_2 and NO^-_3 (Bremner, 1965). Five or 10 g samples of soil were taken from the contents of each flask/pot for analysis.

3.4.2 Plant Material Analysis

Analyses for total N in plant tissues obtained from growth chamber and field experiments were conducted using the regular Kjeldahl method as outlined by Bremner (1965). One and 2 g samples of shoots and roots, respectively, were taken for analyses.

3.4.3. ^{15}N Determinations

Procedures used for the determination of isotopic composition of soil and plant samples were similar. Sample analyses of the incubation experiment were done in duplicate; analyses of samples from growth chamber experiments were performed in triplicate; field sample analyses were carried out in quadruplicate.

3.4.3.1. Preparation of Samples: After Kjeldahl analyses of total nitrogen were completed, the titrated distillates were acidified with a drop of reagent grade conc. H_2SO_4. The acidified solutions were evaporated on a hot plate under hood to a volume of approximately 4 ml. Samples were removed and transferred to 10 ml capacity test tubes. The samples were stored in stoppered tubes until analyzed.

Nitrogen gas (N_2) was obtained by the oxidation of ammonium solution with alkaline hypobromite according to the following reaction:

$$NH^+_4 + OH^- \rightleftharpoons NH_3 + H_2O \qquad (6)$$

$$2NH_3 + 3NaOBr \longrightarrow 3NaBr + 3H_2O + N_2 \qquad (7)$$
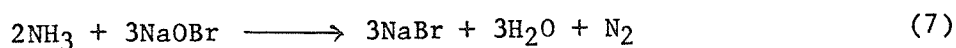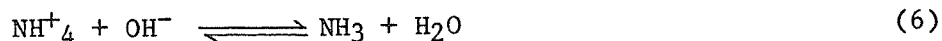
The reaction vessel consisted of a Rittenberg tube that was attached to the vacuum manifold system. The released N_2 was collected either over

KOH pellets or anhydrous $CaSO_4$ (Drierite) placed in the gas collecting flask.

3.4.3.2. Isotope-Ratio Analysis

The ion current intensities corresponding to atomic mass unit (amu) 28 ($^{14}N^{14}N$) and amu 29 ($^{14}N^{15}N$) were measured on a micromass 602 C mass spectrometer manufactured by VG-Micromass, England. The atom percent ^{15}N contents of the samples and that of standard were calculated using the following expression (Bremner, 1965).

$$\text{Atom \% } ^{15}N = \frac{100}{2R + 1} \qquad (8)$$

where R is the ratio of the ion current intensities (peak heights at M/e (28) and M/e (29).

The ion currents at M/e (28), M/e (29) are proportional to the respective molecular ions as mentioned above. Because of the random distribution of isotopes in the N_2, it is generally not necessary to measure the ion current corresponding to M/e (30)($^{15}N^{15}N$).

The relationship in equation (8) is based on the assumption that samples of N_2 prepared by the NaOBr reaction are in equilibrium with regard to the reaction below:

$$^{14}N^{14}N \; + \; ^{15}N^{15}N \; \xrightleftharpoons{\hspace{2cm}} \; 2\,^{14}N^{15}N \qquad (9)$$

Theoretical and experimental value of the equilibrium constant (Keq.) of this reaction is 4.0 and is expressed as:

$$\text{Keq.} = \frac{(^{14}N^{15}N)^2}{(^{14}N^{14}N)\;(^{15}N^{15}N)} \qquad (10)$$

In a mass spectrometer analysis of N_2, the relative number of ions of species $(^{14}N_2)^+$, $(^{14}N^{15}N)^+$, and $(^{15}N_2)^+$ approach, the ideal fraction-

al distribution given by the term of the following relation:

$$(a + b)^2 = a^2 + 2ab + b^2 \tag{11}$$

where $\qquad$ a = atom fraction of ^{14}N

$\qquad\qquad$ b = atom fraction of ^{15}N

and $\qquad$ a + b = 1

using equation (10) and (11)

$$Keq. = \frac{(2ab)^2}{(a^2)\,(b^2)} = 4.0 \tag{12}$$

3.4.4. Recovery of Fertilizer Nitrogen

Percentage recovery of fertilizer N was calculated by the following methods:

3.4.4.1. Isotopic Method:

Percent recovery of fertilizer N in soil and plant material was calculated by using the following equation:

$$\text{Percent fertilizer N recovery} = \frac{N_T \times (A-B)}{(C \times D)} \times 100 \tag{13}$$

w $\qquad$ N_T = Total nitrogen in the soil or plant material from

$\qquad\qquad$ N fertilized pot/plot.

$\qquad$ A = Atom % ^{15}N in soil or plant material from N

$\qquad\qquad$ fertilized pot/plot.

$\qquad$ B = Atom % ^{15}N in soil or plant material from N

$\qquad\qquad$ untreated pot/plot, which was 0.373%.

$\qquad$ C = Excess atom % ^{15}N in applied urea (standard).

and $\qquad$ D = Amount of urea-N applied.

3.4.4.2 Difference Method:

Percent recovery of fertilizer N in

plant material was also calculated by the following equation:

$$\text{Percent fertilizer N recovery} = \frac{N_T - N_U}{D} \times 100 \qquad (14)$$

where N_T = total N in the plant material from N treated pot/plot.

N_U = Total N in the plant material from N untreated pot/plot.

and   D = Amount of fertilizer N applied.

3.4.5 Statistical Analysis

The data from the growth chamber experiments were analyzed using the analysis of variance suited for completely randomized factorial designs. The field experiment data were analyzed using analysis of variance suited to a randomized block factorial design. Specific treatment comparisons were made by Duncan's New Mutiple Range Test. Comparisons of means were performed at the 5 percent significance level unless otherwise specified.

4. RESULTS AND DISCUSSION

4.1 Laboratory Incubation Experiment

The purpose of this investigation was to determine the magnitude of N retained by soils from added urea as a function of various soil characteristics. The transformation of urea into NH_4^+- and NO_3^--N with time was also investigated.

4.1.1 Experimental Design

The study was conducted by incubating 6 fine, 2 medium and 3 coarse-textured soils (Table 4) under controlled environmental conditions. The soils were selected to obtain a range in texture, CEC, pH values, $CaCO_3$ equiv., N content and OM content. Electrical conductivities of all soils were < 0.7 mmho/cm except for the Osborne saline soil which was 4.80. Cation exchange capacities ranged from medium to high except for the Colby soil which was very low (Table 5). The pH range was very narrow varying between 7.21 and 7.96 with an average of 7.60 if the Osborne soil (pH 6.70) was excluded. With the exception of the Beaverdam and Lenswood soils, the C/N ratios were fairly similar. However, the $CaCO_3$ equiv. and organic carbon were quite variable (Table 5).

Prior to use, the soil samples were air dried and passed through a 2-mm sieve. In testing the effect of time of incubation on the magnitude of immobilization and transformation of added N, a soil sample equivalent to 200 g oven dry soil was throroughly mixed with 10 ml of urea solution (21.0 atom $\%^{15}N$) containing 200 ug N per g of soil. A relatively high rate of N was applied to simulate a concentration comparable to band applied N. Samples treated with N were transferred

to preweighed 500-ml Erlenmeyer flasks. The soils in flasks were brought up to their field capacities with distilled water. Flasks were then incubated in a thermostatically controlled chamber maintained at 20 C for periods of 4, 8 and 12 weeks under aerobic conditions by keeping flasks unstoppered. During the incubation period the soils in the flasks were maintained at field capacity moisture contents by weighing daily the contents of the flasks and adding the required amount of distilled water. Soils which were not supplied with N were used as controls. Treatments were run in duplicate.

At the end of the prescribed incubation periods, flasks marked for the appropriate period, were removed from the incubator and their contents air dried as soon as possible. After uniform mixing of the contents, the air dried soils were subsampled and total, NH^+_4-, NO^-_3-, NO^-_2- and isotopic N determined. The levels of NO^-_2- -N in soil samples were found to be $\leq$ 0.5 ppm and were not included for presentation. Determinations of total, NH^+_4-, NO^-_3- and NO^-_2-N on all samples at zero time were made from the contents of unincubated flasks stored at $\leq$ 4 C until the analyses were completed. It took 2 - 3 days to complete the analyses of samples assigned zero time.

The effect of soil characteristics on the tie up of added N by soils was investigated by extracting treated soils with 2N KCl at specific intervals of incubation. Soil from which KCl extractable N was removed was termed 'residue'. The amount of labelled N recovered in the residue was assumed to be the amount of added N which was either fixed

or immobilized by the soil. The relationships of amount of added N immobilized or fixed as a dependent variable to texture, pH, CEC, total N, and OM as independent variables were determined for each period of incubation using forward stepwise linear and multiple linear regression analyses.

4.1.2 Results

4.1.2.1. Retention of ^{15}N by the Soil:

The amount of N that was retained in the soils immediately after addition of urea to soils ranged from 3 to 32 ppm (Table 7). Retention of N increased rapidly during the first 4 weeks of incubation in all soils except for the Colby VFS (Fig. 3). Between 4 and 8 weeks of incubation, immobilization proceeded more slowly in 5 out of 11 soils, was negative in two soils and did not increase in the others. Only the Osborne soil showed a significant increase in immobilization after 8 weeks, the immobilization in all other soils virtually remained constant. By the end of 12 weeks, 16 to 91 ppm of added N (about 8 to 46% of the applied N) was tied up in the soils indicating very different levels of fixation.

4.1.2.2. Effect of Soil Characteristics on N Immobilization and/or Fixation:

In an attempt to determine whether the wide differences in N retention could be related to the differences in soil characteristics, the results were subjected to regression analyses. The relationships between N immobilization at various time intervals and the soil characteristics (independent variables), as obtained by forward stepwise regression, are shown below:

$$Y_0 = 61.4 + 0.18\% \text{ (S+Si)} - 8.73 \text{ pH} \quad R^2 = 0.86^{**}; \quad S_e = 2.0 \quad (15)$$
$$ (0.03) \phantom{\% \text{ (S+Si)} - } (1.72)$$

Table 7. Retention of added N in soils treated with 200 ppm urea N

| | Retention of N (ppm) | | | |
Soil Series	Zero time	4 weeks of incubation	8 weeks of incubation	12 weeks of incubation
Colby	15.2	16.8	16.9	16.3
Osborne-Saline	3.3	21.2	22.6	21.6
Gross Isle 1	4.5	23.6	25.6	26.2
Delmar	8.2	30.6	29.0	27.2
Gross Isle 2	4.5	23.8	26.4	28.4
Lakeland	7.6	26.6	27.6	28.4
Marquette	5.3	24.6	31.4	31.4
Fort Garry	6.8	55.8	56.2	53.8
Beaverdam	17.4	52.4	56.8	58.4
Lenswood	32.0	68.2	60.8	61.4
Osborne	26.0	66.6	79.6	91.2
Average	11.9	37.3	39.4	40.4
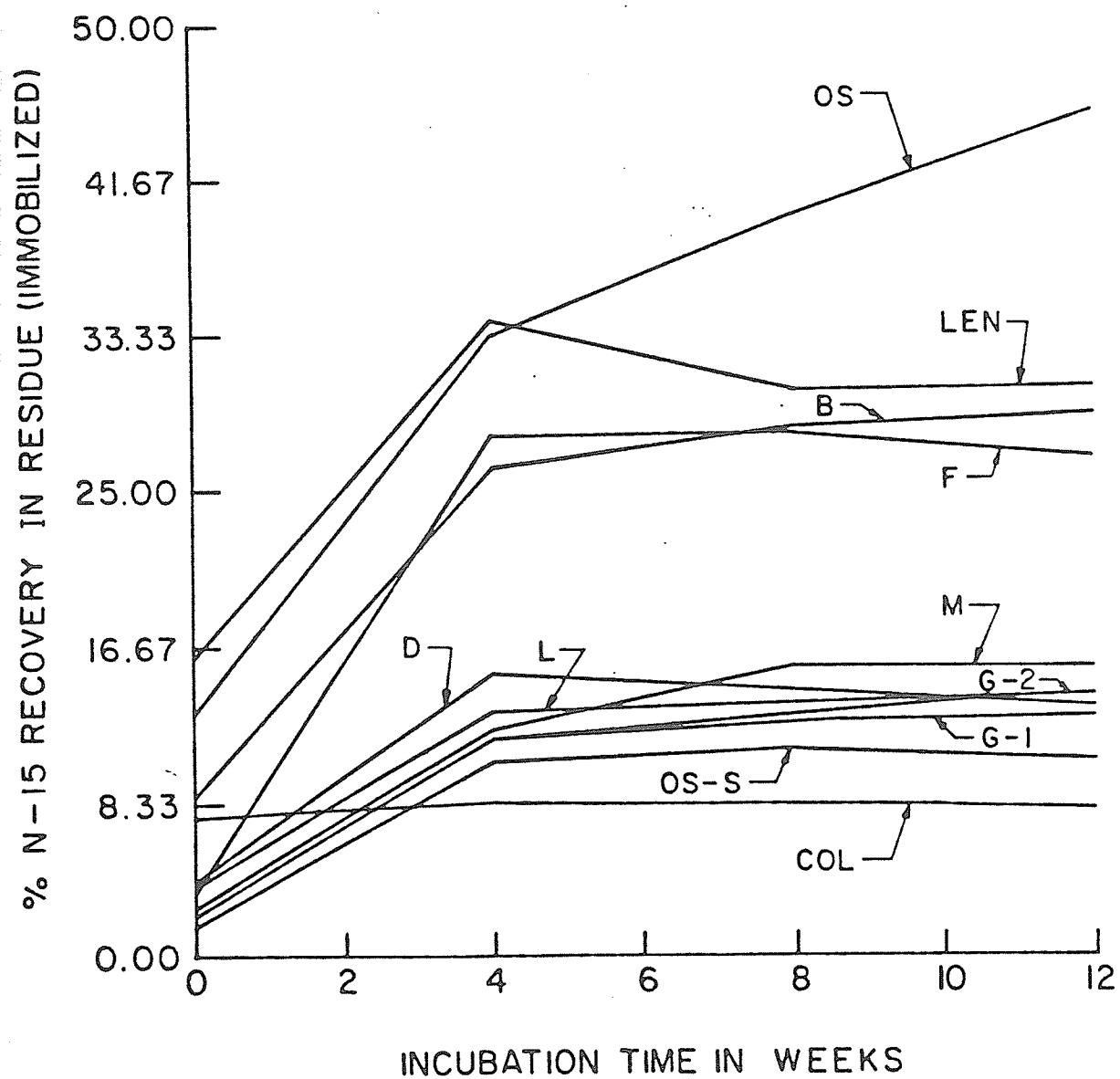
Figure 3. Relationship between ^{15}N immobilized and time of incubation.

$$Y_4 = 7.02 + 1.44\% \text{ OM} \qquad\qquad R^2 = 0.40 \text{ *}; \qquad S_e = 7.9 \text{ (16)}$$
$$(0.58)$$

$$Y_8 = 5.70 + 1.74\% \text{ OM} \qquad\qquad R^2 = 0.53 \text{ *}; \qquad S_e = 7.3 \text{ (17)}$$
$$(0.54)$$

$$Y_{12} = 118 \quad + 1.39\% \text{ OM} - 14.5 \text{ pH} \quad R^2 = 0.74 \text{ **}; \qquad S_e = 6.5 \text{ (18)}$$
$$(0.55) \qquad (6.3)$$

where Y_0, Y_4, Y_8 and Y_{12} represent the percentage of ^{15}N retained at zero time, 4, 8 and 12 weeks of incubation, respectively. Standard errors of regression coefficients are given below the coefficients in parentheses and the standard error of estimate is represented by S_e.

The initial fixation of added N (eq. 15) was positively correlated with sand + silt content and negatively correlated with pH of the soil. With time of incubation, OM of soil played an increasingly important role in influencing the retention of N added to soil (eq. 16-18). Retention of N at 4 and 8 weeks of incubation was positively correlated with OM content of soil. The tie up of N for the 12-week incubation period was positively correlated with OM and negatively correlated with pH of the soil (Figs. 4 and 5).

