RESEARCH SUB-PROGRAM

AN INVESTIGATION INTO THE MANAGEMENT OF MANURE-NITROGEN TO SAFEGUARD THE QUALITY OF GROUNDWATER

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FORWARD

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From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes through land application, with emphasis on water quality implications
   A. Animal Manure Management (nutrients and bacteria)
   B. Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. On-Farm Research: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. Development of an integrated monitoring capability to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

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This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

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This report is a comprehensive summary that integrates the information obtained in studies on manure management funded under several research programmes. The main agronomic investigation at Winchester Research Station of Kemptville College of Agricultural Technology was funded by the National Soil Conservation Program of Agriculture Canada, Contract 01686-1-0347/01-LON. The tracer studies were funded by the Programe of the O.M.A.F.R.A. Chair of Land Stewardship, University of Guelph, and by The Land Management Assistance Program of Agriculture and Agri-Food Canada. The main agronomic investigation at the Elora Research Station of the Ontario Ministry of Agriculture, Food and Rural Affairs was funded by the Ontario Ministry of Envrionment and Energy, File No. 488G through a grant to R. G. Kachanoski. The tracer studies werepart funded through this grant, partly by the Programe of the O.M.A.F.R.A. Chair of Land Stewardship, University of Guelph, and also by The Land Management Assistance Program of Agriculture and Agri-Food Canada.

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EXECUTIVE SUMMARY

In this study the fate of nitrogen from liquid dairy cattle manure and from composted cattle manure was investigated in two field experiments. These were conducted at the Elora Research Station of the Ontario Ministry of Agriculture, Food and Rural Affairs in collaboration with Drs. D.L Burton, E.G. Beauchamp and R.G Kachanoski, and at Winchester Research Station of Kemptville College of Agricultural Technology in collaboration with W.E. Curnoe.

In the first experiment carried out at Elora in 1991-1992, the soil was a Conestogo silt loam (Gleyed Melanic Brunisol). The particle size fraction of the Ap horizon consisted of sand (0.26), silt (0.55), clay (0.18); the organic matter fraction was 0.056, and the pH was 7.0. A sub-programme of a larger investigation was established with the objective of evaluating the risk of nitrate leaching from spring-applied manure, and identify how much of the mineral N from the liquid cattle manure (LCM) was incorporated into a corn crop. The contribution to N in the crop due to mineralization of soil organic matter was also investigated. Liquid cattle manure was applied in spring before planting corn on a randomized complete block design with fourfold replication. Corn was also planted in 1992.

In the second experiment carried out at Winchester in 1991-1993, the soil was a Dalhousie clay loam (Humic Gleysol). The particle size fraction of the Ap horizon consisted of sand (0.20), silt (0.52), clay (0.28); the organic matter fraction was 0.037, and pH was 6.3. Both liquid manure from dairy cattle and composted cattle manure were applied to ploughed-down alfalfa forage during late summer. The liquid cattle manure was injected, and the solid manure applied with a conventional spreader. The objective of the programme was to evaluate the risk of nitrate leaching over the fall, winter and spring from fall-applied manure, and evaluate whether this could be alleviated by timely agronomic practices without impairing the productivity of the land. The following ten experimental treatments were replicated fourfold in 4 randomized blocks, and test crops planted:

1. Alfalfa ploughed in; grass (Timothy); no manure; **corn** (Control)
2. Alfalfa ploughed in; grass (Timothy); 172 x 10^3 L ha^{-1} liquid cattle manure; **corn** (manure control - LCM)
3. Alfalfa ploughed in; 54 t ha^{-1} composted cattle manure; **corn** (CCM)
4. Alfalfa ploughed in; liquid manure; **barley** ; wheat (LCM + barley)
5. Alfalfa ploughed in; liquid manure; oilseed radish cover crop; **corn** (LCM + OSR)
6. Alfalfa ploughed in; liquid manure; 3.8 t ha^{-1} straw (dry weight) incorporated; **corn** (LCM+straw)
7. Alfalfa ploughed in; liquid manure, straw; oilseed radish cover crop; **corn** (LCM + straw +OSR)
8. Alfalfa ploughed in; liquid manure; winter wheat, **corn** (LCM + winter wheat)
9. Alfalfa ploughed in; winter wheat, **corn** (Control + winter wheat)

10. Alfalfa ploughed in; **barley**; wheat. (Control + barley)

Winter wheat was sown in the fall of 1992 on the plots where spring barley had been grown. In the spring of 1993 all plots not growing winter wheat were planted with corn.

The soil, soil water, and plant material was sampled to assess the availability of the nitrogen to crops, determine the presence of mineral nitrogen, including nitrate, in the soil, and determine the magnitude of the fluxes of nitrogen. ^{15}N was used to trace the fate of the nitrogen present in the mineral fraction of the manures at both experimental sites. Tracer was also applied directly to the soil to identify the fate of mineral nitrogen produced by mineralization of soil organic matter prior to the application of manure, and to help identify potential sources of the nitrogen mineralized after manure application.

From ^{15}N tracing, it was shown that the loss of mineral nitrogen from manure was greater during surface spreading and mechanical incorporation in spring than after early fall application to recently cultivated land followed immediately by hand-digging.

At Winchester, the soil at the time of manure application contained about 80 kg ha^{-1} mineral nitrogen. Only 16 kg ha^{-1} of mineral nitrogen was present in the 320 kg N ha^{-1} from the composted cattle manure, but of the 301 kg N ha^{-1} applied in the liquid manure 216 kg N ha^{-1} was mineral nitrogen. The volumetric water content of the top 100 mm of soil was approximately 0.15 at the time the manure was applied at the end of August. This was ideal for injection, but severely impaired the establishment of the grass. Growth of the winter wheat, oilseed radish was good in the fall of 1991. There was considerable growth of volunteer oats from seeds present in the incorporated straw, and wild mustard weeds grew on plots where liquid cattle manure was applied but no crop was planted in the fall. The uptake of mineral nitrogen (y, kg N ha^{-1}) by all crops in the fall was directly related to the dry matter produced (x, t ha^{-1}) according to the equation: $y = 43x - 10.2$ ($p < 0.001$). However, less than 10% of mineral-N applied in the liquid cattle manure was taken up by the sown cover crop. By the end of November much of the mineral nitrogen applied in the manure could be accounted for in the soil and plants. In un-manured plots there was 55 kg NO_3-N ha^{-1}, 78 kg NO_3-N ha^{-1} in plots that received composted manure, and 134 kg NO_3-N ha^{-1} in plots given liquid manure. All this nitrogen was at risk of leaching. However, from analysis of the ^{15}N present in the soil it appeared that only about 60 kg N ha^{-1} had been derived from the mineral fraction of the liquid cattle manure, at least 50% of that fraction had already transferred into the organic pool of the soil. Remineralization of a small part of this fraction appeared to take place in early spring. But much of the ^{15}N was still retained in the soil organic matter after two years. Only small amounts became available even in the second year.

The winter was cold and the snow cover was ended by heavy rain on 14 January, after which the temperature dropped sharply and killed the winter wheat crop.

There was little through drainage in the early spring of 1992, and all plots contained at least as much mineral nitrogen at planting in May than in November. Nonetheless, loss of ^{15}N over this period was consistent with about 50 kg N ha^{-1} of the nitrogen present in the mineral fraction of the liquid cattle manure being lost from the soil over winter. The loss was about 25%; less where cover crops were grown and straw had been incorporated. Two further periods of leaching were identified in late spring and early summer. The maximum concentration of nitrate-N recorded in the water draining from the rooting zone for all treatments exceeded the Ontario Drinking Water Objective of 10 mg L^{-1} during one or both periods.

Growth of the corn crop on the microplots at Elora was good in both years, and there was no significant benefit to yield from application of manure compared with control plots in either season. Previously corn had been grown continuously on the site, so the lack of any effect on yield due to manure application in the first season was probably due to residual nitrogen from the management of those crops. The crops at Winchester grown on land injected with liquid manure produced significantly greater grain yields than the Control treatment when harvested by hand, except where straw had been incorporated or oilseed radish planted, but this was not converted into significantly more combinable yield. The yield of barley was influenced by the lodging that took place preferentially on the manured plots. Although earlier in the season nitrogen uptake by barley was greater on manured plots than on plots that received no manure, there was no significant difference at harvest. In the first cropping year the uptake by corn of nitrogen derived from the mineral-N in manure was greater from a spring application (39 kg N ha^{-1}) than from a fall application (31 kg N ha^{-1}). Uptake in the second season was about 5% of the mineral nitrogen in the manure at application in both cases. Only 16% of the nitrogen in the cover crop was transferred to the following corn crop. Evidence from crop sampling indicated that much of the nitrogen from the cover crop did not become available until after 20 August. This was also true for nitrogen from the organic fraction of the manure. There was no clear evidence that nitrogen was released from the organic fraction of the liquid cattle manure to the crop planted after the spring application. There was evidence that some of the organic nitrogen in manure became mineralized in the late summer, twelve months after application, when it was at risk to leaching over winter.

Nitrogen released by the ploughing of the soil under alfalfa-hay at Winchester provided sufficient nitrogen for the corn crop. The total nitrogen in the control treatment at harvest was 150 kg N ha^{-1}. The crop on land injected with liquid manure contained 225 kg N ha^{-1}, but this was not converted into significantly more combinable yield. About half of the additional nitrogen was present in the grain, but the remainder was in the harvest residues that contribute to the organic matter pool of the soil and therefore could be remineralized in the future. The results indicated that a value of 110 kg N ha^{-1}, currently used in Ontario, was an appropriate credit for the underground residues of the alfalfa hay.