Since humic acids constitute a major portion of soil OM and are capable of retaining plant nutrients, their effect on the immobilization of added N was also investigated. Using the 12-week data, a good agreement between percent ^{15}N immobilized and percent humic acids content was obtained. The regression equation developed for the above relation is shown in Fig. 6. The inclusion of humic acids and pH as the independent variables in the multiple regression equation did not show any improvement over the relationship obtained for humic acids alone. The r^2 value for the 12-week incubation period between percent ^{15}N
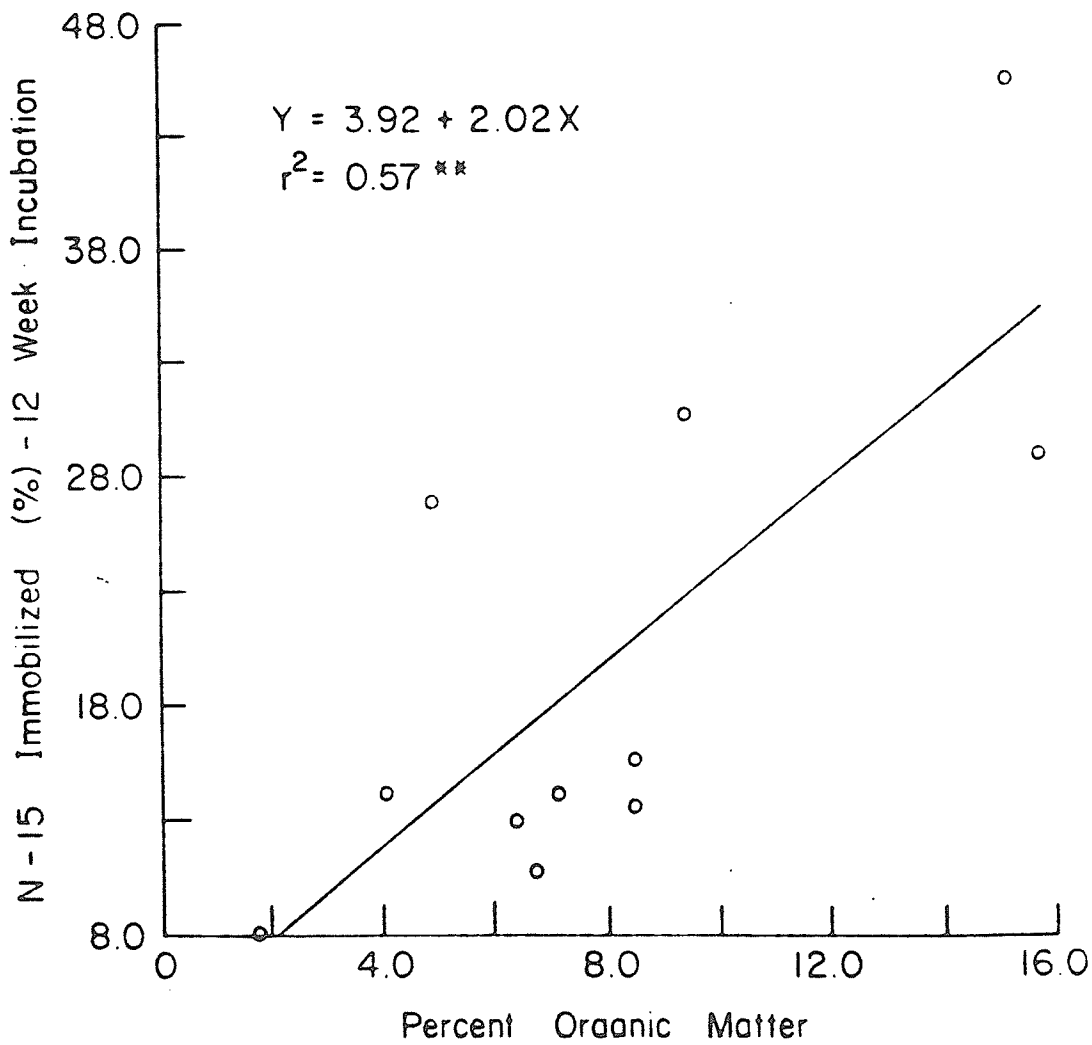
Figure 4. Relationship between ^{15}N immobilized and organic matter content of the soil (** significant at 1% level)
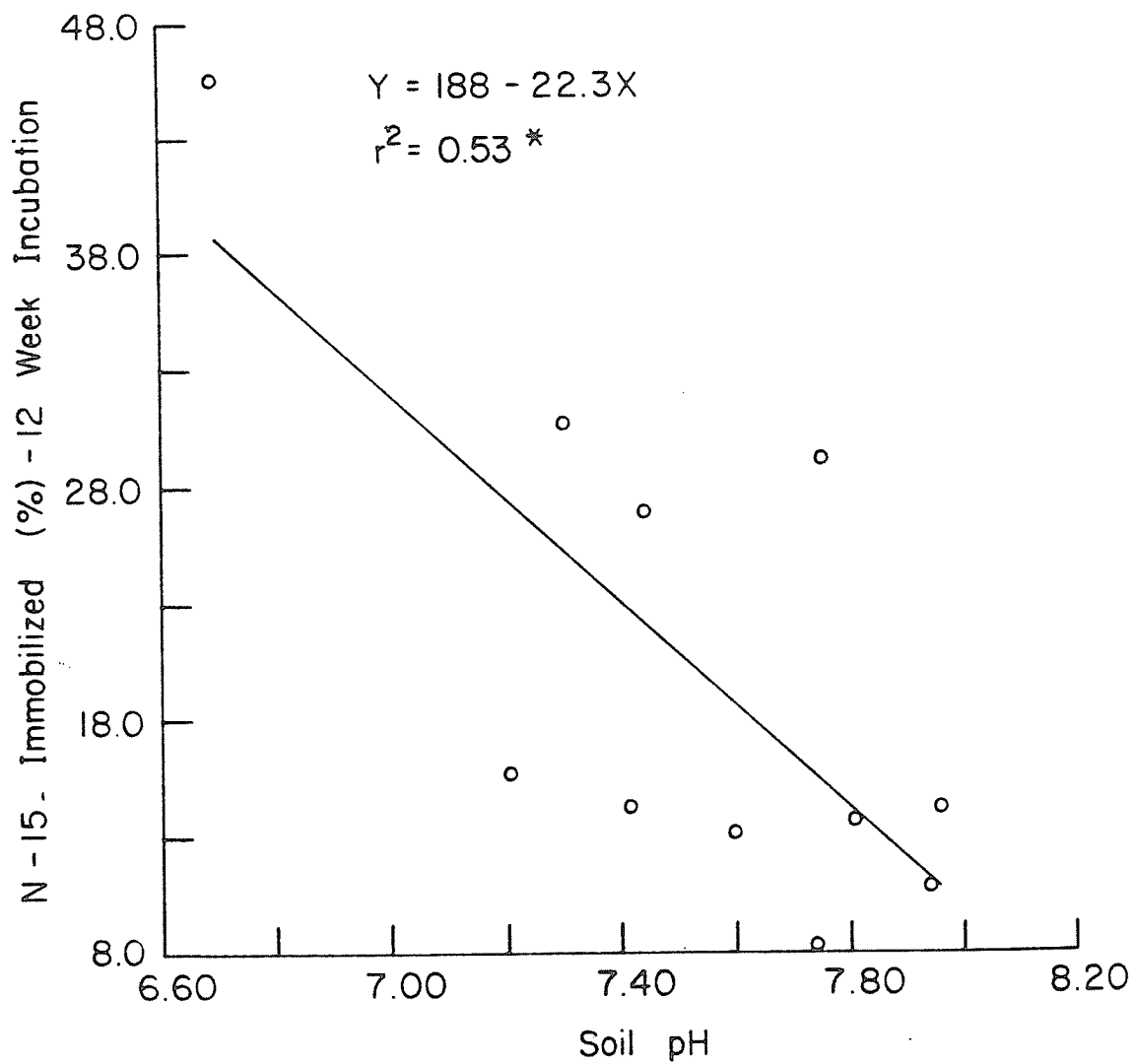
Figure 5. Relationship between ^{15}N immobilized and pH of the
soil (* significant at 5% level).
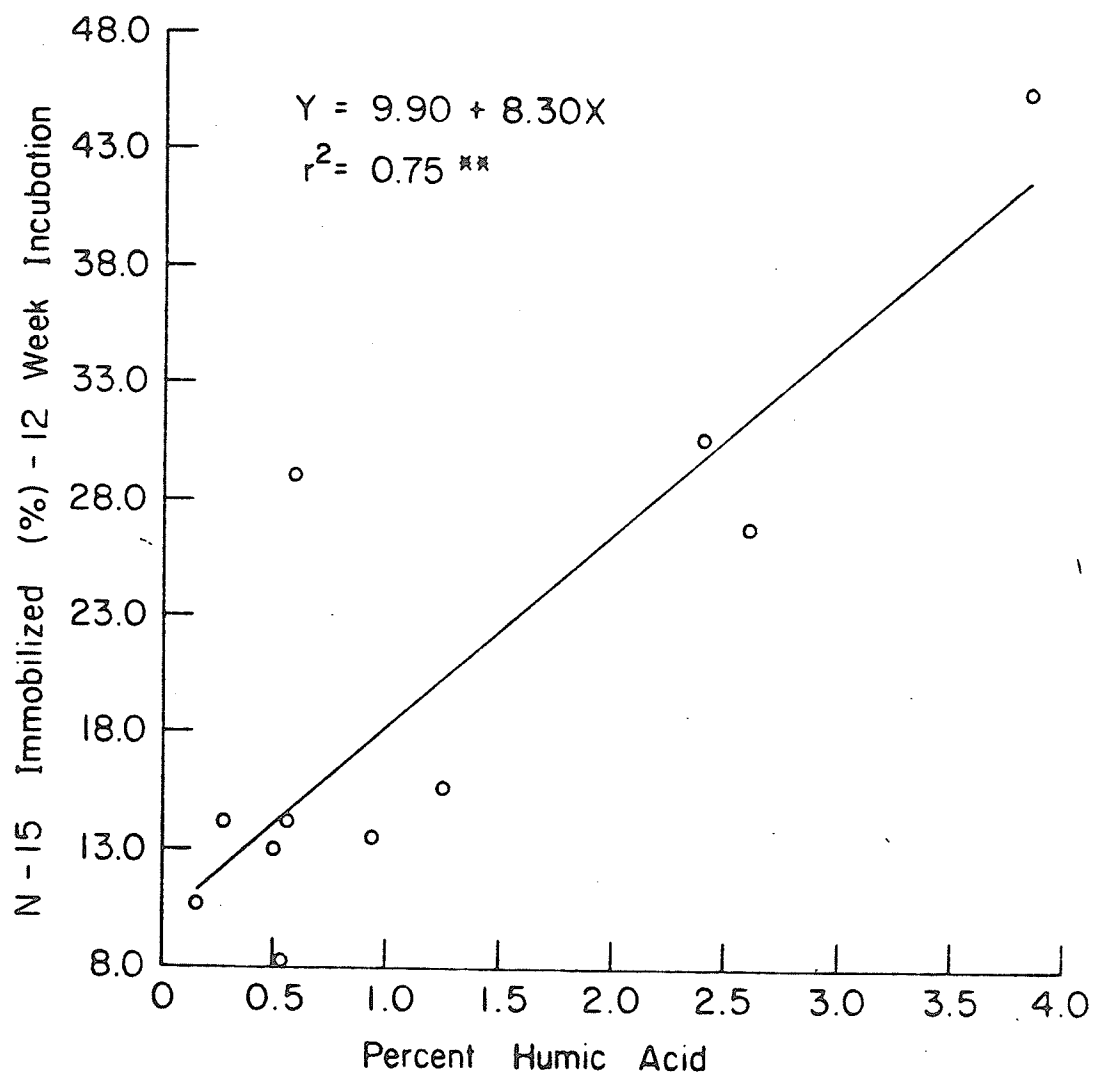
Figure 6. Relationship between ^{15}N immobilized and humic acid content of the soil (** significant at 1% level).

immobilized and humic acids was better (0.75** vs. 0.57**) than that found between percent OM content and percent ^{15}N immobilized. From this result it would appear that humic acids either were or were correlated with the more active components of OM in influencing the immobilization of added N. Subtracting the initial NH^+_4- fixation from the corresponding values of N immobilized at 4, 8, and 12 weeks of incubation did not improve the relationships between N immobilized and OM content or between N immobilized and humic acids content of soil.

In view of the agronomic implication of the amount of fertilizer N retained in the soil over time, the effect of soil characteristics on the immobilization of added N was also investigated by treating the data of various incubation periods as a single group. The pooled data thus obtained when subjected to the multiple linear regression and to all possible subset regression analyses generated the following equation:

$$Y = 140 + 1.36\% \text{ OM} - 16.2 \text{ pH} - 0.30 \text{ CEC} \qquad R^2 = 0.73^{**}; \ S_e = 5.7 \quad (19)$$
$$ (0.28) \qquad\quad (3.4) \qquad (0.10)$$

The relationship represented by equation (19) is similar to that given in equation (18) except that the percent retention of applied N (Y) was shown to bear a further negative relationship with another factor, CEC of the soil. A relationship similar to that given by equation (19) was also obtained through parallel regression analyses when total N content of soil rather than the OM of soil was selected as the independent variable.

To obtain an estimate of net microbial immobilization, the initial N retention by soil was subtracted from the corresponding values of N retained at 4, 8 and 12 weeks of incubation assuming that some of the

added urea was hydrolyzed during time zero and that the initial N retained by soils was mainly due to chemical fixation of NH^+_4 by clay materials. This, however, did not improve the relationships between N retained and OM content of soil.

4.1.2.3. Mineralization vs. Immobilization of Nitrogen:

Consideration of the fact that both microbial immobilization of N and mineralization of soil organic N are biochemical processes, led us to look for some possible relationship between the two. Plots of retained labelled N against the net amount of soil organic N mineralized (after zero time values were subtracted) for each of the 4, 8 and 12 weeks of incubation indicated a mutual relation between the processes of immobilization and mineralization. The calculated r^2 values for 4, 8 and 12 weeks of incubation were 0.42*, 0.52* and 0.42*, respectively.

4.1.2.4. Changes in Mineral Nitrogen:

The quantities of NH^+_4-N extracted from soils at zero time, after the values in control soils were deducted, ranged from 5 to 110 ppm (Table 8). More than one half of the added N was recovered as NH^+_4-N in the Colby soil at zero time, suggesting a very high urease activity in the soil. The amount of NH^+_4-N present at zero time generally related to the amount of N retained by soils except for the Colby soil. The levels of NH^+_4-N in most of the soils became quite low by the end of 4 weeks except for the Osborne soil. Since no incubation interval between zero time and 4 weeks of incubation was included in this study, the amount of NH^+_4 present during this time interval could not be ascertained. It is suspected that the NH^+_4 concentration could have increased from zero time to 4 weeks with a peak

Table 8. Concentration of KCl-extractable NH^+_4-N and standard error $(s\bar{x})^\#$ in soils treated with 200 ppm urea N.

| Soil Series | Extractable NH^+_4-N (ppm) | | | |
	Zero time	4 weeks of incubation	8 weeks of incubation	12 weeks of incubation
Colby	110 ± 3.0	1 ± 0.1	1 ± 0.0	0 ± 0.0
Osborne-Saline	5 ± 0.2	2 ± 0.2	2 ± 0.1	1 ± 0.0
Gross Isle 1	7 ± 0.2	1 ± 0.0	2 ± 0.1	0 ± 0.0
Delmar	9 ± 0.3	1 ± 0.0	2 ± 0.0	1 ± 0.0
Gross Isle 2	5 ± 0.2	3 ± 0.2	1 ± 0.0	0 ± 0.0
Lakeland	15 ± 0.6	2 ± 0.2	0 ± 0.0	0 ± 0.0
Marquette	6 ± 0.2	5 ± 0.3	1 ± 0.1	0 ± 0.0
Fort Garry	20 ± 1.3	9 ± 0.5	0 ± 0.0	0 ± 0.0
Beaverdam	17 ± 0.5	1 ± 0.0	0 ± 0.0	0 ± 0.0
Lenswood	32 ± 2.0	2 ± 0.1	0 ± 0.0	1 ± 0.0
Osborne	18 ± 1.5	51 ± 2.6	2 ± 0.1	1 ± 0.0
Average	22 ± 1.3	7 ± 0.8	1 ± 0.1	0.4 ± 0.0

$^\# s\bar{x} = \quad s^2/n$, where s^2 = variance and n = 2.

occurring some time during this period.

When control soil values were subtracted from treated soil values, the NO_3^--N extracted at zero time was found to be negligible (Table 9). The amounts of urea N nitrified at 4, 8 and 12 weeks of incubation averaged 79.0, 79.6 and 82.2% of the N applied, respectively. The values for the Gross Isle 2, Lakeland and Beaverdam soils obtained at 8 weeks of incubation, and for the Lenswood soil found at 12 weeks of incubation were lower than those recorded at 4 weeks of incubation. Conditions of the experiment did not lead to nitrite accumulation in soils of this study.

4.1.2.5. Recovery of Added Nitrogen:

Both direct and indirect methods were used to determine the total recovery of N applied to soils. Direct recoveries of added N were calculated using the ^{15}N data obtained from the analyses of intact soil samples (Table 10). Indirect recoveries of applied N (Table 11) were estimated by adding the percentage recoveries of ^{15}N from residues (Table 7) and those of applied N recovered as NH_4^+ and NO_3^- in extracts after the latter values were adjusted for control treatments (Tables 8 and 9). The extent of N interchange between labelled and soil organic N was assessed by comparing the recovery values of added N by means of the ^{15}N and indirect methods. The indirect recovery from the Osborne soil for 4, 8 and 12 weeks of incubation were much higher than 100% while the recovery from the Colby soil much lower than 100%. There was good agreement between the two methods of determining N recovery for the three periods of incubation when the Osborne soil was excluded.

Table 9. Concentration of KCl-extractable NO^-_3-N in soils treated
with 200 ppm urea N.

Soil Series	Zero time #	Extractable NO^-_3-N (ppm)		
		4 weeks of incubation	8 weeks of incubation	12 weeks of incubation
Colby	1 ± 0.0	136 ± 1.5	139 ± 5.0	145 ± 3.0
Osborne-Saline	2 ± 0.0	167 ± 6.5	172 ± 4.0	171 ± 2.0
Gross Isle 1	0 ± 0.0	177 ± 4.0	177 ± 1.0	188 ± 7.5
Delmar	2 ± 0.0	164 ± 4.5	162 ± 3.5	182 ± 1.0
Gross Isle 2	1 ± 0.0	164 ± 8.0	160 ± 4.6	164 ± 2.5
Lakeland	1 ± 0.0	168 ± 6.5	155 ± 5.5	161 ± 0.5
Marquette	1 ± 0.0	173 ± 3.5	184 ± 4.5	180 ± 3.0
Fort Garry	1 ± 0.0	147 ± 4.5	157 ± 1.5	165 ± 2.0
Beaverdam	1 ± 0.0	140 ± 2.0	128 ± 0.0	145 ± 6.5
Lenswood	1 ± 0.0	152 ± 3.2	160 ± 3.5	126 ± 2.5
Osborne	0 ± 0.0	150 ± 5.6	164 ± 6.0	181 ± 6.0
Average	1 ± 0.0	158 ± 5.0	160 ± 4.0	164 ± 3.9

#$s\bar{x}$ = s^2/n, where s^2 = variance and n = 2.

Table 10. Recovery of added ^{15}N from soils incubated with 200 ppm
labelled urea N

Soil Series	Recovery of ^{15}N (%) after			
	Zero # time	4 weeks of incubation	8 weeks of incubation	12 weeks of incubation
Colby	92.6+1.5	94.6+0.7	86.5+0.4	80.8+0.6
Osborne-Saline	83.2+0.5	101+2.0	99.5+0.2	100+0.0
Gross Isle 1	91.0+1.2	99.9+0.2	103+0.4	99.5+0.1
Delmar	99.7+0.4	98.1+1.1	101+1.9	98.1+0.6
Gross Isle 2	98.5+1.6	94.2+0.6	102+0.2	97.7+2.3
Lakeland	95.4+0.1	91.7+1.2	93.0+0.8	96.6+2.0
Marquette	103+2.8	96.1+2.8	100+1.6	105+1.8
Fort Garry	96.1+2.1	97.9+2.9	99.1+0.4	102+0.6
Beaverdam	91.5+1.1	90.8+1.0	96.6+0.0	98.1+0.4
Lenswood	93.9+1.2	98.2+2.2	98.1+0.8	105+0.4
Osborne	97.2+1.2	97.2+0.0	99.1+1.0	97.2+1.6
Average	94.2+1.4	96.3+1.6	98.0+1.1	98.2+1.2

$s\overline{x} = \quad s^2/n$, where s^2 = variance and n = 2.

Table 11. Indirectly determined recovery of added N ($\%^{15}N$ in
residues + $\%(NH_4^+-N + NO_3^--N)$ in soil extracts) from
soils incubated with 200 ppm urea N.

Soil Series	Recovery of added N (%) after		
	4 weeks of incubation #	8 weeks of incubation	12 weeks of incubation
Colby	76.8+0.7	77.9+2.4	80.7+1.7
Osborne-Saline	95.3+3.1	98.5+4.2	96.8+0.4
Gross Isle 1	101+1.8	102+0.4	104+3.9
Delmar	95.2+2.2	97.1+1.8	104+0.1
Gross Isle 2	94.8+4.1	89.4+0.8	94.6+0.9
Lakeland	98.1+2.8	92.2+2.8	100+0.6
Marquette	97.6+1.7	108+2.2	105+1.6
Fort Garry	99.4+4.4	107+0.4	105+1.2
Beaverdam	97.2+0.9	92.1+0.3	104+2.2
Lenswood	110+7.8	111+1.8	95.1+1.6
Osborne	113+7.8	123+2.5	140+3.6
Average	98.0+4.2	99.8+2.1	103+2.0

$\#s\bar{x} = s^2/n$, where s^2 = variance and n = 2.

4.1.3 Discussion

The initial fixation of added N can be attributed to the high concentration of NH^+_4 resulting from the hydrolysis of urea applied to soils. The fact that fixation of NH^+_4 in soils can proceed very quickly has also been reported by Kowalenko and Cameron (1976) who found that approximately one-half of added NH^+_4-N was fixed within 2 days after $(NH_4)_2SO_4$ was applied to a clay loam soil. The lack of improvement in the correlations between N retained and OM content of soil after the amount of NH^+_4 retained by soils at zero time was subtracted may indicate that NH^+_4-N which was assumed to be fixed initially in the inorganic fraction of soils may have been subsequently released; and that N retained beyond the zero time was mainly due to microbial activities in the soils. A subsequent release of fairly large amount of clay-fixed NH^+_4 over time was reported by the authors of the above-mentioned study.

A positive correlation between N fixed vs. sand+silt fraction obtained at time zero implies that some NH^+_4- fixing minerals were present in the sand+silt fraction of the soils of this study. These results agree with those reported by Kowalenko and Ross (1980) where fine silt (2-5 um) and sand fractions played an important role with regard to fixation of added NH^+_4.

A mineralogical study in Manitoba by Mills (1965) showed that coarse-textured soils in Eastern Manitoba contain minerals such as biotite, muscovite and chlorite in the fine sand fraction (250-100 um) and illite, chlorite and vermiculite in the fine silt fraction (2-5 um). These clay minerals are known to fix NH^+_4 in soils (Barshad 1950;

Nommik 1965). The corresponding negative correlation between N fixed and clay content was unexpected and is difficult to explain.

The positive correlation of N retained vs. OM content of soils obtained in this study is in agreement with a previous study reported by Walunjkar et al. (1959) where the amount of immobilized N was also directly related to the OM content of soils. A significant continuous increase in the retention of added N in the Osborne soil up to the 12 weeks of incubation appear to be associated with the high OM content and relatively low pH of the soil.

The negative correlation between N tie up and soil pH obtained in this study (eq. 15, 18 and 19) contradicts the results reported by earlier workers. Numerous studies in the past have indicated that microbial immobilization and chemical fixation of NH^+_4 tend to increase with increase in soil pH (Winsor and Pollard 1956; Nommik 1957). Recent studies by Salonius (1972) and Salonius and Mahendrappa (1979) suggest that where pH of acid forest soils was increased by urea application, there was an increase in biological immobilization and possible chemical fixation of fertilizer N. The possible explanation of these differences in the results can be attributed to the variations in the initial pH ranges of soils of this study and those used by other workers. For example, the pH of the soils studied by Winsor and Pollard (1956) ranged from 3.35 to 7.99 and a majority of these soils (14 of total 24 soils) were moderately to very strongly acidic. A greater response in the activity of the soil microbes was, therefore, anticipated as pH approach neutrality. The pH values of soils used in our study were neutral to alkaline (Table 5) and a temporary increase in pH fol-

lowing urea application may have been detrimental to soil microflora or their activities. A somewhat different population of microorganisms for soils investigated in our laboratory may have also been responsible for the observed variation in the relationship between N retained and pH of the soils. These results are not, however, conclusive and need further investigation.

The negative correlation between the amounts of N retained and CEC of the soils when the pooled data from 4, 8 and 12 weeks of incubation were introduced in the regression analyses (eq. 19) may be due to the close relationship observed between clay content and CEC of these soils. A regression analysis showed that 73% of the variation in CEC of the soils was associated with the clay content of the soils used. The clay content had been found to be negatively correlated with N fixation in the soils of this study (eq. 15). The contribution of CEC to the over-all retention of applied N, however, appears to be relatively small (eq. 19).

Significant correlations found between the ^{15}N immobilized and soil organic N mineralized for 4, 8 and 12 weeks of incubation seem to suggest that the mineralization of soil N and immobilization of NH^+_4- and NO^-_3-N or both involve some common mechanism(s). The assumption that such mechanism(s) between the two processes might occur is reasonable since both the release of soil organic N and immobiliza-tion of mineral N result from the microbial decomposition of OM in the soil.

The similarity in direct and indirect recoveries of added N in 8 out of a total 11 soils indicates that mineralization-immobilization

turnover of N was small and hence the fertilizer N appeared to be truly immobilized in these soils. A highly significant difference in recovery of added N between the direct ^{15}N and indirect methods obtained for the Osborne soil, especially for the 12-week incubation period, does indicate an appreciable biological interchange between ^{15}N and ^{14}N atoms, the tagged N being immobilized at the same time as untagged soil N being released. The differences in recoveries for the Osborne soil for all incubation periods and for the Lenswood soil for 4 and 8 weeks of incubation, between the two methods of determination, could be due in part to either the stimulation of N mineralization by the applied N (Broadbent, 1965; Westerman and Kurtz, 1973) or chemical processes as hypothesized by Laura (1975).

This incubation study has shown that certain soil characteristics can play an important role in the immobilization and/or chemical fixation of a significant portion of fertilizer N applied to soil. Up to 57% of the variation in N tie up was accounted for by the organic matter content of soils of this study. The majority of soils used in this investigation showed no or little N interchange, indicating that a good portion of the applied N was truly immobilized and/or fixed. Evidence suggested that an appreciable biological interchange of N or the apparent priming occurred in one soil only.

4.2 Growth Chamber Studies

The laboratory incubation study reported earlier showed that as much as 46% of the N added as urea was retained in soils over an incubation period of 12 weeks. The organic matter content of the soil was found to play a significant role ($r^2 = 0.57**$) in influencing the immobilization of N when urea was mixed with the soils. This led us to believe that microbial immobilization of N might be a more important factor causing the low recovery of applied N by plants than has generally been recognized in the past. It was also suspected that the magnitude of biological immobilization may possibly be related to the placement of organic residues and fertilizer N in the soil and could cause variations in the recoveries of applied N for different methods of application. These considerations resulted in the initiation of growth chamber studies reported here.

4.2.1 Growth Chamber Experiment 1

The first growth chamber experiment was designed to (a) evaluate the effect of point placed (band-like application) and mixed N treatments on the efficiency of N use by the plant (b) examine the influence of soil incorporation of organic materials on the immobilization of N, and (c) see if biological immobilization of N could account for the observed differences in the efficiency of fertilizer uptake for the two methods of N application. Residual effects of fertilizer N commensurate with the application of organic residues were also measured by growing a second crop of rapeseed.

4.2.1.1. Experimental Design:

The study was conducted using a completely randomized experiment of factorial design. The soil used was from the surface horizon (A_p) of

Pine Ridge Association with the following properties: loamy sand texture (8% clay), pH in $CaCl_2$ (soil - solution ratio of 1:2) 6.20, organic carbon 3.1%, total N 0.19%, NO_3-N 13.5 ug/g soil, and cation exchange capacity 20 meq/100g soil. The soil was air dried and passed through a 2-mm sieve. Uniform applications of 2 ug of Cu/g soil as $CuSO_4.5H_2O$, 100 ug of P/g soil as $Ca(H_2PO_4)_2.H_2O$, and 200 ug of K/g soil as K_2SO_4 were made in solution to each of 36 pots containing 3 kg soil (oven dry basis). The treatments also provided 80 ug S per g of soil. Plant residues (2-mm size) and sucrose (Table 6) were thoroughly mixed with the moist soil to supply 0 and 30 g material /3 kg soil. At the same time, urea labelled with 20.2 atom % excess ^{15}N was either applied in solution and mixed throughout the soil or placed (as powder) as a point source in the centre of the entire soil to supply 0 and 100 ug N/g soil. Where N was applied as a point source, one-half of the amended soil (by wt.) was removed from the container which was subsequently replaced after the proper amount of urea N was placed in position. Thus, the experiment consisted of one soil, four amended treatments combined factorially with three N treatments, and each treatment replicated three times.

After the treatments were completed, each pot was irrigated with distilled water to about the field capacity moisture content of the soil. (The amount of water needed was relatively small and should not have caused any displacement of point placed fertilizer since soils were already moist from the previous basal nutrient applications). The contents of the pots were then incubated at 20 C and near field capacity moisture content (by weighing randomly selected pots daily) for 30 days.

In our view, this period appeared adequate to reach an equilibrium between the two simultaneous and opposing processes of immobilization and mineralization ocurring in the system.

At the end of incubation, the pots were seeded (10 seeds/pot) to 'Tower' variety of rapeseed (Brassica napus, L.), and they were thinned to four plants/pot after emergence. The pots were rotated twice a week within the growth chamber to minimize the random error due to variations in light intensity, spatial position, and humidity in the growth chamber. The temperatures were regulated for light and dark periods at 20 and 15 C, respectively. The photoperiod was 15-hour long. The moisture content of the soil was kept near field capacity throughout the growing season by weighing randomly chosen pots daily and adding distilled water.

When after a growing period of 5 weeks the crop became N deficient (visual symptoms), plant tops were removed at the soil level and combined with leaves that had fallen during the growing period. The roots were separated from the soil as completely as possible by sieving while soil was still moist. Harvested plants and roots were air dried for 3 days at room temperature then oven dried at 60 C, weighed for dry matter yield, ground to a fine state in an electric blender and stored in iron containers for analysis. Total N in plant tissues was determined by the macro-Kjeldahl procedure. The titrated Kjeldahl distillates containing NH_4^+-N were acidified with one drop of reagent grade conc. H_2SO_4 and evaporated to a volume of approximately 5 ml. The concentrated samples were stored at room temperature until $^{15}N/^{14}N$ ratios were determined. Analysis of isotope-ratio was done in accordance with the

procedure followed by Richards and Soper (1979).

Percentage recovery of applied N was calculated by the difference as well as isotopic methods.

To study the residual effects of fertilizer N the air dry soils after sampling were transferred back into the original containers. The soils were then reincubated for a further period of 60 days at 20 C. Throughout the incubation period, the moisture content of soils was approximately field capacity. At the end of this incubation period, soil samples were obtained from each pot after the soils were air dried and analysed for NO^-_3-N. The soil remaining in each pot after sampling and used for residual study was equivalent to 2.5 kg of oven dry soil. The pots were replanted with the same variety of rapeseed. The pots also received an additional application of 200 ug of K/g soil as K_2SO_4 at planting time of the second crop. The growing conditions during the growing period of the second crop were similar to those used for the first crop. The harvesting, sampling, analytical and fertilizer N recovery procedures used in measuring the residual effects of fertilizer N were the same as those described for the first crop.

4.2.1.2. Results and Discussion

I. Main Experiment

a. Dry Matter Yield: (First crop)

Application of N significantly increased the dry matter yield for each organic matter treatment (Table 12). Although dry matter yields were consistently higher from the mixed than from the point source N placements, signficant increases in yields from mixing N into the soil over those obtained from the point placed N occurred only where

Table 12. Mean yields of dry matter as affected by added organic matter
and fertilizer treatments. First crop.

Source of O.M.	N placement		
	Mixed throughout	point source	No N
	(g/pot)		
Barley	13.0 ef*	12.3 e	8.33 c
Fababean	13.6 f	12.2 e	8.22 c
Sucrose	7.32 bc	7.11 b	0.86 a
No OM	12.2 e	10.6 d	6.91 b

* Means followed by the same letter do not differ significantly at $p = 0.05$ by Duncan's New Multiple-Range Test.

no organic matter was added. This resulted in significantly greater average yield from the mixed as compared to the point source fertilizer treatments.

Dry matter yields were related to the N content of the organic matter applied. The production of dry matter was significanly depressed by the application of sucrose whether or not any N was added to the soil. The yield was drastically reduced where sucrose was added without the application of N and amounted to only 0.86 g per pot. Plants growing in sucrose amended soils were small and stunted and exhibited a strong N deficiency as reflected by their color and appearance.

Application of barley plant material and fababean straw gave similar yields for each N treatment which were significantly larger than those obtained from the no organic matter treatment except when barley plant material was added and N was mixed throughout the soil. Yield increases resulting from the addition of these organic materials were suspected to be due to the mineralization of N from these N-rich materials.

b. Uptake of Nitrogen by Plants: (First crop).

In general, trends between N uptake by plants and production of dry matter were similar.

Nitrogen fertilization resulted in significant increases in the uptake of N by the crop (Table 13). Significantly more N was removed by the crop from the mixed than from the point source N treatments where barley and fababean residues were added or when no organic matter was applied. When sucrose was added the reverse was true, i.e., significantly greater amount of N was taken up from the point source than from

Table 13. Nitrogen uptake by plants as influenced by added organic
matter and placement of nitrogen. First crop.

Source of O.M.	N placement		
	Mixed throughout	Point source	No N
	(mg N/pot)		
Barley	369 h*	334 g	148 d
Fababean	330 g	315 f	121 c
Sucrose	112 bc	146 d	16.4 a
No OM	326 g	282 e	103 b

* Means followed by the same letter do not differ significantly at p =
0.05 by Duncan's New Multiple-Range Test.

the mixed N treatments. From these results it may be inferred that point source or band applied N is used by plants more efficiently than the soil incorporated or broadcast N only when low N organic residues are applied to the soil. Whereas, there is no evidence at hand which would indicate that banded N is superior to the mixed N when high N content organic materials are added to the soil.

Nitrogen uptake was significantly increased by treating the soil with barley and fababean organic materials except when fababean straw and urea were mixed together in the soil. Addition of sucrose significantly depressed the uptake of N by the crop. Both the barley and fababean materials had rather high N contents and N was actually released upon decomposition of these materials, whereas, addition of sucrose resulted in the tie up of N. In the field situation, cereal straw is more likely to immobilize N than not; therefore, the results represented by sucrose amendment may have a more practical signficance as compared to barley and fababean treatments. Nitrogen uptake from pots treated with barley plant material was significanly higher than those supplied with the fababean straw for each N treatment.

Several investigators in the past have reported the effects of C/N ratios on the release or tie up of N by decomposing organic materials. Waksman (1924) suggested that the N content of organic materials must be 2.0 to 2.5% (C/N ratios of 17 to 21) for ready release of NH_4-N. Lemmermenn et al. (1930) and Engel (1931) indicated that decomposing organic substances cease to be harmful when the C/N ratio is near 20 and

the N content is above 2.0%. Russell (1973) reported that where the N content of a residue is less than 1.2%, there is a tendency for the soil population to immobilize N while decomposing the residues, whereas release of N takes place where the N content exceeds 1.8%. Our results also indicate that if the C/N ratio of added organic material is about 21 to 22 (with 1.99 and 1.97% N, respectively), the uptake of N and crop growth will be enhanced through the mineralization of N by decomposing materials.

c. Uptake of Fertilizer Nitrogen and Soil Nitrogen: (First crop).

Data given in Table 14 are consistent in showing that point placed N was superior to the mixed N application where organic matter was added to the soil. When organic matter was not added, essentially the same amounts of fertilizer N were removed by the crop from each N placement. Where sucrose was applied as a source of organic matter, nearly 3 times as much fertilizer N was utilized by the plants from the point source application as from the mixed N placement. Similar trends in N uptake were also evident for barley and fababean treatments, although differences between the two methods of N placement were somewhat less pronounced than those found in the sucrose treatment. Significantly more fertilizer N was taken up from the barley than from the fababean treatments regardless of N placement. When organic matter and fertilizer were mixed together in the soil, there was a larger surface exposure between soil and fertilizer and between organic matter and fertilizer than when N was placed as a point source in the soil. Mixing N with soil should have therefore created more favorable conditions for enhanced microbial activities than placing N in the point form. The

Table 14. Uptake of fertilizer and soil nitrogen by the above-ground
           portion of the first crop.

| Source of O.M. | N placement | | |
	Mixed throughout	Point source	No N
		(mg N/pot)	
		Fert. N.	
Barley	84.0 c*	145 f	0.0
Fababean	75.9 b	139 e	0.0
Sucrose	34.8 a	100 d	0.0
No OM	154 g	155 g	0.0
		Soil N	
Barley	285 j	189 h	148 f
Fababean	254 i	177 g	121 e
Sucrose	77.3 c	46.0 b	16.4 a
No OM	172 g	127 e	103 d

* Means followed by the same letter for each of the two sources of
  nitrogen do not differ significantly at p = 0.05 by Duncan's New
  Multiple-Range Test.

effect was enhanced when sucrose, a more soluble organic substance, was added to the soil. The reduced N uptake by plants from the mixed fertilizer treatment was thus a consequence of increased competition between the growing plants and soil microorganisms for the applied N, indicating the importance of energy source and placement of N for the availability of fertilizer N to plants.

The uptake of soil N was characterized by marked differences between the fertilized and unfertilized pots. Application of N significantly increased the uptake of soil N for each organic matter treatment (Table 14). Large increases in soil N uptake where barley and fababean plant materials were added was suspected to be due to the interchange of N between tagged N and the N mineralized from these materials or that released from the soil organic N. Contrary to the uptake of fertilizer N, significantly more soil N was removed from the mixed than from the point source fertilizer placements for all organic matter treatments. The increase in soil N uptake from the mixed N treatment over that taken up from the point source placement could have been caused by an increased priming effect and N interchange in the mixed N treatment. The decrease in soil N uptake from the sucrose treated soils could be attributed to the increased immobilization of N in the soil.

d. Recovery of Fertilizer Nitrogen by the Crop: (First crop).

The recovery of fertilizer N by the above-ground portion of the crop was determined by two methods: firstly; by the difference method where the amount of applied N taken up by the crop was calculated by the difference between total N uptake from fertilized and unfertilized soils and, secondly; by determining the ^{15}N content of the plants.

Results are shown in Table 15.

Using the ^{15}N method, the percentage recovery of fertilizer N from the point placement was significantly greater than from the mixed N treatment except when organic matter was not added. Also, the recovery of fertilizer N was less affected by the addition of organic matter when N was applied as a point source than when added throughout the soil. Where fababean straw was added, the percentage recovery of fertilizer N from the mixed treatment was about 55% of that obtained from the point source N treatment. The corresponding figure for barley treatment was about 58%. The difference was even more pronounced when sucrose was applied to the soil. In this case the percent recovery of added N from the mixed fertilizer application was only about one-third of that obtained from the point placed N.

With the difference method, adding urea throughout the soil was somewhat superior to placing the urea as a point source when barley and fababean materials were added or where no organic matter was applied. The point source placement was superior when sucrose was added. The reason for these differing results from the two methods of calculating fertilizer N utilization is not clear. The differences in the results are generally attributed to the priming effect of added N as well as the biological interchange of N that takes place in the system.

Our results and several other reports (Cady and Bartholomew, 1960; Zamayatina et al., 1968; Westerman and Kurtz, 1974) indicate that the difference method generally overestimates the recovery of added N by the plant. The possible explanation for the observed differences between the two methods of calculation have been discussed in Chapter 2.

Table 15. Fertilizer N recoveries in aboveground portion of the plants
as calculated by ^{15}N and difference methods. First crop.

Source of O.M.	N placement	
	Mixed throughout	Point source
	(% N recovered)	
	^{15}N method	
Barley	28.0 c*	48.3 f
Fababean	25.3 b	46.2 e
Sucrose	11.6 a	33.5 d
No OM	51.3 g	51.7 g
	Diff. Method	
Barley	73.7 ef	62.0 cd
Fababean	69.7 e	64.7 d
Sucrose	31.9 a	43.5 b
No OM	74.3 f	59.7 c

* Means followed by the same letter for each of the two methods do not
differ significantly at p = 0.05 by Duncan's New Multiple-Range
Test.

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Results presented in Table 16 give some idea of the scope and intensity of the mineralization-immobilization turnover or biological interchange that took place during the course of the present experiment. It is simple to visualize that if there is no turnover in the system the turnover index (Jansson, 1958) will be unity. Since all turnover indexes in this study were greater than 1, and some appreciably so, the occurrence of an appreciable N interchange was evident in each treatment of the study.

Even when no organic matter was added, N turnover continued to take place as indicated by the numerical values given in Table 16. This could be attributed to the excretion of organic materials by plant roots and sloughing off of the roots which served as a source of energy to maintain microorganisms activity in the soil. A greater turnover was revealed when N was mixed throughout the soil than when placed as a point source whether or not any organic matter was applied. This demonstrates that N interchange between tagged and non-tagged N was greater where fertilizer was mixed throughout than when placed as a point source in the soil. Thus, exchange between soil and fertilizer N increased with an increase in the accessibility of applied N.

The turnover process was considerably stimulated by the addition of organic matter, suggesting the role of energy source in stimulating the microbial activity in the system. A larger N turnover, therefore, appears to be associated with a more vigorous biological activity. The close similarity in the values of indexes for a given fertilizer place-

Turnover Index = Percent recovery of applied N by the difference method / Percent recovery of applied N by the ^{15}N isotopic method

Table 16. Mineralization-immobilization turnover as affected by added organic matter and fertilizer treatments.