The Ontario soil nitrogen test suggested that the un-manured plots would require some fertilizer nitrogen to obtain the maximum economic yield, but all manured plots contained sufficient nitrogen. Since yields of corn were unaffected by the treatments imposed despite the indications of the soil nitrogen test, it is clear that adjustments are needed when making fertilizer recommendations based on the test to ensure that the nitrogen from crop residues (straw or cover crop) is included. The soil N test, which only takes account of nitrate-N, clearly underestimated the amount of mineral nitrogen available in the soil on all treatments.

Total loss over two cropping years, estimated as ^{15}N not present in soil or crop, were 35% for the spring application and 40% for the fall application. The potential for leaching loss to occur in the period following the fall application was considerable. The application of manure in the early fall resulted in a large amount of mineral nitrogen in the soil, much of it in the nitrate form. In that experiment, the prevailing weather conditions were not conducive to leaching, but incorporating composted cattle manure at the same time of year did not have a significant impact on the soil pool of mineral nitrogen.

The study strongly indicated that applying liquid manure in the fall was potentially hazardous to water resources. The risk from leaching was high in the fall immediately after application, in the following spring, and in the next fall period, especially if cereals were grown in the spring. None of the fall treatments designed to immobilize nitrogen were adequate to reduce the risk significantly.

Combining straw incorporation and growing a cover crop that would be removed for forage in late fall appeared to offer the best solution to minimize loss of nitrogen from manure applied in early fall. However, in a wet fall the impact of this treatment might not be as great as the results for a relatively dry fall. Furthermore, smaller yields may also result.

RÉSUMÉ

Cette étude examinait le devenir de l'azote provenant du lisier de bovins laitiers et du fumier composté de bovins dans le cadre de deux expériences au champ. L'une a été menée à la Station de recherches Elora du ministère de l'Agriculture, de l'Alimentation et des Affaires rurales de l'Ontario, en collaboration avec D.L. Burton, E.G. Beauchamp et R.G. Kachanoski, et l'autre, à la Station de recherches Winchester du Collège de technologie agricole de Kemptville, en collaboration avec W.E. Curnoe.

Le sol de la première expérience effectuée à Elora en 1991-1992 était un loam limoneux Conestogo (brunisol mélanique gleyifié). La fraction granulométrique de l'horizon Ap se composait de sable (0,26), de limon (0,55) et d'argile (0,18); la fraction organique était de 0,056 et le pH de 7,0. Un sous- programme s'inscrivant dans une étude plus importante a été mis sur pied pour évaluer le risque de lessivage des nitrates présents dans le fumier épandu au printemps et déterminer quelle proportion de l'azote minéral du lisier est assimilée par une culture de maïs. On a également étudié dans quelle mesure la minéralisation de la matière organique du sol fournissait de l'azote aux plantes cultivées. Le lisier a été épandu au printemps, avant l'ensemencement du maïs, suivant un plan expérimental en blocs aléatoires assorti de quatre répétitions. Du maïs a également été semé en 1992.

Le sol de la deuxième expérience, effectuée à Winchester en 1991-1993, était un loam argileux Dalhousie (gleysol humique). La fraction granulométrique de l'horizon Ap se composait de sable (0,20), de limon (0,52) et d'argile (0,28); la fraction organique était de 0,037 et le pH de 6,3. Le lisier et le fumier composté ont tous deux été épandus à la fin de l'été dans un champ où une culture de luzerne fourragère avait été enfouie. Le lisier a été appliqué à l'aide d'un injecteur d'engrais et le fumier composté, à l'aide d'un épandeur conventionnel. Ce programme avait pour objectif d'évaluer le risque de lessivage des nitrates de la fumure automnale au cours de l'automne, de l'hiver et du printemps et de voir si des pratiques agronomiques adéquates pourraient atténuer ce phénomène sans compromettre la productivité du sol. Les dix traitements expérimentaux suivants ont été répétés quatre fois dans quatre blocs aléatoires, et des cultures expérimentales ont été semées:

1. Enfouissement de luzerne; graminée (fléole); aucune fumure; maïs (témoin)
2. Enfouissement de luzerne; graminée (fléole); 172 x 103 L/ha de lisier; maïs (témoin de fumure - lisier)
3. Enfouissement de luzerne; 54 t/ha de fumier composté; maïs (fumier composté)
4. Enfouissement de luzerne; lisier; orge; blé (lisier + orge)
5. Enfouissement de luzerne; lisier; culture-abri de radis oléagineux; maïs (lisier + radis oléagineux)
6. Enfouissement de luzerne; lisier; incorporation de 3,8 t/ha de paille (poids sec); maïs (lisier + paille)

7. Enfouissement de luzerne; lisier, paille; culture-abri de radis oléagineux; maïs (lisier + paille + radis oléagineux)
8. Enfouissement de luzerne; lisier; blé d'hiver; maïs (lisier + blé d'hiver)
9. Enfouissement de luzerne; blé d'hiver; maïs (témoin + blé d'hiver)
10. Enfouissement de luzerne; orge; blé (témoin + orge).

Le blé d'hiver a été semé à l'automne 1992 dans les parcelles où de l'orge de printemps avait été cultivée. Au printemps 1993, toutes les parcelles où du blé d'hiver n'était pas cultivée ont été ensemencées de maïs.

On a échantillonné le sol, l'eau du sol et le matériel végétal afin d'évaluer la quantité d'azote assimilable par les cultures, de mesurer l'azote minéral, y compris les nitrates, dans le sol et d'établir l'importance des flux d'azote. Aux deux endroits, l'azote-15 a servi à suivre l'évolution de l'azote présent dans la fraction minérale des fumures. Ce traceur a également été directement appliqué au sol pour connaître le devenir de l'azote minéral issu de la minéralisation de la matière organique du sol avant l'épandage du fumier et pour faciliter l'identification des sources éventuelles d'azote minéralisé après l'épandage.

Grâce au traceur, il a été démontré qu'un épandage superficiel et une injection mécanisée au printemps entraînaient des pertes plus importantes d'azote minéral provenant de la fumure qu'une application en début d'automne sur une terre récemment cultivée dont le sol avait ensuite été immédiatement travaillé à la main.

Au moment de l'épandage des engrais, la teneur en azote minéral du sol des parcelles expérimentales de Winchester était d'environ 80 kg/ha. Le fumier composté épandu à raison de 320 kg N/ha ne produisait que de 16 kg/ha d'azote minéral, tandis que le lisier épandu à raison de 301 kg N/ha en produisait 216 kg/ha. La teneur en eau volumétrique des premiers 100 mm du sol était d'environ 0,15 lors de l'application des fumiers à la fin d'août. Cette valeur était idéale pour l'injection, mais a gravement ralenti l'établissement des graminées. La croissance du blé d'hiver et du radis oléagineux a été bonne à l'automne 1991. Les resemis d'orge à partir des graines présentes dans la paille incorporée au sol étaient très nombreux, et des plants de moutarde des champs, une mauvaise herbe, poussaient dans les parcelles où du lisier avait été épandu, mais où aucune culture n'avait été semée à l'automne. La quantité d'azote minéral (y, kg N/ha) assimilée par l'ensemble des cultures était directement liée à la quantité de matière sèche produite (x, t/ha), d'après l'équation $y = 43x - 10{,}2$ ($p < 0{,}001$). Toutefois, moins de 10 % de l'azote minéral présent dans le lisier épandu a été assimilé par la culture-abri ensemencée. Dès la fin de novembre, la majeure partie de l'azote minéral du lisier pouvait être retracée dans le sol et dans la végétation. On trouvait 55 kg NO_3-N/ha dans les parcelles sans fumure, 78 kg NO_3-N/ha dans les parcelles engraissées à l'aide de fumier composté et 134 kg NO_3-N/ha dans les parcelles traitées avec du lisier. Tout cet azote menaçait de se lessiver. Toutefois, l'analyse de l'azote-15 présent dans le sol a révélé que seulement 60 kg N/ha provenait de la fraction minérale du lisier, au moins 50 % de cette fraction étant dèjà passée dans les réserves de matière organique du sol. Une petite partie de cette fraction semblait se reminéraliser au début du printemps, mais la majeure partie de l'azote-15 était toujours présente dans la matière organique du sol deux ans plus tard. Seules de faibles quantités étaient disponibles, même la deuxième année.

L'hiver a été froid, et les fortes pluies du 14 janvier ont fait disparaître la neige; les températures ont ensuite baissé brusquement et ont tué le blé d'hiver.

Au début du printemps 1992, toutes les parcelles se sont mal drainées, et leur teneur en azote minéral était au moins aussi élevée lors des semailles de mai qu'en novembre. Néanmoins, la perte d'azote-15 a été régulière pendant cette période, environ 50 kg N/ha de l'azote présent dans la fraction minérale du lisier ayant été éliminés du sol pendant l'hiver. La perte a été d'environ 25 %; elle était moindre dans les parcelles où des cultures-abris avaient été semées et où de la paille avait été incorporée au sol. Deux autres périodes de lessivage ont été constatées, à la fin du printemps et au début de l'été. Dans toutes les parcelles, la teneur maximale en nitrate-N mesurée dans l'eau provenant de l'horizon racinaire dépassait l'objectif de 10 mg/L pour l'eau potable en Ontario pendant l'une des périodes ou les deux.