Source of O.M.	N placement	
	Mixed throughout	Point source
	------- Turnover Index -------	
Barley	2.63	1.28
Fababean	2.75	1.40
Sucrose	2.75	1.30
No OM	1.45	1.15

ment where organic matter was applied indicates that N interchange between ^{15}N atoms from the added fertilizer and ^{14}N atoms from the soil organic N was about the same for each of the materials applied.

e. Immobilization of Nitrogen:

Nitrogen immobilization involves transformation of plant available or inorganic N into the organic form through its assimilation by soil organisms. According to this concept plant utilization of fertilizer N will be influenced by, among other factors, the immobilization of N in the soil. The tie up of N in soil is evidently controlled by the availability of the N and by the inflow of energy necessary to maintain the activity of organisms concerned.

The source of energy used in this experiment consisted of barley and fababean plant materials and the readily decomposable non-nitrogenous sucrose. The purpose in applying these materials to soil was to determine the relative immobilization of N by added organic residues and also to see if the immobilization of added N caused by these substances could account for the difference in efficiency of applied N for mixed and banded fertilizer treatments. This was attempted by estimating the amounts of fertilizer N immobilized for different treatments from the plant viewpoint as well as from measuring the amounts of fertilizer N remaining in the soil at harvest time of the crop. Quantities of fertilizer N remaining in the soil are given in Table 18 and discussed along with the recovery of fertilizer N in soil-plant system in the next section.

In following the influence of N immobilization on N uptake by plant tops it was assumed that losses of applied N were not affected by addition of organic matter to the soil (Table 18). This allowed us to

examine if the differences in results between the two methods of N application could have been accounted for by the immobilization of applied N. The N uptake values given in Table 14 permitted such an evaluation. Immobilization of N resulting from addition of carbonaceous substances was estimated by subtracting the amount of N taken up by plants receiving the organic matter in question from that taken up by control plants. As shown in Table 17, significantly more fertilizer N was immobilized from the mixed than from the point source N placements where organic matter was applied. The decreased immobilization from the point placed N can be attributed to the reduced contact between added N and soil.

Sucrose immobilized more N than did either of barley and fababean organic materials. Evidently, the C/N ratio and decomposibility of the materials applied played an important part in immobilizing the applied N in soil. It is also evident that application of barley and fababean organic materials, in spite of their high content of N, resulted in substantial apparent immobilization of fertilizer N during their decomposition in the soil. The differences in the decomposition characteristics of barley and fababean residues might have accounted for the differences in the amounts of fertilizer N immobilized by these substances.

Fairly large quantities of soil N were also immobilized where sucrose was added to the soil. Where barley and fababean plant residues were added, the figures computed for immobilization were negative which could be attributed to either the mineralization of N from these materials or to the interchange of N or both.

From the data given in Table 17, it is proposed that immobilization

Table 17. Effect of added organic matter and fertilizer treatments on
the immobilization of soil and fertilizer nitrogen.

Source of O.M.	Mixed throughout	Point source	No N
	(mg N/pot immobilized)		
	---- Fertilizer N ----		
Barley	70.0 c*	10.0 a	0.0
Fababean	78.1 d	16.0 a	0.0
Sucrose	119.2 e	55.0 b	0.0
	---- Soil N ----		
Barley	-113.0 a	-62.0 c	-45.0 d
Fababean	-82.0 b	-50.0 d	-18.0 e
Sucrose	94.7 g	81.0 f	86.6 fg

The header "N placement" spans the three placement columns.

* Means followed by the same letter for each of the two sources of N do
not differ significantly at p = 0.05 by Duncan's New Multiple-Range
Test.

of fertilizer N was important in explaining the differences in performances between point source and mixed N treatments where sucrose was added to the soil. On the other hand, where barley and fababean organic materials were applied, N interchange between tagged fertilizer N and non-tagged N in the soil organic fraction or that released from the added plant materials seemed to have contributed to the observed differences in the efficiencies between the two N placements.

f. Recovery of Fertilizer Nitrogen in Soil-Plant System: (First crop).

The distribution of applied N in plant and soil as determined by the ^{15}N method is given in Table 18. The data are expressed as percent of the fertilizer N initially applied. Although the average recovery of added N was significantly greater for the point than for the mixed N treatments, the differences in recovery for the two methods of application were barely significant. When N was applied as a point source, the total percent recoveries of added N were significantly improved by adding organic matter to the soil and were similar for all organic materials applied. When fertilizer was mixed in the soil, addition of fababean straw decreased the total recovery somewhat. Total recovery of fertilizer N was significantly better from pots treated with sucrose than those treated with barley and fababean organic materials when fertilizer was mixed within the soil. Recoveries of fertilizer N in soil plus plants ranged from 89.5 to 97.8% for the point source placement and from 89.7 to 96.6% for the mixed throughout placement, therefore N losses were not large. The unaccounted for N was presumably lost in gaseous form. The results also indicate that gaseous losses of fertilizer N were slightly less from the point than from the mixed N

Table 18. Recovery in tops, recovery in root material, residual nitrogen in soil, and overall recovery of fertilizer nitrogen obtained for the growing period of first crop.

	N placement						
Source of O.M.	Mixed throughout				Point source		
	% ^{15}N recovered						
	In tops	In roots	In soil	Total	In tops	In roots	In soil	Total
Barley	28.0c*	10.0b	54.9f	92.9b	48.3f	15.0c	31.9c	95.2bcd
Fababean	25.3b	9.8b	54.6f	89.7a	46.2e	15.3c	35.5d	97.0cd
Sucrose	11.6a	5.8a	79.2g	96.6cd	33.5d	15.5c	48.8e	97.8d
No OM	51.3g	15.3c	27.5b	94.1bc	51.7g	17.8d	20.0a	89.5a
Average	29.0	10.4	54.0B	93.3A	44.9	15.9	34.0A	94.9B

* Means followed by the same letter for each of the components do not differ significantly at p = 0.05 by Duncan's New Multiple-Range Test.

placements.

Amounts of fertilizer N remaining in the soil after harvest differ-
red significantly between the mixed throughout and point source N appli-
cations. On an average, the quantities of fertilizer N remaining in the
soil amounted to 34.0% for the point source placement and 54.0% for the
mixed fertilizer placement. Addition of organic matter significantly
increased the amounts of fertilizer N remaining in the soil. The lar-
gest amounts of fertilizer N that remained in the soil were where su-
crose was added and amounted to 48.8 and 79.2% for point source and
mixed N placements, respectively. Addition of barley and fababean
organic materials showed similar effects on the amounts of fertilizer N
remaining in the soil. A comparison of the amounts of fertilizer N
remaining in the soil among sucrose, barley and fababean treatments
indicated that significantly more fertilizer N was immobilized in soil
where sucrose was added to the soil than when barley and fababean
organic residues were applied.

The amounts of fertilizer N recovered in the root material ranged
from 5.8 to 15.3% and from 15.0 to 17.8% for the mixed throughout and
point source placements, respectively. This suggests that N from ferti-
lizer was more readily absorbed by plant roots from the point than from
the mixed N applications.

The data presented here indicated that although urea was used as a
source of fertilizer N, the total recovery of added N was very good.
Throughout the experiment care was taken to maintain the moisture con-
tent of the soil at field capacity thereby reducing the losses of ap-
plied N through denitrification. Thus, gaseous losses of fertilizer N

were presumably due to NH_3 volatilization. However, no direct measurements of volatilization losses of applied N were made, and in view of the added organic matter, the possibility of N losses through denitrification may not be completely ruled out.

Results of this study indicate that the immobilization of fertilizer N in soil was signficantly influenced by the placement of N. The immobilization of added N was always greater when fertilizer was mixed in the soil than when it was placed as a point source. The effect was enhanced when organic matter was applied to the soil and was more pronounced with the sucrose than with barley and fababean residue applications. These results agree with those reported by Nommik (1961) where the use of soluble carbohydrate materials resulted in higher net immobilization per unit of substrate than did the use of normal crop residues.

II. Residual Effects of Fertilizer Nitrogen and Applied Organic Matter:

Plant utilization of the fertilizer N remaining in the soil after harvest of the fertilized crop was determined by growing a second crop of rapeseed as the test crop.

a. Dry Matter Yield: (Second crop).

The yield of dry matter when sucrose was not added was about 23 to 57% of that obtained from the first crop (Table 19). When sucrose was added, the dry matter yield ranged from about one-half to five times the yield recorded for the previous crop.

The residual effects of fertilizer N on dry matter yield were absent except where fertilizer was applied as a point source and sucrose was mixed throughout the soil. Yield where sucrose and no N were added was as high as that obtained where barley or fababean residues and N were mixed throughout or where fababean straw was mixed throughout and N was applied as a point source. This observation indicates that N which was immobilized by sucrose earlier in the growing period of the first crop was subsequently mineralized during the growing period of the second crop, suggesting that the half-life of this immobilized N was relatively short. The high yields of second crop from the sucrose amended soil could have occurred due to the increased availability of this mineralized N (Table 20). The agronomic significance of this treatment lies in the fact that addition of crop residues and fertilizer N to the soil over a period of time could help enrich soil N throught the immobilization of applied N in the soil. The remineralization of immobilized or residual N may thus benefit the succeeding crops grown on such soil

Table 19. Rapeseed dry matter yield as affected by residual fertilizer
           nitrogen and organic matter. Second crop.

	N placement		
Source of O.M.	Mixed throughout	point source	No N
	(g/pot)		
Barley	4.39 bc*	4.74 cd	4.70 cd
Fababean	4.18 b	4.44 bc	4.19 b
Sucrose	4.25 b	4.87 d	4.15 b
No OM	2.79 a	2.76 a	2.53 a

* Means followed by the same letter do not differ significantly at p =
  0.05 by Duncan's New Multiple-Range Test.

as was noted by Ferguson (1967). The data also suggest that residual values of added N were affected only slightly by the method of fertilizer application used during the cropping period of the first crop.

The yields were relatively low in pots receiving no organic matter, while in the pots receiving additional organic matter the dry matter yields were significantly increased. When no N was applied, yields from pots treated with fababean straw and sucrose were similar and significantly lower than those treated with barley plant material. Where N was mixed throughout the soil, crop yield response to the residual organic matter was similar for all treatments. In pots receiving point source applied fertilizer N, the yields were variable among the various organic matter treatments. The yield increases from barley and fababean treatments over that found for the no organic matter control, were attributed to the N mineralized from the previously immobilized fertilizer N and the added barley and fababean plant materials. In the case of sucrose application, because of its inferior effect on the first crop due to large N immobilization, the better yield responses to this treatment appeared primarily due to the increased N uptake which might have resulted from the mineralization of previously immobilized N.

b. Nitrogen Uptake by Plants: (Second crop).

Both N uptake and dry matter yields were generally related to each other although some variations in the values of these parameters were observed.

Although the average uptake of N was significantly greater where

fertilizer was applied as a point source than when added throughout the soil or where no fertilizer was added, the data exhibited little evidence of any positive effect of residual fertilizer N upon the uptake of N by the crop (Table 20). The uptake of N was actually decreased where urea and barley residue were both mixed together in the soil. The increased N uptake from the fertilized soils over that taken up from the unfertilized soils was evident only in two cases. These were where fertilizer was mixed with the soil and no organic matter was added, and where fertilizer was placed as a point source and sucrose was incorporated. These data demonstrate that addition of N as well as method of N application did not seem to contribute to any significant differences in the uptake of N and hence in the production of dry matter for most of the treatments.

Nitrogen uptake by the crop was significantly increased by the residual organic matter for all N treatments. Residual effects of sources of organic matter on N uptake were rather variable. The residual response was greatest when N was placed as a point and sucrose was added to the soil. The increased N uptake from this treatment might have resulted from the increased mineralization of residual fertilizer N from the organic fractions of the soil (Table 22). The similarity in the amounts of N removed by the crop from no N and mixed N treatments where sucrose was added to the soil was presumably due to the mineralization of comparable amounts of soil and fertilizer N which were immobilized during the growing period of the first crop. The residual effect from the barley plant material was more pronounced where fertilizer was placed as a point source or where no N was applied and relatively less

Table 20. Effect of residual fertilizer nitrogen and organic matter on the uptake of nitrogen by the second crop.

Source of O.M.	N placement		
	Mixed throughout	Point source	No N
		(mg N/pot)	
Barley	66.5 c*	74.1 de	76.4 e
Fababean	68.5 cd	68.7 cd	67.4 c
Sucrose	68.0 c	93.1 f	69.9 cd
No OM	40.5 b	36.8 ab	34.4 a

* Means followed by the same letter do not differ significantly at p = 0.05 by Duncan's New Multiple-Range Test.

noticeable where fertilizer was mixed with the soil. Residual effects of fababean straw were similar for all N treatments. Where fertilizer was not applied, the barley treatment was superior to other organic matter treatments. Where N was mixed into the soil, residual effects of applied organic materials were similar. The residual effects of barley plant material and fababean straw were also similar where N was placed as a point source in the soil.

c. Recovery of Applied and Residual Fertilizer Nitrogen in the Soil-Plant System: (Second crop).

The percentage recovery of the applied N in the harvested portion of the crop, root material, and soil after cropping was calculated by the ^{15}N isotopic method. The distribution of fertilizer N in the soil-plant system at harvest time is given in Table 21. For a given organic matter treatment, the cumulative recoveries of tagged N were significantly higher where fertilizer was added throughout the soil than where applied as a point source except when organic matter was not added. The overall recoveries of fertilizer N from both barley and fababean treatments were similar for a given N treatment and were significantly lower than those obtained for the sucrose treatment. In pots receiving sucrose application, the total recovery of labelled N was significantly greater where fertilizer was mixed into the soil than when applied as a point source.

Data collected at the end of the experiment indicated that 82.8% (44.7% of the labelled N initially applied) and 87.4% (29.7% of the labelled N initially applied) of the amounts of residual fertilizer N present in the soil at harvest time of the first crop could still be ac-

Table 21. Plant recovery in tops, recovery in root material, recovery in soil and over-all recovery of fertilizer nitrogen during the growing period of second crop.

	N placement							
Source of O.M.	Mixed throughout				Point Source			
	(% ^{15}N recovered)							
	In tops	In roots	In soil	Total	In tops	In roots	In soil	Total
Barley	3.6d*	2.6d	38.8c	45.0c	2.7c	1.7bc	21.9b	26.3b
Fababean	4.0e	3.0e	36.4c	43.4c	2.5c	2.0c	22.1b	26.6b
Sucrose	6.3f	3.7f	56.7d	66.7d	6.0f	3.4f	36.6c	46.0c
No OM	2.1b	1.4b	20.2ab	23.7ab	1.4a	1.0a	17.3a	19.7a
Average				44.7				29.7

* Means followed by the same letter for each of the components do not differ significantly at p = 0.05 by Duncan's New Multiple-Range Test.

counted for in the soil and plants from the point source and mixed fertilizer treatments, respectively. Thus, 12.6 to 17.2% of the residual fertilizer N could not be accounted for in soil and plant at the conclusion of the experiment and was thought to be lost mainly by denitrification rather than by NH_3 volatilization since no fresh N application was introduced during this phase of the experiment. It may, also, be pointed out that during the post-harvest incubation of soils at the end of the first crop, the soils were accidentally flooded and remained water-logged for about 2 to 3 days. Therefore, denitrification of N might have played a major role in affecting the losses of residual fertilizer N as indicated earlier.

At the end of harvest of second crop, the percent recovery of applied labelled N in the whole plant ranged from 2.4 to 9.4% for the point source and from 3.5 to 10.0% for the mixed throughout N application. The recovery of fertilizer N in roots varied between 1.0 and 3.4%, whereas in the shoot it was from 1.4 to 6.0% where fertilizer was applied as a point source. The corresponding figures in root and shoot for the mixed N application were 1.4 to 3.7% and 2.1 to 6.3%, respectively. More of the fertilizer N utilized by the crop was in the aboveground portion and less in the roots. In general, the utilization of fertilizer N by the crop was relatively greater from the mixed than from the point source N treatments. It would, therefore, appear that N use efficiency of the applied N was related to the amounts of residual fertilizer N remaining in the soil at the planting time of the second crop.

Percentage uptake of fertilizer N by the subsequent crop was signi-

ficantly increased by the residual organic matter. The residual effects of a given organic matter treatment on the uptake of fertilizer N were similar for roots and shoots of the plant. Responses to barley and fababean organic materials were similar where N was applied as a point source but the fababean treatment was superior to barley where fertilizer was mixed into the soil. The reason for this difference is not clear. The residual effect of the sucrose treatment was greater than any other organic material applied and was not influenced by the methods of N application.

The utilization of residual fertilizer N by the crop was calculated from the ^{15}N determination of root and shoot samples. The results were expressed as percent of the fertilizer N remaining in the soil at the end of the first crop. At the time of harvest, recovery values of residual fertilizer N by the crop for both mixed and banded N treatments were remarkably similar except when sucrose was added and ranged from 11.3 to 12.7% and 12.0 to 19.3% for mixed and point source N treatments, respectively (Table 22). This indicates that fertilizer N which was tied up in soil by the sucrose became more available from the point source than from the mixed N treatments. The residual effects of organic matter on the uptake of residual fertilizer N appeared to be similar for all treatments except where sucrose was added as a source of OM and fertilizer was placed as a point source. The increased uptake of residual fertilizer N from this treatment was attributed to an increased mineralization of previously immobilized fertilizer N which was evident in both roots and shoots of the plant. The percent recovery of residual fertilizer N by the crop was not influenced by the method of N applica-

Table 22. Percentage utilization* of residual labelled nitrogen by the second crop.

Source of O.M.	N placement						
	Mixed throughout				Point source		
	% ^{15}N recovered						
	In tops	In roots	Whole plant		In tops	In roots	Whole plant
Barley	6.6	4.7	11.3		8.5	5.3	13.8
Fababean	7.3	5.5	12.8		7.0	5.6	12.6
Sucrose	7.9	4.7	12.6		12.3	7.0	19.3
No OM	7.6	5.1	12.7		7.0	5.0	12.0

* % utilization of residual fert.N $= \dfrac{\% ^{15}\text{N recovery in the plants}}{\% ^{15}\text{N recovery in the soil after first crop}} \times 100$

% ^{15}N recovery in the plant $= \% ^{15}$N recovery in the root $+$ $\% ^{15}$N recovery in the shoot

tion except where sucrose was added to the soil.

Approximately 17 to 57% of the initially applied fertilizer N (67 to 86% of the residual fertilizer N) still remained in the soil at harvest time of the second crop. These values ranged from 17.3 to 36.6% (62.2 to 86.5% of the residual labelled N) for the point source applied N and from 20.2 to 56.7% (66.7 to 73.6% of the residual labelled N) for the mixed N applications, respectively. Amounts of fertilizer N present in the soil after the second cropping period were significantly larger from the mixed than from the point source N treatments except when organic matter was not added to the soil (Table 21), where the quantities of applied N were similar for both N placements. However, the amounts of residual fertilizer N found in the soil after harvest of the second crop were somewhat larger from the point than from the mixed N placements where sucrose was added to the soil (75.0 vs. 71.6%) or where no organic matter was applied (86.5 vs. 73.4%).

Results of this growth chamber study show that banding N in the soil (point placement) was not better than mixing N in the soil with regard to the production of dry matter and N uptake by the crop except when sucrose was added. The efficiency of fertilizer use by the crop was also similar for the two methods of N application when organic matter was not applied. However, when organic matter was applied, the point placement of N was superior to the mixed N treatment when the efficiency of added N was evaluated in terms of percent utilization and immobilization of added N in the system.

Release of residual fertilizer N to the above-ground portion of the second crop averaged 7.4 and 8.7% for the mixed and point placed N, re-

spectively. Addition of sucrose increased the utilization of residual fertilizer N through the mineralization of previously immobilized N where fertilizer was applied in a point form. The residual fertilizer N recovered by the crop represented the crop availability of that portion of applied N which might have transformed into soil microbes, their metabolites, and decomposition products of organic residues added to the soil. Approximately 13 to 17% of the residual fertilizer N was lost from the soil-plant system during the growing period of the second crop. Eighteen to 24% of the originally applied N was not accounted for from the system during the entire experiment, with a major portion of the N lost during the growth period of the second crop.

4.2.2 Growth Chamber Experiment 2

Although the results obtained from the first growth chamber experiment helped to explain the differences in efficiencies for the methods of N application, the design of the experiment was limited to one organic matter placement only; namely, mixing the organic materials throughout the entire soil. Consequently, a second growth chamber experiment, in concept and design similar to the first, was set up to obtain additional information regarding the effect of placements of both crop residue (with N content comparable to that normally present in the cereal crop residues) and fertilizer N on the efficiency and immobilization of applied N. The experiment was specifically designed to test the hypothesis that banding fertilizer reduces the immobilization of N, whereas, mixing N would increase the immobilization by the soil. And if such were the case, then immobilization of applied N would likely cause some of the differences in the efficiency between the methods of N application. This was done by varying both fertilizer and organic matter treatments. The effect of placements of N and plant residue on the release and uptake of the residual fertilizer N remaining in the soil at harvest time of the first crop was investigated by growing a second crop in the same manner as that used in the first growth chamber experiment.

4.2.2.1 Experimental:

The data obtained from the first growth chamber experiment form the basis of this study. The experimental conditions and design of the experiment were similar to those established for the conduct of the first experiment. Throughout the course of the experiment, during both the main and the residual effects, the soil, amount of soil per pot,

basal nutrients and their rates of application, source of applied N, pre-harvest and post-harvest incubation periods, crops, and procedures for collection of the soil and plant samples, were the same as those used for the first growth chamber experiment.

The pots were divided into sets to meet the requirements of the treatments of the experiment. After the pots received uniform basal applications of Cu, S, P, and K in solution, the barley straw (ground to pass a 2-mm sieve, 0.45% N) at one percent of the soil weight was mixed either throughout the entire soil or with the surface 4 cm of soil. At the same time, urea labelled with 20.1 atom% excess ^{15}N was applied in solution and mixed thoroughly either with the entire soil or with the 4 cm surface soil to give 100 ug N/g soil. The treatments also consisted of placements where powdered urea equivalent to 100 ug N/g soil was applied as a point source and was either placed in the centre of the entire soil (in a cavity) or placed in the centre of the surface 4 cm of soil. Thus, the experiment consisted of one soil, three amended treatments (including no residue application) combined factorially with five urea placements (including no N placement), and each treatment replicated three times. The contents of these pots were then incubated for a period of 30 days at field capacity moisture content and 20 C.

At the end of incubation period, the pots were seeded to rapeseed (8 seeds/pot) and they were thinned to four plants per pot after emergence. When after a growing period of 5 weeks the crop became N deficient, the plants were removed from the soil surface and roots separated. Soil from each pot was air dried, mixed thoroughly, sampled and in-

cubated for a further period of 60 days as per the procedure used in the first growth chamber experiment. After air drying and subsampling the soils for the determination of NO^-_3-N levels, the pots (2.5 kg soil/pot) were again planted with the same rapeseed variety. The experiment was carried out until the crop was harvested after another growing period of 5 weeks. The experiment was conducted under the same environmental conditions as those observed for the first experiment.

Harvested plants and roots from both crops were oven dried at 60 C and weighed for the yields of dry matter. The soils were air dried and mixed thrououghly. Soil, shoot, and root samples were obtained from each pot as before and analyzed for labelled and total N contents. The analytical procedures and methods of calculation of fertilizer N recovery were the same as those described for the first growth chamber experiment.

4.2.2.2 Results and Discussion

I. Main Experiment

a. Crop Yield: (First crop).

The addition of fertilizer N significantly increased the dry matter yield except when fertilizer and straw were both mixed with the surface portion of the soil (Table 23). With no plant residue applied, placement of N had no effect on the yield of dry matter. However, when organic matter was applied, yields of dry matter were significantly larger from the point source than from the mixed N placements except when the fertilizer was mixed throughout the entire soil and straw was added to the surface portion of the soil. For the point placed N, yields were similar for a given straw placement. The dry matter yields were also

Table 23. Dry matter yields of rapeseed as affected by added organic
           matter and nitrogen treatments. First crop.

Straw application	N placement				
	Mixed throughout the soil	Mixed in top 4 cm soil	Point source in the centre of entire soil	Point source in the centre of top 4cm soil	No N
	(g/pot)				
Mixed throughout the soil	7.07b*	7.65b	9.38de	9.28de	0.70a
Mixed in top 4 cm soil	9.91ef	7.74bc	9.85ef	10.5f	7.05b
No straw	9.92ef	10.7f	10.4f	10.4f	8.55cd

* Means followed by the same letter do not differ significantly at
p=0.05 by Duncan's New Multiple-Range Test.

similar for both mixed N treatments except where fertilizer was mixed with the entire soil and straw was added to the surface portion of the soil.

Responses of crop yield to straw application varied according to its placement into the soil. When N was not added, dry matter yields were significantly depressed regardless of the method of straw application. The yield being lowest where straw was mixed throughout the soil. With added fertilizer N also, mixing straw throughout the soil reduced the yield significantly and it did not matter how the fertilizer was applied. With surface mixed straw, a significant yield reduction occurred only when fertilizer was also mixed in the surface portion of the soil, indicating the importance of placement of crop residue relative to the placement of N fertilizer in the soil.

b. Nitrogen Uptake: (First crop).

Trends between N uptake and yield of dry matter were generally similar.

Addition of urea significantly increased the uptake of N by the crop (Table 24). Amounts of N removed by the crop were significantly greater for the mixed than for the point source N placements where straw was not applied. Where straw was applied, the point placements of N were superior to the corresponding mixed N placements. For the point placed urea, significantly more N was taken up when N was centre-placed than when surface-placed where straw was mixed in the surface soil or when no straw was applied. Where straw was mixed throughout the soil, N removed by plants was similar for both point source placements of N. With the mixed N treatments, significantly more N was removed from the

Table 24. Sources of nitrogen used by the first crop.

Straw application	N placement				
	Mixed throughout the soil	Mixed in top 4 cm soil	Point source in the centre of entire soil	Point source in the centre of top 4cm soil	No N
	(mg N/pot)				
Mixed throughout the soil	120c*	130d	157ef	162f	7.77a
Mixed in top 4 cm soil	219g	135d	263h	216g	87.3b
No straw	3901	373k	332j	320i	150e
	Fert. N.				
Mixed throughout the soil	26.5b	54.7c	104f	107f	--
Mixed in top 4 cm soil	74.5d	7.27a	145h	93.3e	--
No straw	138gh	133g	161j	151i	--
	Soil N				
Mixed throughout the soil	93.3e	74.9c	53.9b	55.6b	7.77a
Mixed in top 4 cm soil	145h	128g	119f	122fg	87.3d
No straw	251k	240j	171i	169i	150h

* Means followed by the same letter do not differ significantly for each source of nitrogen at p=0.05 by Duncan's New Multiple-Range Test.

mixed throughout than from the surface mixed N when straw was added to the surface soil or when no straw was applied. The reverse was true when straw was applied throughout the soil.

Addition of organic matter significantly diminished the uptake of N whether or not any fertilizer was added. Mixing straw throughout the soil was inferior to mixing straw into the surface soil except when urea was also mixed with the surface soil where crop removal of N was essentially the same for both the straw treatments.

Amounts of fertilizer N removed by the crop were signficantly greater for the point than for the mixed N treatments whether or not any organic matter was added to the soil (Table 24). The lowest fertilizer N uptake for both point and mixed N treatments occurred where contact between fertilizer and added organic matter was increased by placing them together in a relatively narrow band of the soil. This could have been attributed to the increased immobilization of applied N in this treatment. This was also true when fertilizer and organic matter were both mixed throughout the entire soil, which also resulted in less uptake and more immobilization of applied N. When fertilizer was placed as a point source there was less immobilization since a smaller portion of the soil or organic matter was exposed to the fertilizer N. Also, where N was added by the point source placements, the differences in fertilizer N uptake with and without straw were relatively less when compared with the mixed N treatments for similarly applied straw. This showed that the utilization of point placed N was less affected by the addition as well as the placement of organic matter in the soil.

The amounts of soil N used were also increased significantly by ad-

ding fertilizer N to the soil (Table 24). Contrary to what was observed for the uptake of fertilizer N, significantly more soil N was removed by plants from the mixed than from the corresponding point source N treatments whether or not any organic matter was added to the soil. The increase in soil N uptake from mixed vs. point source N placements was significantly enhanced when organic matter was not applied. Amounts of soil N removed by the crop were not related to the point placements of N but were quite dependent upon how the fertilizer was mixed into the soil. Consistently more soil N was removed where urea was mixed throughout than when mixed in only the surface portion of the soil. These results are consistent with those obtained in the first growth chamber experiment where it was postulated that increasing the contact between fertilizer and soil mass/volume stimulated the mineralization of soil N or enhanced the exchange of N between added and soil organic N. Effect of added organic matter on the uptake of soil N were similar to those observed for the uptake of total and fertilizer N.

Certain points need to be attended here. The increased N uptake from the mixed compared to the point placed N, where straw was not applied, was due to the increased uptake in soil N (Table 24). A significant increase in soil N uptake from N fertilization of the crop was attributed to the increased priming effect of added N (Broadbent, 1965; Westerman and Kurtz, 1973) and/or an increased interchange between tagged fertilizer N and soil organic N. Both priming and interchange seemed to depend on the degree of fertilizer distribution in the soil. A comparison of data from the two mixed N treatments clearly illustrates this observation. A more uniform distribution of added N in the soil

might have also enhanced N absorption by the roots. The results also indicate that mixing crop residue and fertilizer N in a narrow band in the soil tended to enhance immobilization as compared to placing the two components apart in the soil. Thus, the lowest uptake of fertilizer N where straw and N were both mixed with the surface soil could have been caused by the largest tie up of N due to close proximity of added straw and N. Some of the reduction in the uptake of N from this treatment could also be attributed to increased losses of N from surface applied urea.

c. Immobilization of Nitrogen:

To further understand the effect of placement of organic matter and fertilizer N on the utilization of applied and soil N, the amounts of N immobilized by the added straw were calculated for various treatments. The calculation was based on the assumption that the losses of fertilizer N were not affected by adding straw to the soil. By subtracting the amount of N removed by the above-ground portion of the crop from a treatment receiving no straw, it was found that significant amounts of fertilizer as well as soil N were immobilized by the organic matter added to the soil (Table 25).

These data do indicate that when the reaction zone between organic matter and fertilizer was increased, the immobilization of N also increased. For example, the largest amount of fertilizer was immobilized when both fertilizer and straw were added together to a portion of the soil, whereas, the amount of fertilizer N immobilized was smallest where straw was placed in a portion of the soil and fertilizer was applied as a point source to the centre of the entire soil which kept the organic

Table 25. Estimated immobilization of fertilizer and soil nitrogen as affected by placements of added organic matter and fertilizer nitrogen. First Crop.

Straw application	Mixed throughout the soil (100 ppm)	Mixed in top 4 cm soil (100 ppm)	Point source in the centre of entire soil	Point source in the centre of top 4cm soil	No N
			(mg N/pot)		
			Fertilizer N		
Mixed throughout the soil	112e*	78.3d	57.0c	44.0b	--
Mixed in top 4 cm soil	63.5c	126f	16.0a	57.7c	--
			Soil N		
Mixed throughout the soil	158f	165f	117d	113cd	142e
Mixed in top 4 cm soil	106c	112cd	52.0a	47.0a	62.7b
			Total N		
Mixed throughout the soil	270g	243f	175e	158d	142c
Mixed in top 4 cm soil	171de	238f	69.0a	104b	62.7a

* Means followed by the same letter do not differ significantly for each source of nitrogen at p=0.05 by Duncan's New Multiple-Range Test.

matter from contacting the fertilizer or a larger volume of the soil.

d.   Distribution of Fertilizer Nitrogen in Soil-Plant System: (First crop)

The percentage distribution of applied N in soil and plant as determined by the isotopic method is given in Table 26. The percent utilization of applied N by the above-ground portion of the plant as influenced by the placements of organic matter and N was the same as the uptake of applied N mentioned earlier in section b. The percent recovery of applied N when calculated by the difference method was consistently higher than that obtained by the direct ^{15}N method (Appendix C). These results are similar to those recorded for the first growth chamber experiment and are in agreement with several other reports appearing in the literature (Legg and Allison, 1959; Hauck, 1971; Westerman and Kurtz, 1974).

The average recovery of the tagged N from the soil-plant system was highest where N was placed as a point source in the centre of the entire soil and lowest where N was mixed in the surface portion of the soil (Table 26). The average recoveries for the remaining N treatments were comparable. On average, significantly less fertilizer N was recovered from the mixed than from the point source fertilizer treatments. The unrecovered fertilizer N was the result of N loss in the gaseous form. The losses of applied N were greatest where N was placed near the surface of the soil in either of the fertilizer treatments. This is another factor which would help to explain why banding (similar to the point source placement) of fertilizer was superior to the surface applied N.

Table 26. Percentage of fertilizer nitrogen recovered in plant and soil for various treatments of added organic matter and nitrogen. First Crop.

	in shoot	in root	in soil	Total	in shoot	in root	in soil	Total
	header: Recovery of added nitrogen (%^{15}N)							

Straw application	in shoot	in root	in soil	Total	in shoot	in root	in soil	Total
Mixed nitrogen application								
	mixed throughout the soil				mixed in the top 4 cm soil			
Mixed throughout the entire soil	8.83b*	8.83b	70.1f	87.bcd	18.2c	10.0bc	47.5d	75.7a
Mixed in top 4 cm soil	24.8d	10.1bc	53.6e	88.5bcd	2.4a	4.14a	76.4g	83.0b
No straw	46.1gh	11.6bc	25.7ab	83.4b	44.3g	17.7g	20.9ab	82.9b
Average			49.8B	86.6B			48.3B	80.5A
Point source nitrogen application								
	in the centre of entire soil				in the centre of top 4 cm			
Mixed throughout the soil	34.5f	16.1f	42.3d	92.9d	35.6f	14.7f	34.8c	85.1b
Mixed in top 4 cm soil	48.2h	15.8f	26.7b	90.7cd	31.1e	12.0cd	41.4d	84.5b
No straw	53.7i	16.0fg	20.4a	90.1cd	48.4h	13.5de	19.5a	81.4b
Average			29.8A	91.2C			31.9A	83.7B

* Means followed by the same letter for each component do not differ significantly at p=0.05 by Duncan's New Multiple-Range Test.

Amounts of fertilizer N not recovered in the harvested crop and roots (residual fertilizer N) were similar for mixed and point source N placements where organic matter was not applied (Table 26). Addition of organic matter significantly increased the amounts of fertilizer N remaining in the soil for mixed as well as point source N treatments, suggesting the role of microbial immobilization in keeping the fertilizer N bound in the soil. The effect was enhanced when fertilizer was mixed in the soil than when placed as a point source. The amount of fertilizer N present in the soil was highest where both straw and fertilizer were mixed together in the surface soil and amounted to 76.4% of the added N. The amount of fertilizer N remaining in the soil was also quite large (70.1% of the applied N) when organic matter and fertilizer were both added throughout the soil. The amounts of residual fertilizer N for the point source N placements also followed similar trends and amounted to 41.4 and 42.3% of the applied N for the surface-placed and centre-placed N, respectively.

These results concerning the residual fertilizer N remaining in the soil as affected by organic matter and its placement are important since they represent the real magnitude of fertilizer N that was immobilized in the soil by the added organic matter. As a consequence of this biologically tied up fertilizer N, a large portion of the added N remained unavailable to the crop. This resulted in low fertilizer N efficiency which was particularly reduced where fertilizer was mixed with the soil.

The amounts of fertilizer N found in the roots were generally smaller for the mixed than for the point placed N except when fertilizer was

mixed in the surface soil and no organic matter applied. These values are consistent with those found in the first growth chamber experiment where also more of the fertilizer N accumulated in roots from the point than from the mixed N treatments. Thus, an appreciable fraction of the added N removed by the crop was present in the roots of the plant and would have constituted part of the immobilized fertilizer N if the roots were not separated from the soil.

All of the results presented here consistently show that fertilizer N applied to soil was more efficiently used when placed as a point source than when mixed in the soil. This effect was considerably enhanced by adding straw to the soil and was more pronounced where straw and fertilizer were both mixed together either in a small portion of the soil or throughout. The poor plant growth and N deficiency, particularly when N was not applied, were characteristically visible from the very outset of the experiment in the these treatments. Response to the applied N was relatively good for the point placements as indicated by the relatively large fertilizer N uptake and yield increases from these treatments when compared with the mixed N treatments.

Comparisons made by subtracting the values of fertilizer N remaining in the soil with a treatment receiving straw from that receiving no straw showed that considerable amount of fertilizer N was immobilized in soil when both organic matter and fertilizer were mixed together throughout or with a portion of the soil. Since roots were separated from the soil, the immobilized N measured in this manner was believed to be all tied up by the added organic matter except that some inorganic N was probably included in these treatments. However, amounts of

NO_3^--N present in the soil at harvest time of the crop were small (0.2-3 ppm) and should not have contributed to the calculated immobilization of N to any appreciable extent. These immobilization results are also consistent with those presented in Table 25 where immobilization of applied N was estimated by using the amounts of fertilizer N removed by the harvested portion of the crop.

II. Residual Effects of Fertilizer Nitrogen and Applied Organic Matter

a. Yield of Dry Matter: (Second crop).

The residual effects of fertilizer N on the yield of dry matter were significant only where straw was mixed with the surface soil or when N was mixed in the surface soil and no straw applied (Table 27). Residual effects of added N were similar for all N placements where straw was mixed throughout the soil or when no straw was applied. Where straw was applied to the surface soil, residual effects of surface-applied N, whether mixed or placed as a point source, were superior to mixed throughout or centre-placed N treatments.

Significant yield increases due to the residual organic matter occurred only in two cases where straw was mixed throughout the soil. These were where N was also mixed throughout the soil or where no N was added to the soil. The yield was actually decreased when organic matter was added to the surface soil and no N applied.

These results suggest that residual effects of fertilizer N on the yield of a succeeding crop were rather small. Mixing straw throughout the soil tended to have better residual effect than mixing straw through a small portion of the soil. The increased yields of dry matter were attributed to the increased availability of N (Table 28) either through the mineralization of immobilized N or perhaps due to the priming effects of residual fertilizer N and/or residual organic matter.

b. Uptake of Nitrogen by Plants: (Second crop).

Residual effects of organic matter and fertilizer N on the uptake of N generally paralleled those observed for the yield of dry matter.

Table 27. Rapeseed dry matter yield resulting from residual fertilizer
nitrogen and residual organic matter. Second crop.

Straw application	N placement				
	Mixed throughout the soil	Mixed in top 4 cm soil	Point source in the centre of entire soil	Point source in the centre of top 4cm soil	No N
	(g/pot)				
Mixed throughout the soil	4.72g*	4.41efg	4.61fg	4.47efg	4.61fg
Mixed in top 4 cm soil	3.61bc	4.51efg	3.26b	4.04cde	2.06a
No straw	4.08cde	4.34efg	4.17def	4.25defg	3.78cd

* Means followed by the same letter do not differ significantly at
p=0.05 by Duncan's New Multiple-Range Test.