La croissance du maïs dans les microparcelles d'Elora a été bonne au cours des deux années, et la fumure n'a pas permis d'augmentation significative des rendements par rapport aux parcelles témoins au cours de l'une ou l'autre campagne culturale. Le maïs y était auparavant cultivé chaque année, et le fait que l'épandage de fumier n'ait eu aucun effet sur les rendements au cours de la première campagne est probablement attribuable à la présence d'azote résiduel provenant de ces cultures. Dans les parcelles de Winchester traitées par injection de lisier, les rendements des cultures ont été significativement plus élevés que dans les parcelles témoins, lorsque les cultures étaient récoltées manuellement, exception faite des parcelles où de la paille avait été incorporée au sol et de celles ensemencées de radis oléagineux, ce qui ne s'est toutefois pas traduit par un rendement combiné plus significatif. Le rendement des cultures d'orge a été affecté par la verse dont ont été plus souvent victimes les parcelles fumées. Bien que l'orge ait assimilé une plus grande quantité d'azote en début de saison dans les parcelles engraissées que dans celles sans fumure, aucune différence significative n'a été constatée lors de la récolte. Pendant la première campagne culturale, l'assimilation par le maïs de l'azote issu de la fraction minérale du fumier était plus élevée après un épandage printanier (39 kg N/ha) qu'après une application automnale (31 kg N/ha). Pendant la deuxième année, l'assimilation était d'environ 5 % de l'azote minéral du fumier, peu importe la période d'épandage. Seulement 16 % de l'azote de la culture-abri a été transféré à la culture de maïs qui a suivi. D'après l'analyse des échantillons, la majeure partie de l'azote provenant de la culture-abri n'est devenue disponible qu'après le 20 août. Il en est de même pour l'azote issu de la fraction organique du fumier. Rien ne laisse clairement voir que l'azote de la fraction organique du lisier soit devenu disponible pour la culture ensemencée après l'épandage printanier. Certains signes de minéralisation de l'azote organique du lisier ont été observés à la fin de l'été, soit douze mois après l'épandage, et cet azote risquait de se lessiver pendant l'hiver.

Winchester, le labourage du sol des parcelles de luzerne- foin a libéré des quantités suffisantes d'azote au profit de la culture de blé qui a suivi. Dans la parcelle témoin, l'azote total était de 150 kg N/ha au moment de la récolte. Dans les parcelles trait es par injection de fumier, la culture en renfermait 225 kg N/ha, mais ceci n'a pas entraîné un rendement combiné significativement plus élevé. Environ la moitié de la quantité supplémentaire d'azote se trouvait dans les grains; le reste était présent dans les résidus de culture enrichissant les réserves de matière organique du sol et pourrait donc être reminéralisé ultérieurement. Les résultats révèlent que la valeur de 100 kg N/ha actuellement utilisée en Ontario pour les résidus souterrains des cultures de luzerne-foin est juste.

Le test utilis en Ontario pour déterminer le teneur en azote du sol laisse voir que les parcelles sans fumure auraient besoin d'un apport d'azote pour avoir un rendement économique maximal, mais toutes les parcelles fum es avaient des teneurs suffisantes en azote. Puisque les traitements appliqués, malgré les résultats des tests, n'ont eu aucun effet sur le rendement des cultures de maïs, il est clair qu'il faudra apporter certaines modifications aux résultats des tests avant de formuler un programme de fertilisation, afin de s'assurer que l'azote des résidus de culture (paille et culture-abri) est pris en compte. Ce test, qui ne tient compte que du nitrate-N, a nettement sous-estimé la quantité d'azote minéral disponible dans le sol de l'ensemble des parcelles.

Pendant les deux campagnes culturales, les pertes totales, estimées en fonction de l'azote-15 disparu du sol ou des cultures, étaient de 35 % dans le cas des épandages printaniers et de 40 % dans celui des épandages d'automne. Après une application automnale, le risque de pertes par lessivage était considérable. L'épandage de fumier au début de l'automne a entraîné la présence d'une quantité importante d'azote minéral dans le sol, la majeure partie sous forme de nitrates. Lors de cette expérience, les conditions météorologiques dominantes ne favorisaient pas le lessivage, mais l'incorporation de fumier composté à cette même période de l'année n'a pas eu d'effet significatif sur les réserves en azote minéral du sol.

L'étude a nettement révélé que l'épandage automnal de lisier pouvait être dangereux pour les réserves en eau. Le risque de lessivage était élevé à l'automne, immédiatement après l'application, et au cours du printemps et de l'automne suivants, surtout lorsque des céréales étaient cultivées au printemps. Aucun des traitements automnaux destinés à immobiliser l'azote n'a permis de réduire ce risque de façon significative.

L'incorporation de paille au sol combinée à une culture-abri récoltée comme fourrage à la fin de l'automne semble être la meilleure solution pour réduire au minimum la perte de l'azote présent dans le fumier épandu au début de l'automne. Toutefois, ce traitement n'aurait peut-être pas eu des effets aussi positifs s'il avait été appliqué pendant un automne pluvieux, plutôt que relativement sec. De plus, il aurait pu y avoir une diminution des rendements.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BACKGROUND

At workshops held in Ontario to discuss problems and opportunities in manure management, farmers stressed that ways had to be found for the utilization of liquid and solid manures in crop production without causing contamination of the environment (Anon., 1993). The farmers perceived benefits of manure application, but concern was expressed about the impact of manure on the environment.

The main environmental issues associated with applying animal manures in the field are nitrate leaching, gaseous losses of methane, ammonia and other gaseous nitrogen compounds (Burford *et al.*, 1976), and transport of bacteria into rivers and lakes via tile drains (Dean and Foran, 1991; Foran and Dean, 1991). Odour is also an issue. The main benefits from manure are seen as the better use of nutrient resources, improved soil tilth and greater resilience of soil to erosion.

There is considerable uncertainty about the availability of manure N once incorporated in the soil. It differs between the types of manure, the form in which manure is applied, and the method of application. Part of the nitrogen is present in mineral and part in organic form. In solid manure from cattle, most of the nitrogen is in organic form. At least half the nitrogen from liquid manures is in the ammoniacal fraction. More of the nitrogen in liquid poultry manure is present in mineral form than is that in liquid dairy manure (Beauchamp, 1986). Because of losses by leaching and by volatilization, and because some of the mineral nitrogen is immobilized while some of the organic N appears to be resistant to transformation, less than 20% of the total nitrogen applied to the soil may be recovered in the crop (Paul, 1991). Results suggest that most of the nitrogen recovered in the first year after application comes from the mineral component (Paul, 1991). The availability of the mineral fraction may be between 75 and 80% as available to a crop as urea fertilizer. Immobilization and denitrification may have accounted for the apparent difference in availability between these two forms of fertilizer.

For liquid cattle manure, the method of application influences nutrient availability mainly through differences in the potential for gaseous losses (Table 1). Ammonia can be readily lost from surface applications by volatilization (Beauchamp, 1983; Thompson *et al.*, 1987). In contrast, the gaseous losses from manure after injection mainly result from denitrification (Thompson *et al.*, 1987). Overall, the total nitrogen available to crops is generally greater after injection than after surface spreading (Paul, 1991; Thompson *et al.*, 1987) mainly because the gaseous losses are reduced (Thompson *et al.*, 1987).

Table 1. Comparison of different methods of manure application on the losses by volatilization of ammonia (% of applied nitrogen).

Method of Application	Type of Waste	% Nitrogen Lost 0-7 days
Broadcast	Solid Liquid	15-30 10-27
Broadcast with immediate cultivation	Solid Liquid	1-5 1-8
Injection	Liquid	1-5
Sprinkler irrigation	Liquid	14-37

Source: Fleming, 1988; Meisinger and Randall 1991; Van der Molen 1990.

The timing of manure applications is critical for the availability of nitrogen to crops, and because of the potential for environmental impacts. As manure storage on many farms is limited, the common periods for application are the fall, winter and spring. Spring applications may be as a pre-plant fertilization or as a side- or top-dressing. In conventionally cultivated soil, the recovery of nitrogen by corn in grain yield was similar for manure incorporated at pre-plant, and as a side-dressed application (Beauchamp, 1983). The experimental evidence shows that compared with spring applications, manuring land in fall or winter results in lower recovery of applied nitrogen by the crops, and greater risk of leaching and denitrification (Table 2).

The C and N characteristics of manure as well as soil characteristics determine the dynamics of N immobilization and mineralization i.e. the immobilization of ammonium-N and the rate of its release from the organic N fraction (Bernal and Kirchmann, 1992). Incubation studies in the laboratory may indicate the short term effects of applying manure, but appear not to be of value in predicting behaviour over the whole growing season (Chesheir *et al.* 1986).

Table 2. Sinks for N following application of slurry in three treatments to grassland in winter and spring: results corrected for the appropriate control plots. Values in parentheses are the amounts of N expressed as % of the total N applied. Data from Thompson et al. (1987).

	Nitrogen Sinks†			
Application	Apparent Recovery in Herbage	NH_3 Volatil. Loss	Denitrification. Loss	G Sinks
Winter Experiment	S)))))))))))))))))))Q kg N ha^{-1} (%) S)))))))))))))))))))Q			
Surface spread slurry	49.0 (19.8)	77.1 (30.8)	29.9 (12.1)	156.1 (62.9)
Injected slurry	82.7 (33.4)	2.1 (0.9)	52.7 (21.3)	137.5 (55.4)
Injected slurry + nitrapyrin	90.1 (36.3)	2.1 (0.9)	22.7 (9.2)	114.9 (46.3)
CV‡	17.0% -	25.3% -	98.2% (42.6%)	--
Spring Experiment				
Surface spread slurry	66.9 (25.5)	53.0 (20.2)	4.5 (1.7)	124.4 (47.5)
Injected slurry	93.9 (35.5)	2.4 (0.9)	17.7 (6.8)	114.0 (43.5)
Injected slurry + nitrapyrin	109.9 (42.0)	2.4 (0.9)	14.0 (5.3)	126.3 (48.2)
CV‡	13.8% -	21.1% -	182% (74.8%)	--

† In both experiments leaching losses from all treatments were negligible

‡ Coefficients of variation determined as follows:

Apparent recovery: from the total apparent recoveries for each of the four plots for the three treatments in each experiment.