The uptake of N was significantly increased by residual fertilizer N whether or not organic matter was added to the soil (Table 28). The mineralization and utilization of N by the subsequent crop appeared to be related to the amounts of N that had been immobilized during the growing period of the first crop.

c. Recovery of Applied and Residual Fertilizer Nitrogen in the Soil-Plant System: (Second crop).

The percentage distribution of initially applied fertilizer N in the soil-plant system at the end of the second crop is presented in Table 29. Total recoveries of added N were significantly greater for the mixed than for the corresponding point source N treatments when organic matter was applied. When organic matter was not applied, amounts of fertilizer N recovered in the plant plus soil were similar for mixed and point source N treatments except when fertilizer was applied in the centre of the entire soil. These recovery values appeared to be related to the amounts of residual fertilizer N remaining in the soil at harvest time of the first crop.

Both addition of organic matter and placement of organic matter seemed to influence the percentage utilization of residual fertilizer N by the crop (root + shoot) (Table 30). When organic matter was not applied, the percent recovery of residual fertilizer N was highest and similar for the mixed as well as for the point source N placements and ranged from about 15 to 20%. The recovery of residual fertilizer N was lowest when organic matter was mixed in the surface soil and varied between about 8.0 and 11.0% for both mixed and point source N placements. Where organic matter was mixed throughout the soil, the recovery of

Table 28. Effect of residual organic matter and residual fertilizer nitrogen on the uptake of nitrogen by the harvested crop. Second crop.

Straw application	N placement				
	Mixed throughout the soil	Mixed in top 4 cm soil	Point source in the centre of entire soil	Point source in the centre of top 4cm soil	No N
	(mg N/pot)				
Mixed throughout the soil	76.0 gh*	76.3 gh	78.6 h	77.4 h	68.5 ef
Mixed in top 4 cm soil	47.4 c	73.1 fgh	39.5 b	59.0 d	23.5 a
No straw	58.5 d	63.9 de	70.2 efg	67.3 ef	48.0 c

* Means followed by the same letter do not differ significantly at p=0.05 by Duncan's New Multiple-Range Test.

Table 29. Fertilizer nitrogen recovery in plant and soil at harvest time of the second crop.

Straw application	Recovery of applied nitrogen ($\%^{15}$ N)						
	Plant shoot	root	Soil	Total	Plant shoot	root	Soil	Total

Straw application	Mixed nitrogen application							
	Mixed throughout the soil				Mixed in the top 4cm soil			
	shoot	root	Soil	Total	shoot	root	Soil	Total
Mixed throughout the soil	5.04f*	3.30e	39.2g	47.1g	3.88e	2.49d	33.3f	49.6fb
Mixed in top 4 cm soil	2.27b	2.09cd	30.7ef	35.1e	4.79f	3.44e	50.2h	58.5h
No straw	2.40b	1.45ab	14.4b	18.3bc	2.65bcd	1.50abc	12.5ab	16.7ab
Average				33.5C				38.3D

Straw application	Point source nitrogen application							
	Placed in the centre of entire soil				Placed in the centre of top 4 cm soil			
	shoot	root	Soil	Total	shoot	root	Soil	Total
Mixed throughout the entire soil	3.11d	2.02bcd	23.0d	28.1d	3.04cd	1.85bc	23.2d	28.1d
Mixed in top 4 cm soil	1.18a	1.08a	17.9c	20.2c	2.67bcd	1.91bcd	29.4e	34.0e
No straw	2.53bcd	1.27a	10.4a	14.1a	2.50bc	1.43ab	12.0ab	14.9ab
Average				20.8A				26.0B

* Means followed by the same letter for each component do not differ significantly at p=0.05 by Duncan's New Multiple-Range Test.

Table 30. Percent uptake of residual fertilizer nitrogen by the second crop.

Straw application	N placement											
	Mixed through- out the soil			Mixed in top 4 cm soil			Point source in the centre of entire soil			Point source in the centre of top 4cm soil		
	%^{15}N recovered											
	shoot	root	crop	shoot	root	crop	shoot	root	crop	shoot	root	crop
Mixed through- out the soil	7.2	4.7	11.9	8.2	5.2	13.4	7.4	4.8	12.2	8.7	5.3	14.0
Mixed in top 4 cm soil	4.2	3.9	8.1	6.3	4.5	10.8	4.4	4.1	8.5	6.4	4.6	11.0
No straw	9.3	5.6	14.9	12.7	7.2	19.9	12.4	6.0	18.4	12.8	7.3	20.1

residual fertilizer N was intermediate between those obtained for the surface mixed and no organic matter treatments and ranged from approximately 12.0 to 14.0% for both mixed and point source N placements. It is of interest to note that the ranges of these recoveries were distinct and did not overlap each other. These recoveries were very closely related to the placement of organic matter and hence the immobilization of applied N. The low recovery of residual fertilizer N where straw was mixed in the surface soil was probably due to an increased immobilization of added N which had resulted from mixing the partially (residual) decomposed straw into the entire soil at the end of the first phase of the experiment. Similarly, the high recovery of residual fertilizer N where organic residues were not added might have resulted from reduced immobilization of fertilizer N in the absence of any additional decomposable organic matter. A similar reasoning could also explain the intermediary recovery values when straw was mixed throughout the soil.

About 67 to 71% and 77 to 83% of the residual fertilizer N (data calculated using Tables 26 and 29 and not shown) could be accounted for in the plant and soil for the mixed throughout and surface mixed N applications, respectively. Of these amounts, 56.0 to 57.3% was present in the soil where fertilizer was mixed throughout and 59.8 to 70.1% was where fertilizer was mixed in the surface portion of the soil. The recoveries of residual fertilizer N in the plant and soil varied from 66.4 to 75.6% for the centre-placed and from 76.4 to 82.1% for the surface-placed point source N treatments. The amounts of residual fertilizer N that remained in the soil for the two point placements ranged from 51.0 to 67.0% and from 61.5 to 71.0%, respectively. The effect of

residual organic matter on the percent of fertilizer N remaining in the soil at the termination of the experiment showed no distinct pattern for any of the treatments. The unaccounted for fertilizer N assumed to be lost through gaseous losses suggest that an appreciable portion of the immobilized fertilizer N was mineralized in a fairly short period. This also indicates that the amount of N that can mineralize from the previously immobilized fertilizer N during the succeeding growing periods is much higher than that which normally finds its way into the subsequent crops(s).

The results of this study showed that the recovery of residual fertilizer N in the harvested portion of the crop was 4.2 to 12.8% with an appreciable amount of fertilizer N still remaining in the soil. These recovery values were relatively high when compared to other work reported in the literature (Jansson, 1971). Placement of fertilizer N which tended to affect the availability of initially applied N to the first crop, did not seem to have any appreciable effect on the percent utilization of residual fertilizer N by the second crop. The addition of organic matter and placement of organic matter, however, appeared to be the dominant factor in influencing the utilization of residual fertilizer N by the succeeding crop.

The residual fertilizer N which was released to the subsequent crop appeared to be mainly that portion of the applied N, which had been remineralized from the previously immobilized N. The total losses of fertilizer N were somewhat larger in the second growth chamber experiment as compared to the first growth chamber experiment.

4.3 Field Experiment

Although the results obtained in growth chambers helped to explain the differences in efficiencies of N placements, it was felt necessary to extend the growth chamber work to field conditions. With this in mind, a field investigation was carried out in 1978. The objectives of this investigation were to study (a) the effects of placement of fertilizer N and organic matter on the utilization and immobilization of applied N and (b) the role of immobilization in affecting the efficiency of banded and broadcast fertilizer. Labelled urea N was used to estimate recoveries of added fertilizer N from soil and plants as influenced by methods of organic matter and N application.

4.3.1. Soil

The experiment was conducted during 1978 near Morden, Manitoba (NE 28-3-5W). The soil was classified as a Hochfeld loamy sand. In the Canadian system of soil classification, the soil is an Orthic Black Chernozem. The soil had a pH of 6.9 and an organic matter content of 4.2%. The surface sample (0-15 cm) contained 3.4 kg NO^-_3-N/ha (2 ppm NO^-_3-N) and 0.19% total N. About 82 kg/ha of NO^-_3-N was present in the 120 cm depth of soil at planting time. The cation exchange capacity of the surface soil was 21.1 meq/100 g.

4.3.2. Design of Experiment and Treatments

The experiment was set up as a randomized block, 3x3 factorial with four replications. Open-ended iron cylinders (lysimeters) which were 35 cm in diameter and 30 cm in depth, were arranged evenly within a 5x5 m area (Fig. 7) and pressed into the ground to a depth of 25 cm (Fig. 8). In order to ensure the uniformity of surface soil in the lysimeters, the
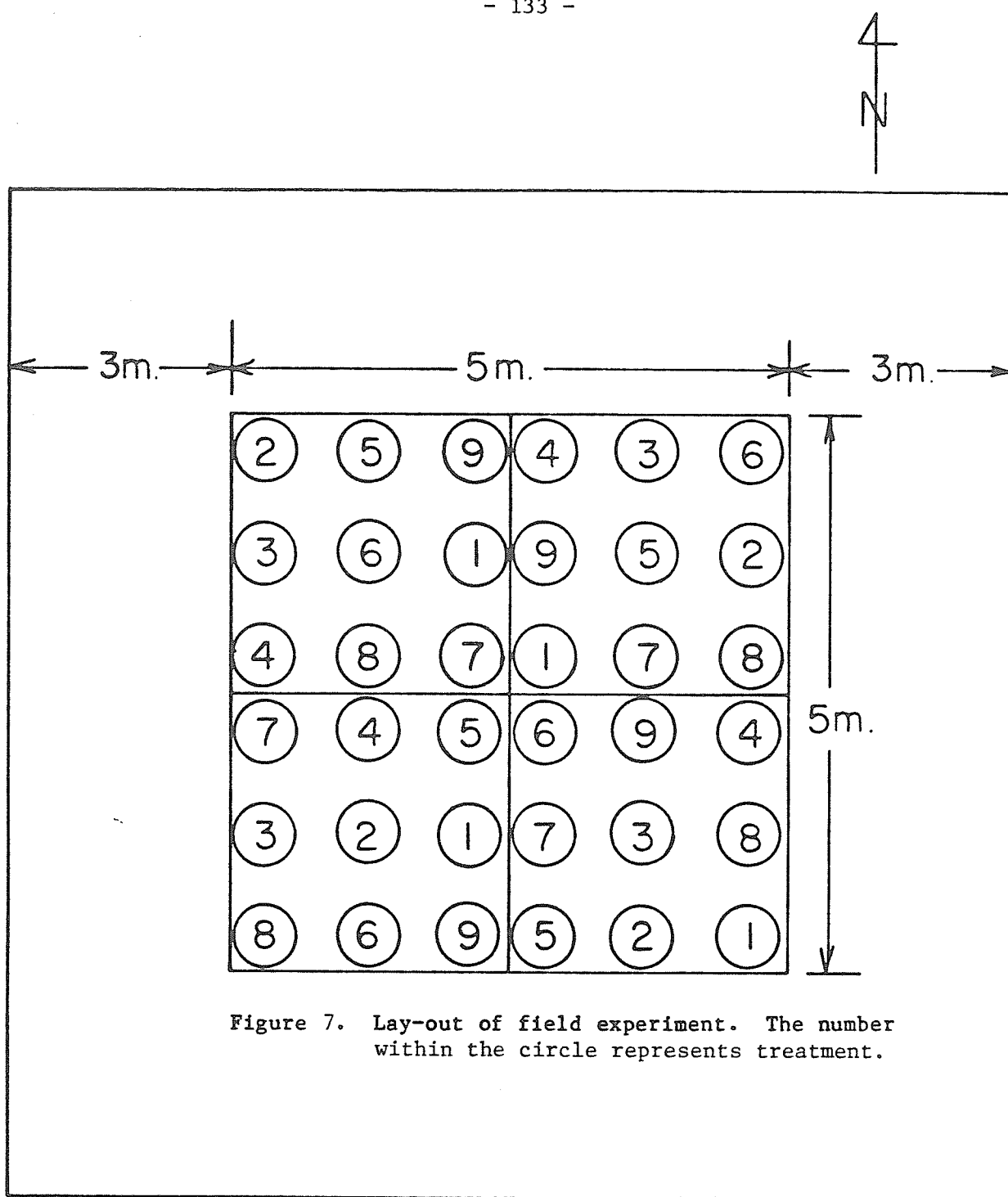
Figure 7. Lay-out of field experiment. The number within the circle represents treatment.

SIDE VIEW
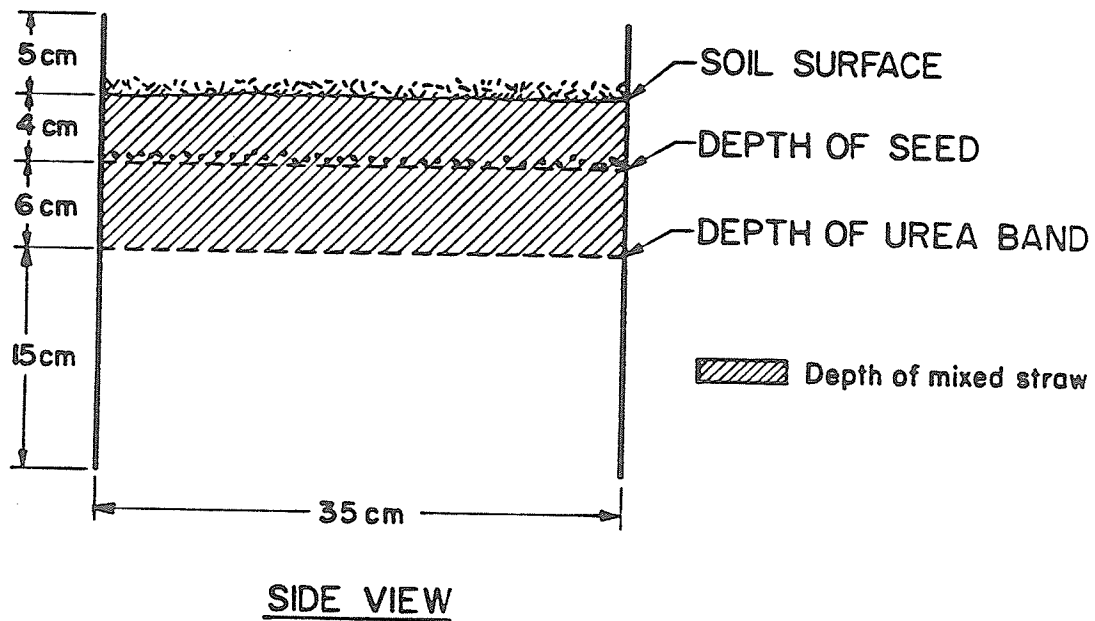
Fig. 8 . Representation of various placements within the lysimeter.

top 10 cm of soil was removed from all lysimeters, cleared of previous organic residues as much as possible, and mixed thoroughly. To help ensure adequate fertility for good barley production, 3 kg Cu/ha, 40 kg S/ha, 98 kg K/ha, and 44 kg P/ha were applied as Na_2Cu-EDTA, K_2SO_4, and $Ca(H_2PO_4)_2 \cdot H_2O$, respectively. Crystalline K_2SO_4 was mixed thoroughly with the soil. Phosphorus as $Ca(H_2PO_4)_2 \cdot H_2O$ in crystalline form was spread at the level where seeds were planted and the soil was replaced in the lysimeters. Copper chelate was liquid-sprayed on the surface.

Two methods of N placement with ^{15}N-labelled urea (19.2 atom % ^{15}N) as the N source were used. Powdered urea was placed either in a band at 10 cm soil depth or broadcast on the soil surface, at the rate of 100 kg N/ha. The band was 30 cm in length and 2.5 cm in width (Fig. 9). The treatments also consisted of the placement of ground oat straw (Avena sativa L.) with N content comparable to crop residues usually found in cereal crops. The straw at the rate of 5,000 kg/ha was either thoroughly mixed with the soil to a 10 cm depth or placed uniformly on the soil surface.

On May 17, 1978, the lysimeters were seeded to barley (Hordeum vulgare-L. 'Conquest') at the rate of 100 kg/ha (27 seeds/lysimeter) at a depth of 4 cm. Lysimeters where N fertilizer and straw or both were surface applied, were covered with pieces of a fine porous cloth which was removed before any impedence to the emergence of seedlings occurred. This arrangement helped to keep the straw and fertilizer N in place. Areas between and surrounding the lysimeters (a 3m wide boundry around the plots, Fig. 7) were sown to barley and received the same rates of N
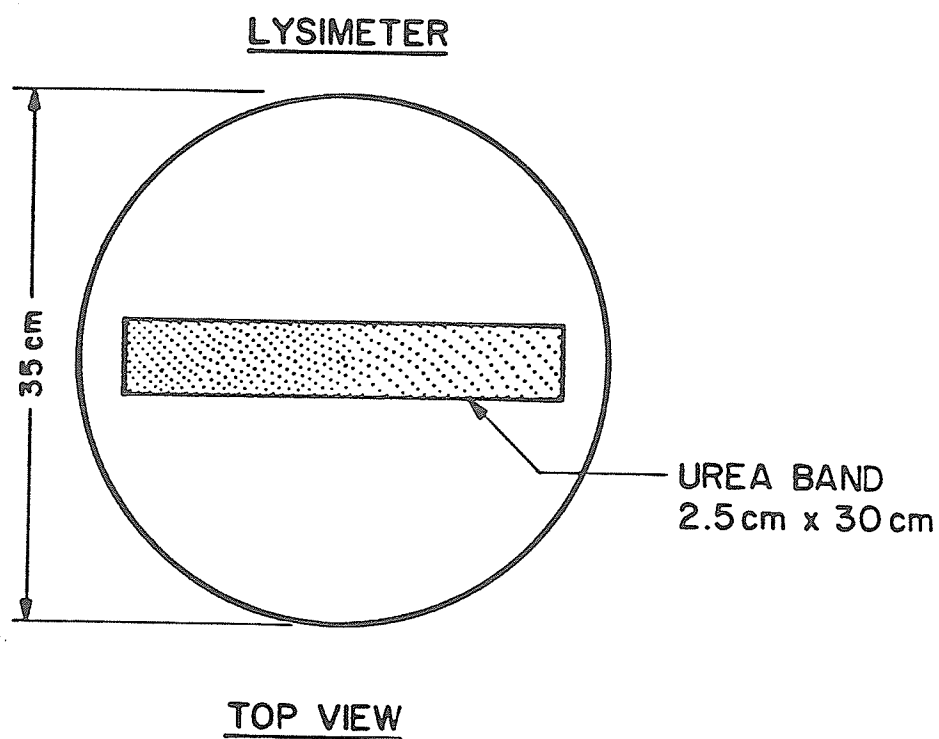
Fig. 9 . Disposition of urea banded in the lysimeter.

and other nutrients (except for the P application which was broadcast at twice the rate of P applied in lysimeters) as were applied to the lysimeters.

4.3.3. Harvesting, Soil Sampling, and Analyses

On August 2, 1978, the crop was harvested at maturity. The plants were removed from the soil surface as completely as possible, dried at 60 C and separated into straw and grain. The dried samples of straw and grain were weighed and ground to a fine state in an electric blender. The ground material was mixed, subsampled and analyzed.

To estimate the amount of fertilizer N remaining in the soil after harvest, contents of the lysimeters were removed completely in layers of 0 - 6.7, 6.7 - 13.4, 13.4 - 20.1, 20.1 - 40, 40 - 60, 60 - 80, and 80 - 100 cm. The contents were packed in plastic bags and transported to the laboratory where they were stored at $-40°C$ until analyzed. At the time of analysis the contents of plastic bags were thawed and oven dried at 105° C, ground in a Wiley mill, mixed thoroughly and subsampled for analysis. Bulk density values of soil for the upper (0 - 20.1 cm) and lower (20.1 - 100) cm) depths (appendix D) were estimated by core and auger methods, respectively. These values were then used to convert volumes of the soil to masses of the soil for the determination of ^{15}N concentrations remaining in the soil.

Nitrogen contents and excess atom $\%^{15}N$ in the soil and plant material were determined by the procedure followed by Richards and Soper (1979). Percentage recovery of fertilizer N in the plant was calculated by both direct (^{15}N) and indirect (difference) methods. The percent recovery of applied N in the soil was obtained using ^{15}N

method.

4.3.4 Results

The weather conditions during the growing season (May 17 to August 2, 1978) were unusually favorable. The total rainfall from May through July was 21.5 cm. Of this 6.3 cm fell in May, 7.5 cm in June, and 7.7 cm in July. The daily minimum temperatures for this period ranged from 5.0 to 14.1 C and the daily maximum temperatures ranged from 17.4 to 26.7 C. Such weather conditions were conducive to plant development and yield response to fertilizer application.

4.3.4.1. Yield:

Plant and grain yield response to applied N was significant for both methods of application. Grain yields were significantly increased with N fertilization of the crop (Table 31). Yield increases from applied N ranged from 953 to 1683 kg/ha and from 1348 to 2787 kg/ha for the broadcast and band applications, respectively. Although the yield responses to added N were less pronounced for the broadcast than for the band application, the yield difference between the two N application methods was signifcant only where organic matter was applied to the soil surface. Maximum grain yields were approached when N was applied in a band.

Grain yields of barley were not significantly affected by the surface application of straw. Mixing straw in the soil significantly depressed the grain yield levels when fertilizer was added to the soil. For applied N, the lowest grain yield occurred where fertilizer was broadcast and organic matter was mixed with the soil. The response of straw production to the applied organic matter and N treatments was

Table 31. Comparisons of grain yield and straw yield as affected by added organic matter and nitrogen applications.

Straw application	N placement		
	Surface broadcast	Banded at 10 cm depth	No N
	(kg/ha)		
	Grain		
Mixed in soil to 10 cm depth	2612 bc*	3007 cd	1659 a
Spread on soil surface	3218 cde	4322 f	1535 a
No straw	3629 def	3965 ef	2128 ab
	Straw		
Mixed in soil to 10 cm depth	3636 bc	4243 cd	2325 a
Spread on soil surface	4579 de	5568 f	2340 a
No straw	4916 def	5108 ef	2894 ab

* Means followed by the same letter do not differ significantly at p=0.05 by Duncan's New Multiple-Range Test.

similar to the grain yield response since straw/grain ratios were fairly constant.

4.3.4.2. Nitrogen Uptake:

The effects of organic matter and N treatments on N uptake by plants were similar to those observed for yields. Amounts of N removed by the crop (roots excluded) generally paralleled the crop yields. A highly significant linear relationship (r^2 = 0.98**) between N uptake in the plant and grain yield of barley was obtained (Fig. 10) indicating that N was a limiting factor for yields in this experiment.

Urea application significantly increased the uptake of N (Table 32) by barley (grain + straw). The only exception occurred where N was broadcast and straw was mixed with the soil in which N uptake was not significantly greater than that where N and organic matter were not added to the soil. More N was usually removed by the crop from the banded than from the broadcast fertilizer applications. The difference was, however, significant only where straw was added to the soil surface.

The addition of organic matter, without the addition of N, resulted in a small but non-significant decrease in N uptake by the crop. With N application, there was no significant difference between N uptake due to surface applied and no straw treatments for both N placements. However, N uptake for each method of N application was significantly reduced when straw was mixed in the soil. The lowest N uptake occurred when fertilizer was broadcast and straw was mixed in the soil although this did not differ significantly from the treatment where N and organic matter were both surface broadcast.
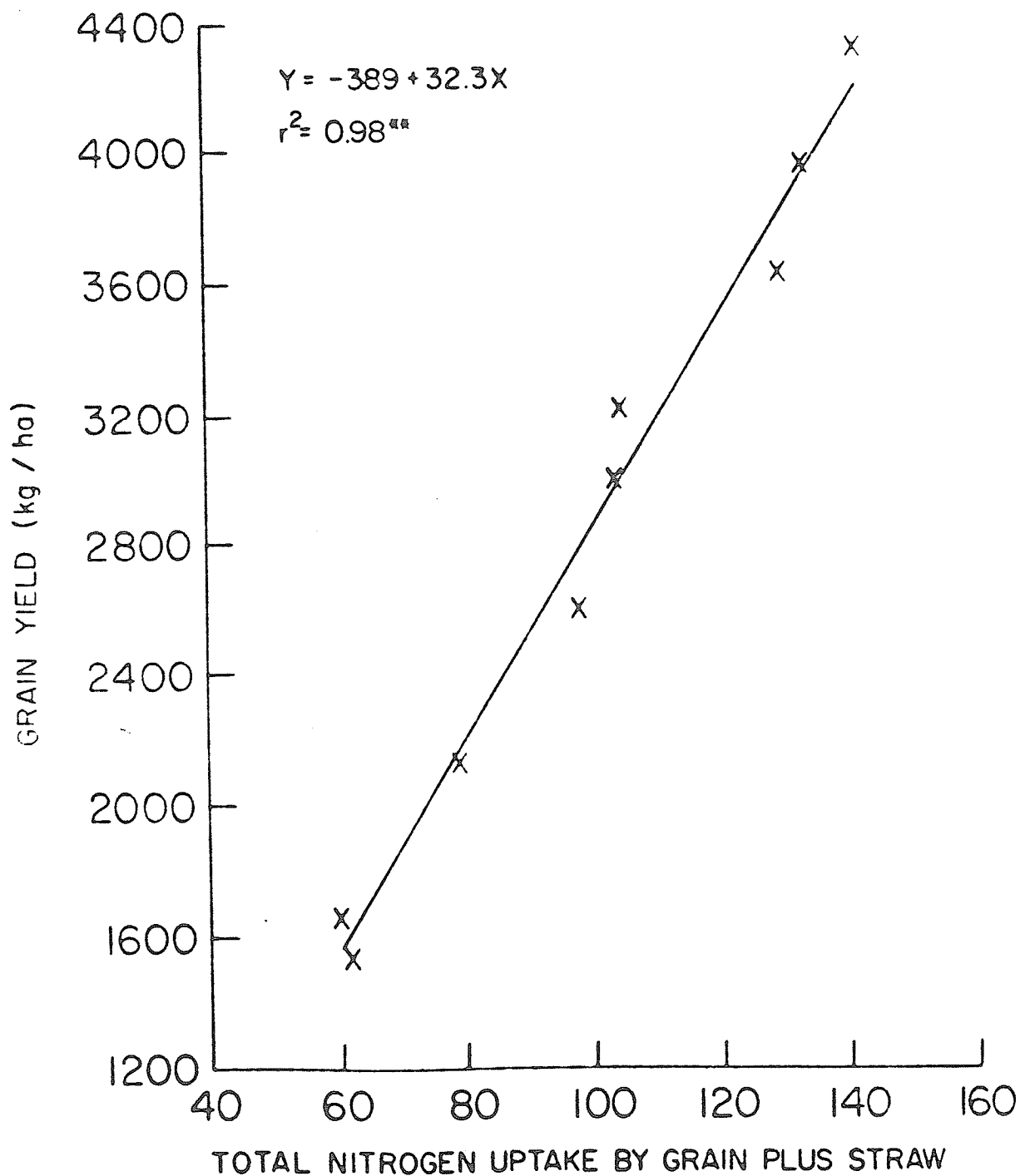
Figure 10. Relationship between grain yield and total nitrogen uptake by grain and straw. (** significant at 1% level).

Table 32. Uptake of fertilizer and soil nitrogen by barley (grain + straw).

Straw application	N application		
	Surface broadcast	Banded at 10 cm depth	No N
		(kg N/ha)	
	------Fert N.------		
Mixed in soil to 10 cm depth	22.8 a*	42.0 c	0.0
Spread on soil surface	29.0 b	49.0 d	0.0
No straw	42.8 c	53.1 d	0.0
	------ Soil N ------		
Mixed in soil to 10 cm depth	75.4 abc	63.0 ab	60.5 a
Spread on soil surface	76.0 abc	94.0 c	61.7 a
No straw	87.2 bc	80.9 abc	78.8 abc
	------Fert. N + Soil N------		
Mixed in soil to 10 cm depth	98.2 bc	105 cd	60.5 a
Spread on soil surface	105 cd	143 e	61.7 a
No straw	130 de	134 e	78.8 ab

* Means followed by the same letter for each component of nitrogen do not differ significantly at p=0.05 by Duncan's New Multiple-Range Test.

The uptake of fertilizer N by the crop was calculated from separate determinations for grain and straw samples. Since fertilizer N was applied at a rate of 100 kg/ha, the N uptake by the crop and percentage recovery of applied N have the same value numerically. Results presented in Table 32 indicate that band applied fertilizer was superior to broadcast fertilization of the crop whether or not any organic matter was added to the soil. Also, the difference between the amounts of fertilizer N taken up from plots receiving straw and those receiving no straw were relatively small when fertilizer was applied in a band. These differences were enhanced when fertilizer was broadcast.

The addition of straw resulted in a significant reduction in the uptake of fertilizer N except when N was banded and straw was added to the soil surface. The superiority of band fertilizer placement over broadcast fertilizer placement was enhanced considerably by the addition of straw. For example, N uptake from fertilizer was 24.1% greater from the band than from the broadcast application without the addition of straw, whereas, with surface placed straw, the banded N placement proved to be 69% more effective in regard to the utilization of N from fertilizer than the broadcast placement. The effect was even more pronounced when straw was mixed with the soil, where 84% more fertilizer N was used by the crop from the band than from the broadcast N applications.

Soil N uptake was calculated by subtracting the amount of tagged N removed by the crop from the uptake of total N. With no N applied, addition of straw caused a somewhat small but non-significant decrease in the uptake of soil N. Methods of organic matter and N application

did not significantly influence the uptake of soil N except when fertilizer was banded and straw was added to the soil surface where an increase in soil N uptake was observed.

4.3.4.3. Fertilizer Nitrogen Remaining in the Soil at Harvest Time:

To further evaluate the effects of different placements of organic matter and fertilizer on the utilization and immobilization of added N, the amounts of applied N remaining in the soil were determined at harvest time.

The amounts of fertilizer N found in the soil after harvest at various depths for each treatment are presented in Table 33. Even when no organic matter was added, considerable quantities of applied N remained in the soil. Significantly greater amounts of fertilizer N remained in the soil from broadcast than from band placements. (40.3 vs. 34.0 kg N/ha) where organic matter was not added. The effect was enhanced when organic matter was applied. In each case, amounts of fertilizer N present in the soil were significantly larger when straw was mixed with the soil than when applied to the surface. Furthermore, where N was placed in the soil in a band, the amounts of applied N remaining in the soil were less affected by straw treatments than when N was broadcast.

Most of the broadcast fertilizer N remained in the 0 to 40 cm depth. Of the total fertilizer N present in the soil, 43.4, 53.2, and 55.2%, respectively, were in the surface 6.7 cm for no straw, surface applied straw, and mixed straw treatments, and 96% was in the upper 40 cm for all treatments. Thus extremely small quantities of applied N were found beneath the 60 cm soil depth with and without straw. A

Table 33. Recovery of fertilizer nitrogen in the soil at harvest time
as affected by the placements of organic matter and
fertilizer nitrogen.

Straw application	Soil depth (cm)							
	0-6.7	6.7-13.4	13.4-20.1	20.1-40	40-60	60-80	80-100	Total
	————————————————(% ^{15}N recovered) —————————————————							
———————————————— N Surface Broadcast —————————————————								
Mixed in soil to 10 cm depth	39.6	14.8	2.9	11.8	1.3	0.6	0.7	71.7d*
Spread on soil surface	28.3	7.3	3.4	12.2	1.0	0.3	0.7	53.2c
No straw	17.5	6.6	3.1	11.7	0.7	0.2	0.5	40.3b
Average								55.1B
———————————————N Banded at 10 cm depth———————————————								
Mixed in soil to 10 cm depth	11.2	17.3	6.8	4.1	1.2	0.7	0.2	41.5b
Spread on soil surface	9.8	13.2	5.0	4.2	1.0	0.6	0.4	34.2a
No straw	9.4	13.6	5.9	3.6	0.6	0.4	0.5	34.0a
Average								36.6A

* Means followed by the same letter for each placement of nitrogen do
not differ significantly at p=0.05 by Duncan's New Multiple-Range
Test.

noticeable feature of the broadcast fertilizer treatment, as opposed to the band placement, is the fact that the concentration of ^{15}N in the 20.1 - 40 cm depth showed an increase over the layer above it. This observed distribution of fertilizer N was not influenced by the addition of organic matter since the recoveries of applied N were essentially similar with and without straw. The reason for this unexpected distribution from surface applied urea at this particular soil depth was not clear.

Most of the band applied N (94 to 96%) also remained in the 0 to 40 cm soil depth. Of the total amount of fertilizer N found in the soil, the largest percentage (38 - 42%) was at the depth of the band. Some movement of added N occurred from the band into the 0 - 6.7 cm layer presumably through the mechanisms of root absorption and capillary rise of solutes. The amount of fertilizer N beyond the depth of the band placement decreased progressively throughout the remainder of the soil layers. Amounts of fertilizer N recovered below 60 cm were comparable to those found in the broadcast N application.

4.3.4.4. Recovery of Fertilizer Nitrogen in the Soil-Plant System:

Total recovery of fertilizer N, expressed as percent of the urea N initially applied, was calculated from separate ^{15}N determinations of soil (roots included) and plant samples. The unaccounted for fertilizer N was assumed to be lost from the system. Total average recovery of ^{15}N was not significantly affected by the method of N application but was significantly influenced by the organic matter treatments.

Total recovery of fertilizer N was similar for band and broadcast N applications except where urea was added to the soil surface and straw

was mixed into the soil (Table 34). In this case, the recovery of
fertilizer N was significantly higher than other treatments. The ^{15}N
recovery data showed that, on an average, 13.3 and 15.5% of fertilizer N
was not accounted for at the end of the experiment for broadcast and
band fertilizer placements, respectively.

4.3.5. Discussion

The larger yield responses of barley to banded N obtained in this
study can be attributed to the greater N uptake from the band than from
the broadcast N applications. These results agree with those reported
by other researchers in the Canadian prairies (Ridley, 1977; Nyborg et
al., 1977; Toews and Soper, 1978) who also found that fertilizer N was
more efficiently utilized by the crop when N carriers were banded or
drilled in the soil than when broadcast and incorporated.

The better utilization of fertilizer N from banded as compared to
broadcast N applications in this study appears to have been caused by
decreased immobilization of N applied as a band in the soil. Even when
no organic matter was added, significantly more fertilizer N remained in
the soil or was immobilized from broadcast than from banded N treatments
(40.3 vs. 34.0%). These results are consistent with those reported in
the laboratory study where incubation of several soils in the absence of
any additional organic matter resulted in a fairly large fraction of
urea N being immobilized by the soils. The addition of organic matter
increased fertilizer N immobilization and decreased its uptake by bar-
ley. These effects were enhanced both by mixing the organic matter with
the soil and broadcasting the N. Consequently, the treatment where or-
ganic matter was mixed with the soil and the N broadcast, proved to

Table 34. Total recovery of labelled fertilizer nitrogen at the end of one cropping season.

Straw application	Surface broadcast			Banded at 10 cm depth		
	Plant	Soil	Total	Plant	Soil	Total
			—%[15]N recovered—			
Mixed in soil to 10 cm depth	22.8	71.8	94.6 b*	42.0	41.5	83.5a
Spread on soil surface	29.0	53.2	82.2 a	49.0	34.1	83.1a
No straw	42.8	40.4	83.2 a	53.1	33.9	87.0a
Average			86.7A			84.5A

* Means followed by the same letter do not differ significantly at p=0.05 by Duncan's New Multiple-Range Test.

be the most inefficient. Immobilization of N with the correspondingly lower N uptake by barley appeared to be related to amount of contact between organic matter and fertilizer N. A reasonably heavy rain occurred just after planting time with the result that the surface applied urea was washed into the soil and away from any surface applied organic matter. This rain may also have reduced gaseous losses of ammonia from urea thus permitting greater N immobilization.

The amounts of NO_3^--N remaining in soil at harvest time were relatively small and similar for both methods of fertilizer application which indicated that proximity of applied N in relation to the roots of plant should not have contributed to the differences in the amounts of fertilizer N removed by the harvested crop for the different methods of N application. Since leaching losses of added N were negligible and gaseous losses for the broadcast and banded N were small and similar in magnitude (13 and 15%, respectively), immobilization of applied N was the major factor in causing the differences in efficiencies for the banded and broadcast applications of N.

There have been some conflicting reports by workers in the Canadian prairies regarding the effect of organic matter addition to the soil on the yield of cereal crops. Hedlin et al. (1957) indicated that yields of wheat were decreased when cereal residues were returned to the soil. On the other hand, Ferguson (1967) in Manitoba and Myers and Paul (1971) in Saskatchewan, reported that incorporation of straw into the soil had no significant effect on yields of such crops. The latter investigators also indicated that the uptake of fertilizer N was not affeced by mixing straw into the soil. Results of this field study demonstrate that

barley grain yield levels and N uptake can be significantly depressed by mixing straw into the soil, indicating the importance of placement of crop residues in the soil.

The results of the field experiment reported here indicate that biological immobilization of fertilizer N can play a critical role in causing low efficiency of applied N as well as in explaining the differences in efficiencies between banded and broadcast N applications. The data also show that when organic matter is incorporated into the soil, placement of N becomes increasingly important.

5. SUMMARY AND CONCLUSIONS

The study reported here consisted of a laboratory incubation exper-
iment, two growth chamber experiments with rapeseed as the test crop
which were continued to measure the residual values of previously
applied fertilizer N, and a field experiment with barley.

The laboratory experiment, using 11 Manitoba soils with varying
physical and chemical properties, was conducted to determine the
magnitude of biologically and/or chemically immobilized N over
incubation intervals extending in duration up to 12 weeks. The
transformation of applied N into NH_4^+- and NO_3^--N was also
examined. The extent and scope of biological interchange of N between
labelled and soil organic N was evaluated by comparing directly (using
^{15}N data) and indirectly determined percent recoveries of applied
N.

Rapid fixation of added N at zero time resulting from a high con-
centration of NH_4^+ showed a positive correlation with sand + silt
content and negative correlation with soil pH (R^2 = 0.86**). As incu-
bation of soils proceeded, organic matter content of soil became the
most important factor in influencing the immobilization of N added to
the soils. The most significant relationship between organic matter
content and ^{15}N immobilized was obtained after 12 weeks of incuba-
tion, the r^2 value being 0.57**. Humic acids content of soil was
closely correlated (r^2 = 0.75**) with ^{15}N tie up in soil
suggesting that the humic acids fraction of organic matter was the more
active component in affecting the immobilization of fertilizer N as

compared to the organic matter content of soil as a whole.

Both the conversion of urea N into NH^+_4-N and its subsequent nitrification into NO^-_3-N were essentially completed in 4 weeks of incubation in most of the soils. About 96 to 98% of the added N was nitrified or immobilized in soils for the incubation period ranging from 4 to 12 weeks. Biological interchange between added N and soil organic N was evident in only one soil suggesting that a fairly large portion of the added N (8 - 46%) was truly immobilized in these soils.

The growth chamber experiments were designed to study the effect of placement of both organic matter and N on the efficiency of fertilizer N use by plants as well as the immobilization of applied N by the soil. The fate of immobilized N for the placements of organic matter and fertilizer N was also determined by using a second crop of rapeseed.