NH_3 volatilization: from the total NH_3 loss determined for each of three wind tunnels used for investigating the surface application treatment.

Denitrification: the average coefficient of variation for all denitrification measurements in each experiment. In parenthesis the average for values greater than 0.10 kg N ha^{-1} d^{-1}

It is not uncommon for animal manure to be disposed of into an alfalfa ley after the second or third cut but before ploughing in the fall. In such a case, the possibility exists for nitrate to be formed by mineralization and nitrification from the alfalfa residues and the manure. The latter may contain a significant quantity of mineral N (Beauchamp, 1983). Ammonia volatilization could result in significant losses of this N (Beauchamp et al., 1982), and also of N from the legume ploughed down. Evidence from Europe shows that the ploughing of old grassland or 2- to 3-year old alfalfa sod can release about 300 kg ha^{-1} of mineral N that can readily nitrify and is vulnerable to leaching (Juergens-Gschwind, 1989). In Ontario, it is estimated that 110 kg N ha^{-1} becomes available to a succeeding crop from plough-down of alfalfa. If one-third to one-half of the stand is made up of legume, then 55 kg N ha^{-1} is made available, and none if the stand is less than one-third legume (Field Crop Recommendation, OMAF Publ. 296, 1995-96).

A number of strategies are possible to minimize the leaching of NO_3 without stimulating its loss in gaseous form (denitrification) to a significant extent. These are listed as follows:

1. to immobilize mineral N in the organic matter of the soil.
2. to permit uptake by growing cash-crop plants
3. to intercept nitrate N in fall by growing cover-crop plants, which can then be used as manure for spring planted cash crops.
4. the mineral N in animal manure can be partly immobilized into an organic form by composting before application to the soil.

Uptake of mineral N into a cash crop has the greatest advantage as some of the nitrogen will be removed from the system in the harvested portion of the crop. In eastern Ontario, winter crop options are restricted mainly to winter wheat. The uptake of N by winter wheat in the fall period will depend largely on the extent of its growth. On the other hand, it will begin taking up N much earlier than spring-planted crops.

A cover crop also provides a sink for mineral N in the fall period and so will reduce NO_3 leaching compared to leaving the land fallow over winter (Goss, 1990). Oilseed radish has been found to grow well in parts of Ontario and, depending on soil type and date of sowing, can take up almost 100 kg N ha^{-1} in the fall (Miller et al., 1992).

Adding a carbon source, such as straw, at the same time as the manure before sod is ploughed should encourage mineral N immobilization (Power and Legg, 1978; Power and Doran, 1988). Incorporating straw residues in the fall has been shown to reduce leaching by approximately 30% in the U.K. (Goss, 1990). It should also be noted that straw as bedding is normally added to manure in "solid" manure-handling systems.

There is clearly a need for field-based studies into the risk of nitrogen contamination of the environment from animal manures applied to agricultural land. Nitrogen is of concern when it is in mineral form because it is more mobile than organic forms. The immediate risk of contaminating the environment and lowering nutrient availability is greatest from applications of liquid manures in fall or winter, but the potential for leaching in the fall following a spring application also needs investigation. It is expected that manure C and N characteristics as well as soil characteristics will determine the dynamics of N immobilization and mineralization of organic forms to nitrate and ammonium.

The nitrification of ammoniacal nitrogen to nitrate is generally a rapid process in soils. Nitrate is always at risk of leaching, and there is a need to identify how quickly mineral nitrogen in animal manure is removed from the soil pool, and when it is re-released to that pool by mineralization of organic matter.

Objectives

The objectives of the experimental programme were to investigate the fate of nitrogen from the mineral- and organic-N in cattle manure applied in spring or fall, to evaluate the use of cover crops and straw residues for conserving N from fall-applied manures or fall-ploughed alfalfa hay .

Overview of the Experimental Programme

Two field experiments were established in 1991. The first experiment at the Elora Research Station was part of a much larger field investigation, and the work reported here studied the availability of nitrogen from liquid manure applied in the spring as a pre-plant fertilizer to corn. The availability of mineral-N in solid beef manure was also considered. The second experiment at the Winchester Research Station of Kemptville College studied the availability of nitrogen from liquid dairy manure applied in the early fall following plough-down of a low-quality alfalfa-grass hay. The availability of mineral-N in composted cattle manure was also studied. Cover crops were grown as a treatment to investigate the cycling of manure nitrogen between soil and crop in the fall, and to identify whether significant nitrogen was transferred from the cover crop to corn planted in the following spring. Incorporation of straw at the time of application of liquid cattle manure was also investigated as a means of immobilizing nitrogen, thereby making it less vulnerable to leaching from the soil.

In both experiments, ^{15}N-labelled ammonium sulphate was used, and samples of soil and crop were collected over two seasons at each site to follow the fate of the mineral nitrogen in the animal manure, and to identify major periods of loss.

MATERIALS AND METHODS

The Field Experiments

Experiment 1

The objective of the main experimental programme was to examine the fate of N in corn production as a function of the source of the N (livestock manure or mineral fertilizer), the amount applied, and the time of application. Within this study a sub-programme was established having the objective of evaluating the risk of nitrate leaching from spring-applied manure, and identify how much of the mineral N from the liquid cattle manure (LCM) was incorporated into a corn crop. The contribution to N in the crop due to mineralization of soil organic matter was also investigated.

Location

The site was located at the Elora Research Station of the Ontario Ministry of Agriculture, Food, and Rural Affairs. The agronomic programme was directed by E.G. Beauchamp and R.G. Kachanoski. The soil was a Conestogo silt loam (Gleyed Melanic Brunisol). The particle size fraction of the Ap horizon consisted of sand (0.26), silt (0.55), clay (0.18); the organic matter fraction was 0.056, and the pH was 7.0.

Agronomic Programme

The plot size for the main experiment was 9 x 9 m. The whole site was mouldboard ploughed in the fall of 1990. The seedbed was created in 1991 by rotary-hoe, which was used to incorporate the manure applied. Corn (Pioneer 3902) was planted on 19 May 1991 at 128000 seeds ha^{-1}, and later thinned to 64000 plants ha^{-1}, thus ensuring a uniform stand. The crop was harvested at the beginning of October. The site was mouldboard ploughed in October 1991. Corn (Pioneer 3902) was planted 16 May 1992 at 64000 seeds ha^{-1}.

Experimental Treatments

Cropping

The full experiment consisted of eighteen treatments and a control. The experimental design was a randomized complete block with fourfold replication of three factors - N-source (NH_4NO_3, liquid dairy cattle manure, solid beef cattle manure), rate of application (0.5, 1.0, 1.5 times recommended rates), and time of application (spring and fall) - together with the control treatment that received no manure or N-fertilizer. The tracing of the fate of the mineral N was confined to main plots where recommended rates of LCM or NH_4NO_3 were applied. Microplots where liquid cattle manure was applied in the spring immediately prior to the planting of corn in 1991 were designated the Manure treatment. Manure was re-applied to this treatment in May 1992. The second group of microplots were established on the main plots receiving NH_4NO_3 in May 1991. These microplots received no fertilizer-N in the first season, but 150 kg N ha^{-1} was applied as ammonium nitrate in May 1992 to ensure adequate growth of the crop in the second year. This group of microplots formed the Control treatment. The application of the tracer introduced the equivalent of about 16 kg N ha^{-1} to the soil, and it was considered more appropriate to site the microplots on this main plot treatment than on the control treatment where no N was applied in any year.

Manure

The liquid dairy cattle manure (LCM) used in the experiment came from the dairy unit on the station. It was transported by tanker to the field site where it was applied on the surface, and incorporated using a rotary hoe within two hours. Based on the total nitrogen content of the liquid manure 300 kg N ha^{-1} was applied to the plots. Mineral nitrogen, almost entirely in the ammoniacal form, constituted 50% of the nitrogen applied (equivalent to 150 kg N ha^{-1}).

Experiment 2

The objective of the programme was to evaluate the risk of nitrate leaching from fall-applied manure, and evaluate whether this could be alleviated by timely agronomic practices. Specific practices considered were the use of cover crops, incorporation of straw residues and sowing a winter cereal crop.

Location

The site was located at the Winchester Research Station of Kemptville College of Agricultural Technology. The agronomic programme was under the direction of W.E. Curnoe The soil was a Dalhousie clay loam (Humic Gleysol). The particle size fraction of the Ap horizon consisted of sand (0.20), silt (0.52), clay (0.28); the organic matter fraction was 0.037, and pH was 6.3. The chosen site had been in alfalfa-grass hay for at least seven years prior to 1991. Adjacent plots, which had grown small grains and corn, had consistently shown about 50 kg N ha^{-1} present in the soil at planting for corn, and a maximum economic fertilizer-N application of 95 kg N ha^{-1} based on the linear yield response (125 kg N ha^{-1} assuming a quadratic relationship between yield and fertilizer applied).

Agronomic Programme

Plot size for the main experiment was 30 x 15 m, and conventional farm equipment was used for the establishment of the treatments.. The old alfalfa-hay stand was sprayed with glyphosate (Roundup) on 01 August 1991. Desiccated herbage was chopped and removed on 06 August. The whole site was mouldboard ploughed on 07 August.

Straw incorporation was carried out in the preparation of treatments starting on 09 August 1991. Liquid manure and composted manure was applied to appropriate plots from 20 to 23 August.

The planting dates and seeding rates used for all the crops grown in the experiment are given in Table 3. All varieties selected were expected to perform well under normal weather conditions in Eastern Ontario.

Experimental Treatments

Cropping

Poor regrowth of the alfalfa in the spring and early summer 1991 made it impossible to maintain areas of the fodder crop as controls in the experiment. The crop was sprayed-out and the control plots replanted with Timothy (Table 3). In consequence there was no treatment where minimum leaching was not possible. However, few if any plants survived over winter on treatments where Timothy grass or winter wheat was sown in the fall of 1991(Table 3). As a result it was necessary to revise these treatments. The following ten experimental treatments were replicated fourfold in 4 randomized blocks, and test crops planted in 1991-1992:

1. Alfalfa ploughed in; grass (Timothy); no manure; **corn (Control)**
2. Alfalfa ploughed in; grass (Timothy); 172 x 10^3 L ha^{-1} liquid cattle manure; **corn (manure control - LCM)**
3. Alfalfa ploughed in; 54 t ha^{-1} composted cattle manure; **corn (CCM)**
4. Alfalfa ploughed in; liquid manure; **barley** ; wheat **(LCM + barley)**
5. Alfalfa ploughed in; liquid manure; oilseed radish cover crop; **corn (LCM + OSR)**
6. Alfalfa ploughed in; liquid manure; 3.8 t ha^{-1} straw (dry weight) incorporated; **corn (LCM+straw)**
7. Alfalfa ploughed in; liquid manure, straw; oilseed radish cover crop; **corn (LCM + straw +OSR)**
8. Alfalfa ploughed in; liquid manure; winter wheat, **corn (LCM + winter wheat)**
9. Alfalfa ploughed in; winter wheat, **corn (Control + winter wheat)**
10. Alfalfa ploughed in; **barley**; wheat. **(Control + barley)**

In the spring of 1993 all plots not growing winter wheat were planted with corn (Table 3).

Table 3. Crop seeding programme at Winchester, 1991-1992

Date	Crop	Seeding rate (kg ha^{-1})
28 Aug 1991	Timothy (cv marapos) Oilseed radish	11 9
12 Sept 1991	Wheat (cv Hanus)	72
12 May 1992	Barley	101
14 May 1992	Corn (Pioneer 3921 (2600 heat unit)	(78,600 plants ha^{-1})
17 Sept 1992	Wheat (cv Hanus)	72
13 May 1993	Corn (Pioneer 3921 (2600 heat unit)	(78,600 plants ha^{-1})

Manure

The liquid cattle manure used in the experiment came from the dairy unit at Kemptville college. It was transported by tanker to the field site, and then injected at approximately 150 mm depth using a six-tine unit on a 0.82 m spacing. The injector was drawn through all plots, and the valve opened and closed as appropriate to deliver 166 x 10^3 L ha^{-1} on the appropriate plots. A calibration run made in the discard area outside the plots was used to determine the correct speed for the tractor. Based on the total nitrogen content of the liquid manure (Table 4) 300.7 kg N ha^{-1} was applied to the plots. Mineral nitrogen, almost entirely in the ammoniacal form, constituted 72% of the nitrogen applied.

The composted cattle manure came from the dairy unit at Kemptville college. It was windrowed and turned every 2 months for 8 months before application. The manure was weighed in the conventional spreader, and then transported to the experimental site where it was distributed and then incorporated using heavy discs. Grab samples were taken in the field during application. Approximately 95% of the nitrogen in the composted manure was in organic form (Table 4). Based on the total nitrogen content, 319.6 kg N ha^{-1} was present in the 54 t ha^{-1} of manure applied to the plots. The C:N ratio of the composted manure was approximately 21:1. The N content of the composted manure was substantially greater than that of the SBM applied at Site 1, which averaged 4224±468.7 mg N kg^{-1}, but was similar to the value of 6200 mg kg^{-1} commonly reported for well-rotted farmyard manure.

Table 4. Analysis of cattle manure applied in Experiment 2 to plots in August 1991. Nutrient contents are expressed on a fresh weight basis.

Manure type	**Mineral nitrogen**		**Total nitrogen**	**Dry matter**
	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}	mg kg^{-1}	%
Liquid	1300	1.8	1811	4.2
Composted	89±50.2	264±73.1	5919±331.7	30±3.9

At the time of manure application the soil contained approximately 80 kg N ha^{-1} mineral nitrogen to a depth of 0.9 m (see page 24). Only 16.9 kg N ha^{-1} of mineral nitrogen were added to the soil in the composted cattle manure, but the application of liquid manure added 216.4 kg N ha^{-1} of mineral nitrogen.

Experimental Treatments - nitrogen immobilization

The experimental programme involved the sampling of soil, soil water, and plant material to assess the fate of the nitrogen from the manure, the availability of the nitrogen to crops, and the presence of mineral nitrogen in the soil.

The cover crop treatments and the fall sowing treatments were designed to immobilize mineral nitrogen in fall and early spring by its incorporation into growing plants.

Cover cropping: Oilseed radish (*Raphanus sativus*) was chosen because it had been shown by Miller et al.(1992) to take up considerably more nitrogen per unit weight of dry matter than other cover crops.

Fall cropping: Winter wheat (*Triticum aestivum*) was selected as the only autumn-sown cash crop likely to survive the winter in much of Ontario.

Straw incorporation,: The treatments where crop residues were added to the soil were designed to immobilize mineral nitrogen from the manure by incorporation into the soil organic matter fraction. The aim was to incorporate sufficient cereal straw (oat straw in this experiment) to effect a maximum of a 1:10 ratio of mineral nitrogen in the liquid manure to freshly introduced carbon. Oat straw (44% C) was incorporated into the plots at 4.7 t ha^{-1} (fresh weight basis; 3.8 t ha^{-1} dry weight). After taking account of the nitrogen in the oat straw the effective ratio was 1:7.2, somewhat larger than intended because the ammoniacal content of the manure was greater than preliminary measurements suggested.

Field Application of ^{15}N for Detailed Investigations

At both experimental sites, ^{15}N studies were carried out on microplots 2 m x 2.5 m. For Experiment 1 at Elora, microplots were located on each replicate of the Medium Spring Manure treatment (150 kg mineral-N ha^{-1}), and on the Medium Fertilizer treatment (150 kg N ha^{-1}) - although none of this fertilizer-N was added to the microplots. A 1.0766 M solution of ammonium sulphate containing ^{15}N at 99.2 atom per cent was prepared and 250 mL was applied to the soil surface immediately after liquid cattle manure had been applied (Manure treatment), or immediately before the soil was rotary-hoed (Control treatment). The seedbed was prepared by hand forking to leave the surface in a form similar to that of the main plot. Corn (Zea mays) was sown in the microplots with the same pass of the planter as the main plot.

On Experiment 2, a microplot was established on each treatment of the third block. ^{15}N-labelled ammonium sulphate solution was mixed into the manure (liquid dairy or composted cattle) before it was applied to the surface of the microplots. The latter had been treated exactly the same as the main plots except that the valve of the manure injector had been closed prior to the shoe entering a microplot. On microplots not receiving manure, the ^{15}N-labelled solution was applied directly to the soil surface. The microplots were hand-dug immediately after the ^{15}N was applied to mix the labelled materials uniformly through the top 200 mm of soil.

In November 1991, the shoots of the oilseed radish on the microplots at Winchester were removed, and a sub-sample taken for analysis. The remaining material was transferred to a second microplot (2 m X 2 m) from which the unlabelled tops had been removed. Unlabelled tops, equivalent in weight to those removed, were added to the two microplots where the labelled manure had been applied. The contribution of the nitrogen in the oilseed radish tops was obtained by analysis of the following corn crop.

Soil and Crop Measurements

Soil and soil solution

For Experiment 2, the mass of mineral nitrogen was determined from soil cores 70 mm diameter and 0.9 m deep, 4 cores per treatment. Samples from each plot were analyzed separately. Cores were taken prior to imposition of the treatments, and on seven subsequent occasions (Table 5).

Table 5. Soil sampling programme, Winchester 1991-1993.

Date	Agronomic stage
19 Aug 1991	Initial sampling
11 Nov 1991	2nd sampling - end of fall leaching period
11 May 1992	3rd sampling - seed drilling for spring crop
29 Jun 1992	4th sampling - end of spring leaching
01 Sept 1992	5th sampling - harvest of barley
10 Nov 1992	6th sampling - harvest of corn
05 May 1993	7th sampling - end of spring leaching (microplots only)
19 Oct 1993	8th sampling - harvest of corn (microplots only)

Ceramic-cup solution samplers (2 per plot) were inserted vertically in each main plot in Experiment 1, and at an angle of 45 in the microplots of Experiment 2. At both sites the cups were set at a depth of 0.8 m, and samples of soil water extracted on regular occasions to identify the concentration of nitrate in water leaching from the rooting zone. At Winchester samples were collected on fourteen occasions (Table 6). In addition to these measurements through the main growing season for the test crops, samples were also collected at Winchester from the main tile outlet in late April and early May. These samples could not be related to experimental treatments, but provided additional information on the general loss of nitrate by leaching from arable land.

At both experimental sites soil samples were collected from the main plots, and from within and between crop rows on the microplots. For the 0-100 mm and 100-200 mm depths of the microplots, cores 150 mm in diameter were collected, deeper depths were sampled with a 70 mm diameter core tube.

Table 6. Soil solution sampling programme at Winchester 1992.