Judging the efficiency of fertilizer N in terms of dry matter yields and N uptake by the crop, it was found that mixing N throughout the soil could be as good or better as banding N (point placed N) in the soil where the immobilization of applied N in soil biomass was allevi-ated by an equivalent amount of N exchange from the added organic materials. Such conditions may occur when decomposition of high N con-taining organic residues is taking place in the soil system. However, when the addition of readily decomposable and low N containing organic material to soil resulted in net N immobilization, the point placement of N was always superior to the mixed N treatments.

Mixing N into the soil caused a larger amount of fertilizer N to be immobilized by the soil than placing N as a point source. The incorpor-ation of organic matter into the soil greatly enhanced the immobiliza-

tion of N which resulted in decreased N uptake and increased differences in efficiencies between the mixed and point source N treatments.

The amounts of fertilizer N recovered by the crop were lowest where fertilizer and organic matter were both mixed either in a small portion of the soil or throughout the entire soil. The quantities of fertilizer N remaining in the soil were also largest in these treatments. Consequently, the point source placement of N proved to be much superior to the mixed N treatment as a result of reduced N immobilization from the point placed N.

Approximately 5 to 7% of the added N could not be accounted for in plants and soil at harvest time of the first crop for the first growth chamber experiment. The gaseous losses of applied N were somewhat larger for the second experiment and amounted to about 9 - 16% for the point source placements and about 13 - 19% for the mixed N treatments. These losses were greatest where N was added near the soil surface and this could have accounted for some of the differences in efficiencies of applied N between the two methods of fertilizer placement.

The percent recovery of immobilized N by the succeeding crop was similar for both N treatments where organic matter was not applied, but was affected by both the addition of organic matter (reduced) and the methods of organic matter placement. The placement of organic matter proved to be more important with regard to the utilization of residual fertilizer N than the method of N application except when sucrose was added. In this latter treatment the percent recovery of added N by plants was greater for the point than for the mixed N treatments. Where organic matter was mixed into the surface soil and remained relatively

less decomposed, it reduced the utilization of residual fertilizer N by the crop more than did the treatment where straw was mixed throughout the soil and consequently was more decomposed (and immobilized less residual fertilizer N).

The effects of placement of N and organic matter added as urea and oat straw, respectively, on the utilization and immobilization of fertilizer N by the soil were also investigated in a field study with barley. Both barley yield and N uptake were greater from banded than from broadcast N applications. This effect was magnified when organic matter was added to the soil. Both grain yields and N uptake were significantly depressed where straw was mixed into the soil. This effect was much reduced when urea was banded. The yield and N uptake were also decreased when straw and fertilizer were both added to the soil surface. However, when fertilizer was banded in the soil, the surface applied straw did not depress the yield and uptake of N. The unaccounted for fertilizer N ranged from 13 to 15%. The unrecovered $15N$ from the soil-plant system was assumed to be lost in gaseous form since there was no evidence of any leaching of applied N. Again, the immobilization of added N appeared to be main factor for the differences in the utilization of N from the two methods of fertilizer application. Soil N uptake was also decreased by adding organic matter to the soil. Methods of organic matter placement or the added N did not seem to have any effect on the uptake of soil N by the crop except when N was banded and straw was added to the soil surface.

The conclusions derived from the results of this study may be summarized as follows:

A significant relation between ^{15}N immobilized and organic matter content of the soil, even when plants are not grown, seems to suggest that biological immobilization of applied N could be extremely important with regard to the utilization of fertilizer N by the crop. When the results of the two growth chamber experiments concerning the effects of added organic matter and placement of fertilizer N are compared, several common features are revealed. In both experiments, placement of N in a band decreased immobilization and increased the utilization of applied N. The incorporation of organic matter with a low content of N increased immobilization, increased the differences in the efficiencies of applied N for the methods of N application and decreased yields. The immobilization of added N was found to be a critical factor in explaining the differences in the efficiencies of fertilizer N between the two methods of fertilizer application.

The best placement of N was found to depend upon the N content of the added organic matter. The results showed that mixing N in the soil can result in higher yields than banding N when plant residues with high content of N are added to the soil which immobilize added N but can exchange similar amounts of N with the result that no net N immobilization takes place in the soil. The data on immobilized N suggest that freshly immobilized fertilizer N was relatively readily available to the subsequent crop and the total amount of N that might have mineralized from the immobilized fertilizer N was actually larger than that utilized by the crop. A part of this mineralized fertilizer N was, therefore, lost from the system, presumably in gaseous forms.

Results obtained in the field experiment largely support the

findings of the growth chamber studies. Barley yield and N uptake were both greater from banded than from broadcast N applications and the difference was enhanced by adding straw to the soil. Grain yields and N uptake were significantly depressed by mixing straw into the soil but the effect was much less pronounced when the N was banded than when broadcast on the soil surface. Immobilization of fertilizer N appeared to be solely responsible for the differences in the utilization of applied N from the two methods of N application. The fact that gaseous and leaching losses of applied N were quite similar for both N placements supports these findings. It was shown in this study for the first time on the prairies that the incorporation of crop residues into the soil could significantly immobilize added N and reduce yields. These results are in contrast with those reported by Gorby and Ferguson (1964) and Ferguson (1967) in Manitoba and Myers and Paul (1971) in Saskatchewan.

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APPENDICES

APPENDIX A

RAW LABORATORY DATA

Table 1. Atom per cent excess ^{15}N and per cent N of intact soil samples.

Soil	Length of incubation			
	Zero time	4 Weeks	8 Weeks	12 Weeks
			Atom % excess ^{15}N	
Colby	3.700	3.518	3.334	3.088
Osborne-saline	0.837	1.014	0.973	0.975
Gross Isle 1	1.017	1.071	1.116	1.083
Delmar	0.859	0.819	0.876	0.848
Gross Isle 2	1.006	0.994	1.045	0.990
Lakeland	1.797	1.752	1.729	1.772
Marquette	0.936	0.873	0.906	0.945
Fort Garry	1.104	1.407	1.129	1.129
Beaverdam	0.858	1.038	0.896	0.895
Lenswood	1.110	1.089	1.091	1.183
Osborne	0.482	0.534	0.493	0.479
			Total % N	
Colby	0.103	0.111	0.107	0.108
Osborne-saline	0.410	0.411	0.422	0.424
Gross Isle 1	0.369	0.385	0.380	0.379
Delmar	0.479	0.494	0.478	0.477
Gross Isle 2	0.404	0.391	0.402	0.407
Lakeland	0.219	0.216	0.222	0.225
Marquette	0.456	0.454	0.457	0.458
Fort Garry	0.359	0.287	0.362	0.372
Beaverdam	0.440	0.361	0.445	0.452
Lenswood	0.349	0.372	0.371	0.367
Osborne	0.832	0.751	0.829	0.837

Table 2. Atom per cent excess ^{15}N and per cent N of residues.

Soil	Length of incubation			
	Zero time	4 Weeks	8 Weeks	12 Weeks
	--------------Atom % excess ^{15}N------------------			
Colby	0.392	0.402	0.435	0.443
Osborne-saline	0.018	0.116	0.128	0.118
Gross Isle 1	0.028	0.141	0.156	0.158
Delmar	0.039	0.135	0.142	0.130
Gross Isle 2	0.025	0.137	0.147	0.157
Lakeland	0.080	0.290	0.296	0.294
Marquette	0.026	0.118	0.158	0.147
Fort Garry	0.043	0.428	0.353	0.323
Beaverdam	0.082	0.316	0.321	0.275
Lenswood	0.207	0.412	0.385	0.388
Osborne	0.067	0.191	0.226	0.235
	------------------ Total % N --------------------			
Colby	0.080	0.086	0.080	0.076
Osborne-saline	0.382	0.378	0.365	0.379
Gross Isle 1	0.332	0.347	0.339	0.342
Delmar	0.436	0.467	0.422	0.431
Gross Isle 2	0.362	0.358	0.371	0.374
Lakeland	0.195	0.189	0.192	0.200
Marquette	0.424	0.431	0.411	0.429
Fort Garry	0.327	0.269	0.329	0.344
Beaverdam	0.439	0.342	0.365	0.438
Lenswood	0.319	0.342	0.326	0.327
Osborne	0.798	0.719	0.726	0.800

APPENDIX B

RAW DATA: FIRST GROWTH CHAMBER EXPERIMENT

Table 1. Atom per cent excess ^{15}N and per cent N of plant and soil at harvest time of the crops.

Source of carbon-aceous residue	Nitrogen placement				
	Mixed throughout		Point Source		No N
	% Excess N-15	% Total N	% Excess N-15	% Total N	% Total N
	------1st crop------				
Barley					
shoot	4.631	2.860	8.572	2.730	1.780
root	3.013	0.852	4.673	0.989	0.870
soil	0.659	0.170	0.374	0.169	0.166
Fababean					
shoot	4.685	2.420	8.690	2.580	1.470
root	3.142	0.923	4.683	0.924	0.778
soil	0.667	0.167	0.411	0.171	0.173
Sucrose					
shoot	6.302	1.530	13.570	2.060	1.980
root	3.752	0.794	7.318	0.796	0.850
soil	0.946	0.166	0.572	0.169	0.163
No residue					
shoot	9.612	2.680	10.890	2.660	1.490
root	6.013	0.931	6.457	0.992	0.878
soil	0.360	0.154	0.266	0.149	0.161
	------2nd crop------				
Barley					
shoot	2.680	1.520	1.731	1.540	1.620
root	1.469	0.764	0.925	0.778	0.740
soil	0.549	0.144	0.310	0.140	0.123
Fababean					
shoot	2.862	1.641	1.807	1.550	1.610
root	1.779	0.811	1.060	0.713	0.880
soil	0.574	0.129	0.292	0.154	0.154
Sucrose					
shoot	4.503	1.600	3.066	1.920	1.670
root	2.663	0.662	1.797	0.790	0.797
soil	0.755	0.150	0.465	0.154	0.154
No residue					
shoot	2.484	1.450	1.803	1.330	1.360
root	1.393	0.648	1.050	0.768	0.744
soil	0.284	0.143	0.215	0.153	0.152

Table 2. Nitrate-N levels in incubated soils prior to planting of the second crop.

Source of carbonaceous residue	Nitrogen placement		
	Mixed throughout	Point Source	No N
	-----------------ug NO_3 -N/g soil-----------------		
Barley	44.2	47.3	47.2
Fababean	41.4	43.7	45.5
Sucrose	44.5	58.6	50.4
No residue	30.5	26.2	25.4

APPENDIX C

RAW DATA: SECOND GROWTH CHAMBER EXPERIMENT

Table 1. Atom per cent excess 15N and per cent N of plant and soil at harvest time of the first crop.

Straw placement	Nitrogen Placement				
	Mixed throughout		Mixed in surface 4 cm soil		No N
	% Excess N-15	% Total N	% Excess N-15	% Total N	% Total N
Mixed throughout					
shoot	4.444	1.300	8.481	1.300	1.920
root	1.540	0.996	3.396	0.757	1.020
soil	0.659	0.164	0.424	0.173	0.186
Mixed in surface 4 cm soil					
shoot	6.815	1.710	1.166	1.340	1.240
root	2.619	0.640	1.262	0.966	0.846
soil	0.509	0.163	0.665	0.178	0.174
No straw					
shoot	7.139	3.000	7.172	2.680	1.780
root	3.780	0.896	3.194	1.010	0.986
soil	0.253	0.157	0.197	0.163	0.168

Straw placement	Point source in the centre of entire soil		Point source in the centre of surface 4 cm soil		No N
Mixed throughout					
shoot	13.220	1.680	13.220	1.760	1.920
root	5.924	0.859	4.887	0.786	1.020
soil	0.500	0.170	0.400	0.175	0.186
Mixed in surface 4 cm soil					
shoot	11.040	2.680	9.076	2.080	1.240
root	5.521	0.815	3.853	0.772	0.846
soil	0.318	0.170	0.470	0.177	0.174
No straw					
shoot	9.760	3.180	9.397	3.080	1.780
root	4.940	0.891	4.748	1.060	0.986
soil	0.260	0.158	0.238	0.164	0.168

Table 2. Atom per cent excess 15N and total per cent N of plant and soil at harvest time of the second crop.

Straw placement	Nitrogen Placement				
	Mixed throughout		Mixed in surface 4 cm soil		No N
	% Excess N-15	% Total N	% Excess N-15	% Total N	% Total N
Mixed throughout					
shoot	3.069	1.610	2.355	1.740	1.490
root	1.746	0.688	1.236	0.533	0.680
soil	0.500	0.151	0.424	0.152	0.163
Mixed in surface 4 cm soil					
shoot	2.223	1.320	3.035	1.630	1.140
root	1.126	0.585	1.738	0.655	0.612
soil	0.389	0.153	0.604	0.160	0.164
No straw					
shoot	1.955	1.440	1.922	1.480	1.270
root	1.117	0.603	0.754	0.580	0.557
soil	0.186	0.138	0.161	0.151	0.156
	Point source in the centre of entire soil		Point source in the centre of surface 4 cm soil		No N
Mixed throughout					
shoot	2.381	1.710	2.357	1.740	1.490
root	1.290	0.628	1.183	0.587	0.680
soil	0.382	0.154	0.357	0.163	0.163
Mixed in surface 4 cm soil					
shoot	1.793	1.210	2.735	1.460	1.140
root	0.886	0.647	1.497	0.643	0.612
soil	0.305	0.148	0.458	0.161	0.164
No straw					
shoot	2.187	1.680	2.225	1.580	1.270
root	1.188	0.639	0.957	0.615	0.557
soil	0.192	0.140	0.190	0.158	0.156

Table 3. Nitrate-N levels in incubated soils prior to planting of the
          second crop.

Straw placement	Nitrogen placement				
	Mixed throughout	Mixed in top 4 cm soil	Point source in the centre of entire soil	Point source in the centre of top 4cm soil	No N
	------------------------ug NO_3 -N/g soil-----------------				
Mixed throughout	43.3	41.8	47.1	38.9	38.8
Mixed in surface 4 cm soil	25.4	39.5	15.5	29.8	5.70
N straw	35.0	32.4	43.0	36.9	25.9

Table 4. Percent recovery of fertilizer nitrogen in the harvested crop calculated by ^{15}N isotopic and difference methods. First Crop.

Straw placement	Nitrogen placement			
	Mixed throughout the soil	Mixed in top 4 cm soil	Point source in the centre of entire soil	Point source in the centre of top 4cm soil
	(% N recovered)			
----------(Isotopic Method)----------				
Mixed throughout the soil	8.83b*	18.2c	34.5f	35.6f
Mixed in top 4 cm soil	24.8d	2.40a	48.2h	31.1e
No OM	46.1gh	44.3g	53.7i	48.4h
----------(Difference Method)----------				
Mixed throughout the soil	37.3b	40.6c	49.9e	51.6e
Mixed in top 4 cm soil	44.0d	16.0d	58.7fg	42.8cd
No OM	79.7i	74.1h	60.4g	56.4f

* Means followed by the same letter do not differ signficantly for the two methods at p=.05 by Duncan's New Multiple-Range Test.

APPENDIX D

RAW FIELD DATA

Table 1. Atom per cent excess 15N and per cent N of barley grain and straw grown in lysimeters in the field.

Straw placement	Nitrogen placement				
	Surface broadcast		Banded at 10 cm depth		No N
	% Excess N-15	% Total N	% Excess N-15	% Total N	% Total N
	----Grain----				
Mixed in 10 cm depth	4.309	2.32	7.657	2.19	2.17
Surface-spread	5.156	2.20	6.598	2.28	2.24
No straw	6.025	2.24	7.329	2.30	2.31
	----Straw----				
Mixed in 10 cm depth	4.536	1.32	7.892	1.19	1.45
Surface-spread	5.336	0.97	6.324	1.09	1.48
No straw	6.215	1.29	7.566	1.14	1.38

Table 2. Atom per cent excess ^{15}N and per cent N in various soil depths at harvest time of the crop.

Straw placement	Nitrogen placement					Soil wt. (kg.)
	Surface broadcast		Banded at 10 cm depth		No N	
	% Excess N-15	% Total N	% Excess N-15	% Total N	% Total N	
			0 - 6.7 cm			9.05
Mixed in 10 cm depth	0.415	0.196	0.120	0.192	0.102	
Surface-spread	0.305	0.192	0.105	0.191	0.191	
No straw	0.190	0.190	0.104	0.187	0.190	
			6.7 - 13.4 cm			9.65
Mixed in 10 cm depth	0.153	0.187	0.181	0.184	0.180	
Surface-spread	0.076	0.185	0.138	0.185	0.177	
No straw	0.071	0.182	0.145	0.182	0.181	
			13.4 - 20.1 cm			9.52
Mixed in 10 cm depth	0.031	0.176	0.075	0.175	0.177	
Surface-spread	0.038	0.173	0.054	0.178	0.175	
No straw	0.035	0.170	0.066	0.172	0.171	
			20.1 - 40 cm			26.68
Mixed in 10 cm depth	0.062	0.133	0.021	0.136	0.130	
Surface-spread	0.073	0.118	0.024	0.126	0.142	
No straw	0.073	0.113	0.019	0.132	0.124	
			40 - 60 cm			26.02
Mixed in 10 cm depth	0.011	0.088	0.100	0.094	0.094	
Surface-spread	0.009	0.084	0.008	0.085	0.086	
No straw	0.006	0.085	0.005	0.091	0.091	

Table 2 cont'd

	60 – 80 cm				26.82
Mixed in 10 cm depth	0.007	0.066	0.008	0.066	0.062
Surface-spread	0.005	0.062	0.007	0.061	0.058
No straw	0.002	0.059	0.005	0.067	0.068
	80 – 100 cm				28.40
Mixed in 10 cm depth	0.062	0.047	0.006	0.038	0.038
Surface-spread	0.015	0.035	0.007	0.038	0.040
No straw	0.058	0.040	0.008	0.042	0.043

Table 3. Nitrate-N levels in various soil depths at the conclusion of the experiment.

Straw placement	Soil depth (cm)						
	0-6.7	6.7-13.4	13.4-20.1	20.1-40	40-60	60-80	80-100
	----------------------kg NO$_3$ -N/ha----------------------						
	urea surface broadcast						
Mixed in 10 cm depth	4.60	4.12	3.34	3.87	2.63	4.26	10.1
Surface spread	3.78	3.59	2.37	2.27	1.45	2.42	2.31
No straw	4.78	3.25	2.23	2.94	1.97	5.01	5.90
	urea banded at 10 cm depth						
Mixed in 10 cm depth	3.19	2.81	2.08	3.21	2.50	3.39	5.38
Surface-spread	3.96	3.93	2.77	3.07	1.84	3.93	6.91
No straw	4.69	3.59	2.66	3.20	2.89	2.98	4.32
	No nitrogen applied						
Mixed in 10 cm depth	4.13	4.98	3.81	4.45	2.63	5.78	7.30
Surface spread	4.28	4.61	3.43	4.27	2.80	7.60	13.7
No straw	5.51	4.90	3.20	4.54	2.76	4.88	6.05

Table 4. Mass and bulk density values for various depths of the soil
(B.D. for depths between 0-20.1 cm are mean of six replicates;
for depths between 20.1-100cm, mean of four replicates).

Soil depth (cm)	B.D. (g/cm^3)	Mass of soil (kg)
0 - 6.7	1.36	9.050
6.7 - 13.4	1.45	9.648
13.4 - 20.1	1.43	9.515
20.1 - 40	1.35	26.681
40 - 60	1.31	26.021
60 - 80	1.35	26.815
80 - 100	1.43	28.404