Month	Day
May 1992	28
Jun 1992	03, 09, 16, 23
July 1992	06, 16, 22, 28,
Aug 1992	06, 12,
Sept 1992	02, 08,
Oct 1992	23

Crops

Crop samples were also collected to identify the amount of nitrogen immobilized by plant uptake. At site 1 samples were collected from main plots only at harvest in 1991 and 1992. At site 2, samples were collected from the main plots on eight occasions in the 1991-2 season and at harvest in 1993 (Table 7). Plant samples were collected from the microplots at both sites to coincide with soil sampling.

Table 7. Plant sampling programme at Winchester, 1991-1993.

Date	Growth stage
21 Oct 1991	Maximum growth oilseed radish
23 Oct 1991	Maximum fall growth of winter wheat
17 Jun 1992	Corn - 7 leaf; barley - flag leaf visible
08 July 1992	Corn - 10 leaf; barley - heading
20 Aug 1992	Corn - grain fill
24 Aug 1992	Barley - harvest
10 Nov 1992	Corn - harvest
19 Nov 1992	Winter wheat - maximum fall growth
19 Oct 1993	Corn - harvest

Laboratory Measurements

Mineral nitrogen in soil cores collected from the main plots was extracted with 0.5 M K_2SO_4. Soluble carbon was also extracted from cores in Experiment 2. The choice of extractant was governed by the option to measure microbial biomass if differences in mineral-N content warranted further studies, but values for the mineral-N content did not differ significantly in samples where the efficiency of 0.5 M K_2SO_4 and 2 M KCl extraction was compared. Cores were divided into 100 mm long segments in the field, and the water content of the segments was determined gravimetrically using small sub-samples. The total fresh weight of each 100 mm long segment was determined so that the dry weight and bulk density could be calculated. The ammoniacal and nitrate components of the extracted soil mineral nitrogen were determined simultaneously using a Technicon Random Access Automated Chemistry System TRAACS-800 (Alpha-Laval. AB. Stockholm, Sweden). Nitrate was measured colorimetrically after reduction to nitrite using a copper-cadmium coil, and formation of an azo dye using N-1-naphthylethylene diamine. The limit of detection for nitrate was 0.02 mg N L^{-1}. Ammonium ions in the extract were measured colorimetrically after reaction with phenol and hypochlorite to form an indophenol dye. The limit of detection for ammonium was 0.05 mg N L^{-1}. The mineral-N content of each soil layer was summed to give a total value for the profile.

Mineral nitrogen in the samples of soil water, collected from the solution samplers in the field, was also measured on the same auto-analyzer as the K_2SO_4 extracts of soil.

Total nitrogen in plant samples was measured on ground sub-samples of material following a modified Kjeldahl procedure. Nitrogen was converted to ammonium ions by digestion with sulphuric acid with selenium as a catalyst. Salicylic acid was used to reduce any nitrate ions present. Ammonium ions in the digest were measured colorimetrically after reaction with phenol and hypochlorite to form an indophenol dye.

^{15}N Analysis

Soil Preparation for Total ^{15}N Analysis: Soil samples were air dried and ground to pass through a 2 mm sieve. Sub-samples were prepared using an Endocotts rotary sample divider.

Approximately 20 g. samples were ground to fine powder using a rotary jar and bar grinder (Smith, 1990). Duplicate samples were then oven dried at 105EC for 12 h .and 30-50 mg. samples were weighed into tin cups for total ^{15}N analysis by direct combustion mass spectrometry.

Soil Preparation for ^{15}N-Labelled Mineral-N: The following method (adapted from Brooks et al., 1989) was used to extract the ^{15}N-NH_4 and -NO_3 species from soil.

Soil samples (10 g) of <2 mm sieved soil were shaken for 1 h with 100 mL of 2 M KCl solution. The samples were then filtered with Whatman No.42 filter paper. 60 mL aliquots of the extract were transferred by weight to 250 mL Nalgene polypropylene Mason jars, which had been acid washed and rinsed with ultra-pure water. 6 mm disks made from Whatman No.3 filter paper, which had been KCl washed, distilled water rinsed, then oven dried were punctured with 72 mm lengths of stainless steel wire.

For the sequential micro-diffusions a 0.2 g scoop of MgO (heavy) was added to each container, followed by the addition of 4 acid-washed glass beads. 10FL of 2.5 M $KHSO_4$ was pipetted onto each filter disk and quickly suspended over the solutions.

The containers were sealed, mixed gently to prevent splashing onto the disk, and allowed to incubate for 6 days. The wires and disks were then carefully transferred to a Teflon rack inside a desiccator containing $CaSO_4$ and dried for 12 h. The disks were then transferred to tin cups for NH_4-^{15}N analysis by direct combustion mass spectrometry. The previously opened containers were shaken vigorously and allowed to sit for 48 h.,thus permitting any residual NH_4 to volatilize. A 0.4 g scoop of Devarda's alloy was then added to each vessel and new wires with disks containing 10FL of 2.5 m $KHSO_4$ were suspended over each soil extract solution. The jars were then sealed, carefully mixed and incubated for a further 6 days. Again the wires and disks were transferred to the Teflon rack inside the desiccator and dried for 12 h. The disks were then weighed into tin cups for NO_3-^{15}N analysis using the mass spectrometer.

For the combined micro-diffusion technique a 0.2 g scoop of MgO and a 0.4 g scoop of Devarda's alloy was added at the same time to each new 60 mL aliquot of soil extract. The procedure then proceeded identically to the sequential diffusions, except the total incubation time was only 6 days.
The ^{15}N-content of each soil layer was summed to give a total value for the profile.

Plant Preparation for Total ^{15}N Analysis: Plant samples were oven dried at 60 EC for 24 h for total weight. Plants were then separated into leaves, stem, cob and kernels for fine grinding using a Retsch ball mill shaker grinder. The powdered plant material was then dried at 60 EC for 12 h. The component plant material was weighed into tin cups for total ^{15}N analysis again by direct combustion mass spectrometry.

Calculation of Results from Recoveries of ^{15}N in Soil and Plant Material

Recovery of ^{15}N in the crop was calculated as the product of the average mass of ^{15}N in the plants and the number of plants in the microplot. This was then expressed as a percentage of the mass of ^{15}N applied to the microplot. Recovery of ^{15}N in the soil was calculated as the product of the average enrichment of ^{15}N in each soil layer and the mass of soil in the layer, summed for each layer. This was then expressed as a percentage of the mass of ^{15}N applied to the microplot.

On Control plots, the contribution of the mineral-N in the soil on 27 August 1991 to the N in the plant was calculated as the ratio of the ^{15}N-enrichment in the plant to that of the soil mineral-N after ^{15}N-labelled ammonium sulphate had been added, and expressed as a percentage. On Manure plots, the contribution of the mineral-N in the manure to the N in the plant was calculated as the ratio of the ^{15}N-enrichment in the plant to that of the manure at application, and expressed as a percentage. On these Manure plots, the contribution of the mineral-N in the manure and in the soil on 27 August 1991 to the N in the plant was calculated as the ratio of the ^{15}N-enrichment in the plant to that of the manure and soil combined at application, and expressed as a percentage. In this case, the difference in the contribution from manure and soil combined, and manure alone, gave the contribution from the mineral-N in the soil on 27 August 1991.

RESULTS

Experiment 1

Climatic Conditions

The growing season in 1991 at Elora was warmer than average, and June was markedly drier than normal (Figs. 1 & 2). In contrast the growing season of 1992 was cool and wet (Figs. 1 & 2) with some 300 fewer corn heat units than the previous season (R M Brown personal communication, January 1995).

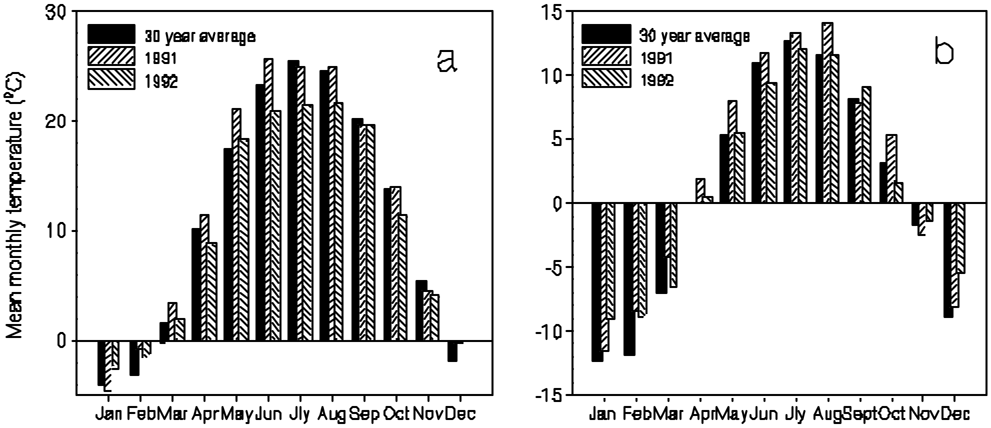

Figure 2. Mean monthly temperatures at Elora in 1991 and 1992 compared with the 30 year average (a) maximum, (b) minimum temperature.

Soil

At the start of the experiment in May 1991, all plots contained approximately 54 kg N ha^{-1} as mineral nitrogen to a depth of 0.6 m, with about 50% of this being in the nitrate form.

Crops

Grain yield on the main plots in 1991 was significantly greater on plots receiving LCM or mineral fertilizer than on plots receiving solid beef manure (8.23 t ha^{-1}), but yields on fertilized (9.57 t ha^{-1}) or manured plots (9.35 t ha^{-1}) were not significantly different (p # 0.05) from those on control plots (8.67 t ha^{-1}). There was no effect of the different rates of manure or fertilizer on yield. In 1992 main-plot yields were smallest on control plots and increased progressively from plots receiving fertilizer to plots receiving LCM and plots receiving solid beef manure. Fertilizer and manure was also applied to some plots in the fall of 1991. Yields on these plots were consistently less than on the plots where fertilization took place in spring.

During 1991, there was no difference in the growth of corn on the microplots between the Manure and Control treatments (Fig. 3). At harvest in 1992 average plant dry weight reflected the difference in grain yield reported for the main plots, but neither plant weight or grain yield differed between treatments at p = 0.05.

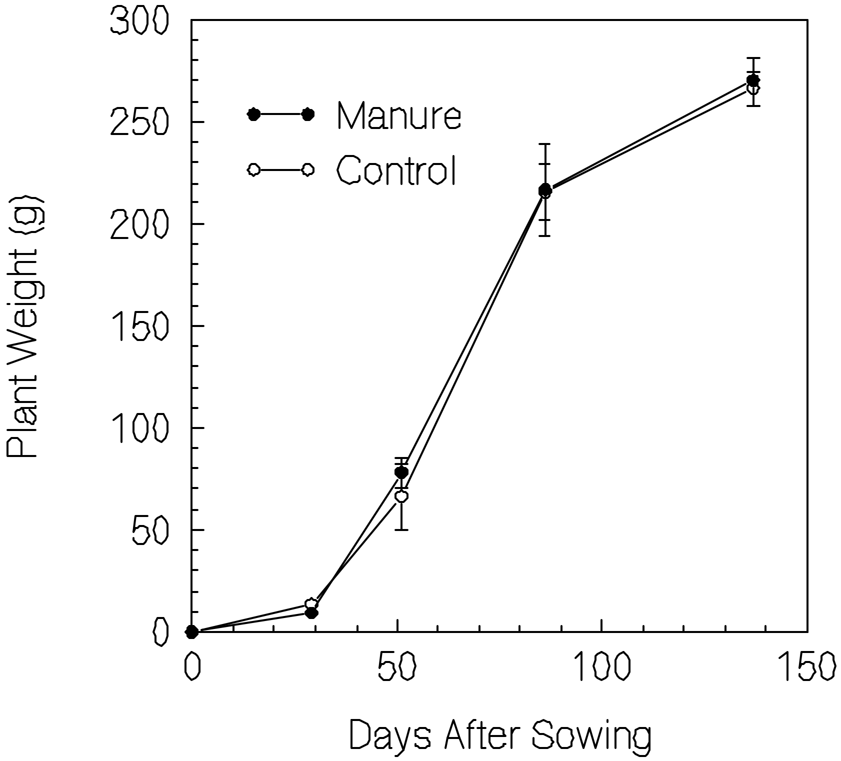

Figure 3. Increase in dry weight of plants from the Manure and Control treatment microplots at Elora over the 1991 growing season.

Fate of manure nitrogen

Data from plots that did not receive manure were used to identify the fate of the mineral nitrogen present in the soil at planting in 1991, and to compare the loss of this nitrogen with that in the mineral-N in the manure. In 1991 the average loss of the ^{15}N from the Manure and Control treatments was approximately 25% (Table 8). This loss was potentially due to a combination of volatilization of ammoniacal nitrogen to the atmosphere, denitrification, and leaching of nitrate nitrogen below the rooting zone. Some 14.8 ± 1.90% of the nitrogen in the crop on the Manure treatment was derived from the labelled mineral nitrogen in the manure (see page 15). This represented about one quarter of the labelled mineral N added to the manure. Half of the ^{15}N remained in the soil.

Table 8. The percentage of ^{15}N in the plant and soil at Elora after harvest 1991, and the loss calculated as the difference between the amount added and the total recovered.

Recovery of ^{15}N in 1991 (%)		
TREATMENT	**Manure (Liquid cattle manure)**	**Control (Without manure)**
COMPONENT		
Plant	**25.7 ± 3.02**	**31.2 ± 4.33**
Soil	**48.3 ± 4.29**	**44.5 ± 5.00**
Loss	**26.0 ± 5.94**	**24.4 ± 2.37**

The time course of N-uptake was similar for Manure and Control treatments, although the crop on the latter treatment removed proportionally more ^{15}N from the soil (Fig. 4a). At harvest the uptake of ^{15}N

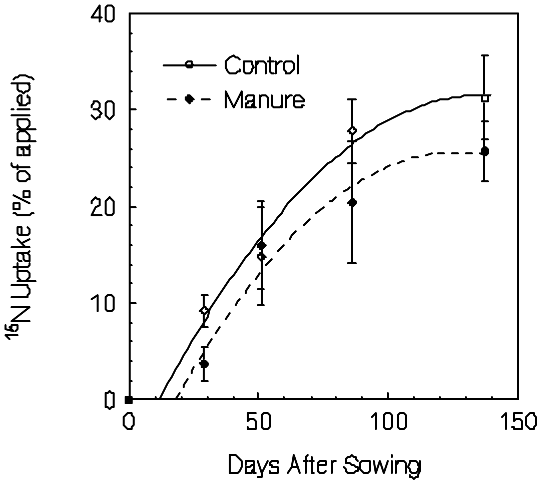

Figure 4a . Uptake of ^{15}N into corn from microplots treated with or without liquid cattle manure.

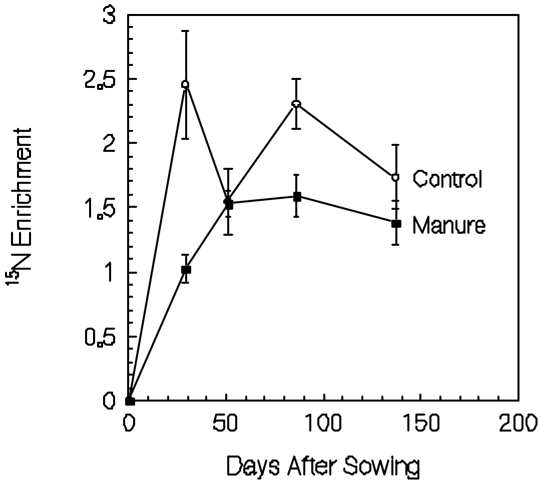

Figure 4b. Variation in ^{15}N-enrichment in plants from microplots treated with or without liquid cattle manure.

by the Control crop was only 5% greater than that in Manure treatment plots, but only 3.6 ± 0.50% of nitrogen in the crop was derived from the mineral nitrogen present in the soil at planting. In this case, over 96% of the nitrogen in the crop had been derived from nitrogen mineralized after planting. ^{15}N-enrichment of the corn plants was greater in the Control treatment than on the Manure treatment at the first sampling in June (Fig. 4b). In July the values were the same for both treatments, and thereafter the average enrichment remained constant on the Manure treatment. Values on the Control treatment were more variable between occasions.

The loss of nitrogen from May 1991 to October 1992 was approximately 35% of the total applied (Table 9). The loss of ^{15}N from manured and non-manured plots over the whole period from harvest 1991 to harvest 1992 was about 12% greater than the loss over the growing season in 1991. The average loss from Control plots (i.e. without manure) was about 15% in the second year, but recoveries of ^{15}N from crop and soil were very similar to those from the Manure treatment plots. The distribution of the ^{15}N over the experimental period was similar for both Manure and Control treatments (Figs. 5 and 6).

Table 9. The percentage of ^{15}N in the crops grown at Elora in 1991 and 1992 combined, and in the soil after harvest 1992, and the loss calculated as the difference between the amount added and the total recovered.

Recovery of ^{15}N in 1991 and 1992 (%)		
TREATMENT **COMPONENT**	**Manure (Liquid cattle manure)**	**Control (Without manure)**
Plant	**31.6 ± 4.36**	**34.3 ± 4.72**
Soil	**33.1 ± 3.74**	**26.4 ± 1.97**
Loss	**35.2 ± 7.90**	**39.3 ± 5.18**

There was no net cumulative drainage during the growing season in 1991, so leaching loss was not determined. In 1992 the nitrate leached from fertilized plots was inversely related to yield, with the greatest loss being from plots receiving NH_4NO_3, least from plots receiving SBM, and LCM plots being intermediate. Plots fertilized in the fall leached more nitrate than did spring fertilized plots. The smallest loss was from the control plots (Table 10).

Table 10. Average loss of N by leaching from main plots at Elora from January to harvest in 1992.

Treatment	**Timing**		**Average annual leaching of NO_3^- January to harvest, 1992 (kg N ha^{-1})**			
		Rate of application	**0**	**0.5**	**1.0**	**1.5**
Control	**-**	**-**	32.3			
$NH_4NO_3^-$ fertilizer	**Spring**			58.7	88.4	130.0
	Fall			114.7	180.4	206.2
LCM	**Spring**			74.8	75.3	85.4
	Fall			136.1	98.7	98.2
SBM	**Spring**			55.3	48.8	60.9
	Fall			56.0	62.8	62.6

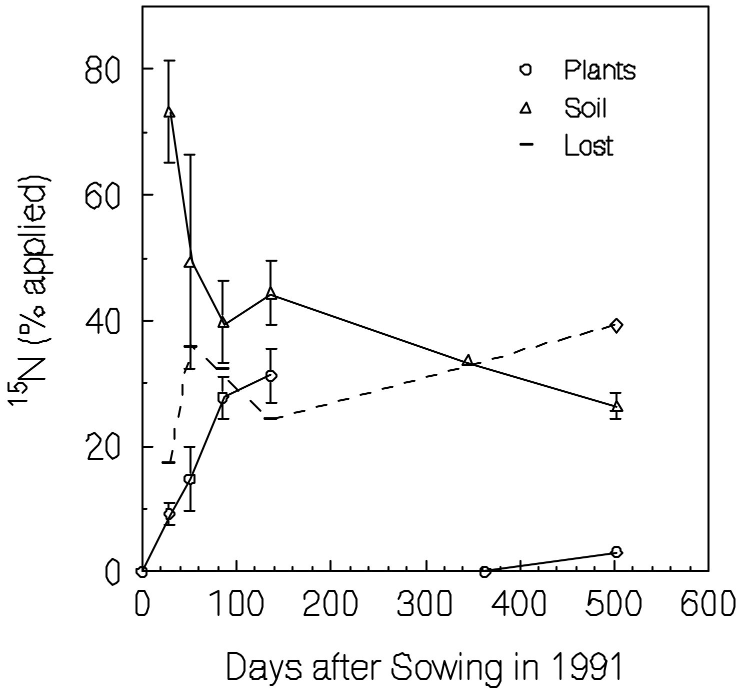

Figure 5. Fate of ^{15}N applied to microplots at Elora as ammonium sulphate.

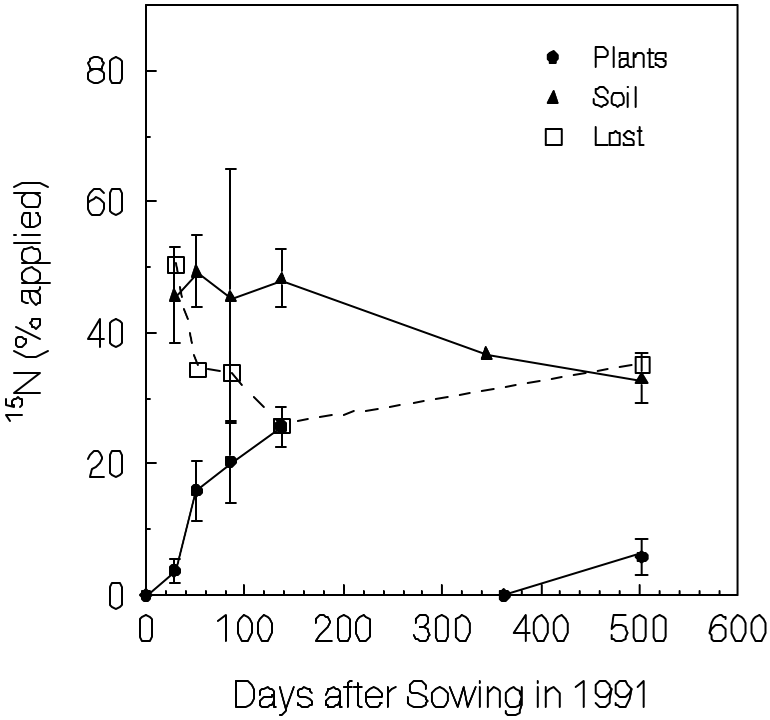

Figure 6. Fate of ^{15}N applied to microplots at Elora as mineral N in liquid cattle manure.

The potential for denitrification was greater in the manured plots than in plots receiving only mineral nitrogen because of the carbon addition. In this experiment, the losses from the two treatments were similar. This suggests that most losses were due to the other mechanisms. Losses due to volatilization would be expected to be greatest during the application of the manure (and ^{15}N). Total loss in 1992 was half that of the previous season, so the results suggest that taken over the whole period, volatilization associated with manure application was probably an important loss mechanism at Elora. The smallest loss from a manured plot recorded in 1991 was 8.7% of the ^{15}N applied. If this represents the loss by volatilization alone, then total leaching loss over the whole experiment could have been as high as 30%, and the latter would then be the most important loss mechanism.

Experiment 2.

As this was a much more complex experiment, the presentation of results has been arranged to identify key features of the fate of the mineral N from the manure and the underground residues of the alfalfa fodder crop. The climatic conditions prevailing during the first year of the experiment from the fall of 1991 to the fall of 1992 have been summarized to give an overview. The distribution of nitrogen in the soil and plants has been reported for the fall of 1991, the spring to harvest of 1992, the fall of 1992, and the spring to harvest of 1993.

Climatic Conditions

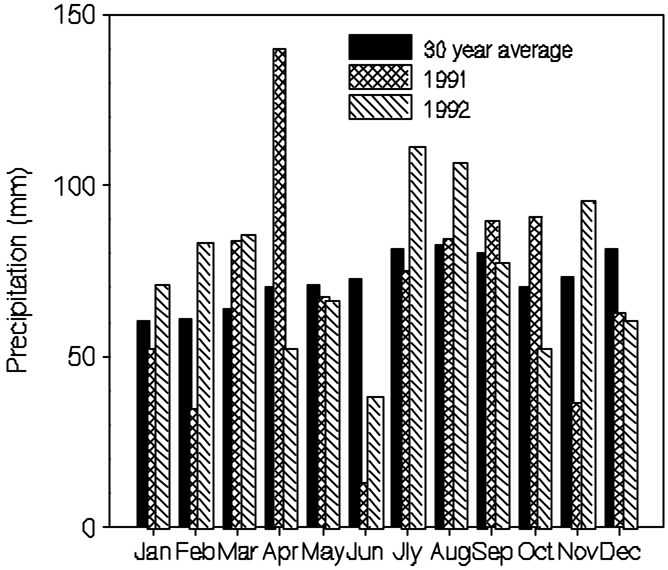

Figure 7. Precipitation at Winchester for 1991 and 1992 compared with the 30 year average.

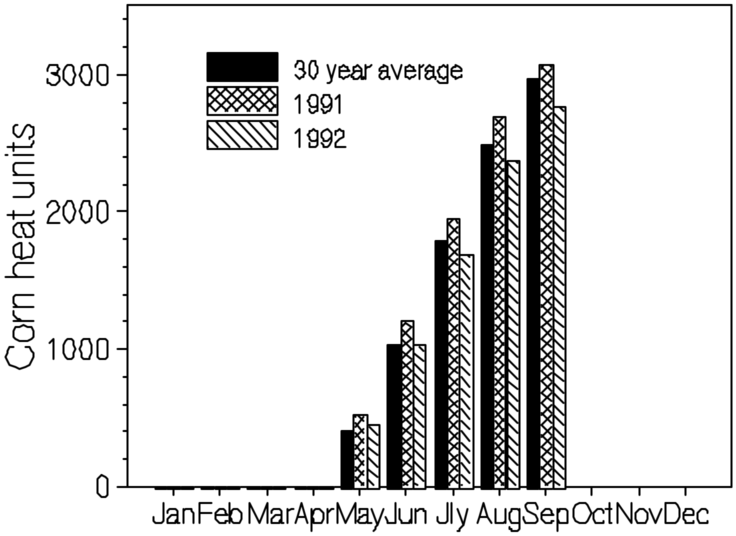

Figure 8. Monthly total corn heat units for the main growing period at Winchester. The values for the two years of the study are compared with long-term average values for the area.

The growing season in 1991 was drier and warmer than average (Figs 7, 8, and 9). The soil was very dry (volume fraction approximately 0.15 in top 100 mm layer) at the time the manure was applied at the end of August. Consequently even the greater than average rainfall in September and October did not result in adverse soil conditions for growth in the fall. The winter was cold and the snow cover was broken by heavy rain on 14 January (Fig.10). The temperature dropped sharply after the rain and killed the wheat crop. There was still frost in the ground until the last week in April. Field drains in the area only ran for a short period in early May. May and June were drier than average, but the corn heat units were similar to the long-term average (Fig. 8). In contrast to the previous year, the summer was particularly wet and cool, especially July and August which followed the very dry but cooler than average month of June. The average temperature in September returned to the long-term norm, but October was cooler than average so that the corn was not ready for harvest before mid-November.

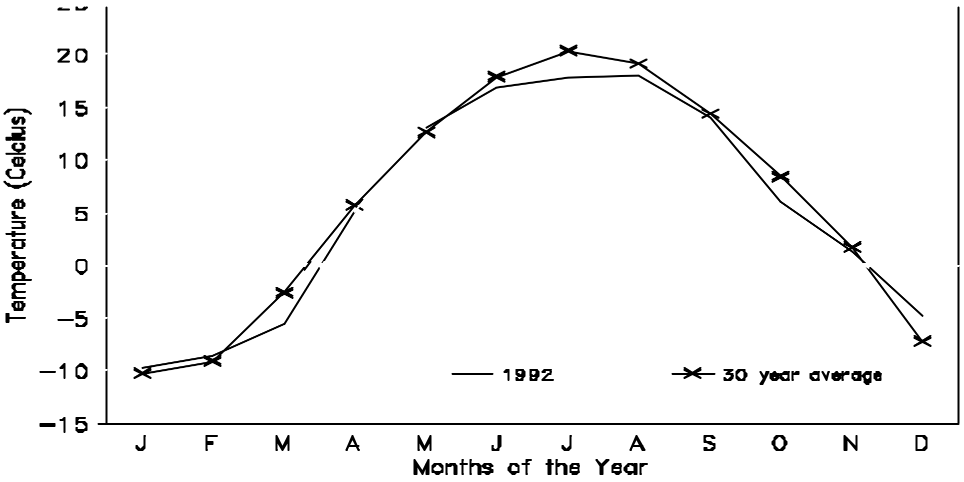

Figure 9. Average monthly temperatures at Winchester during 1992 compared with the 30 year average.

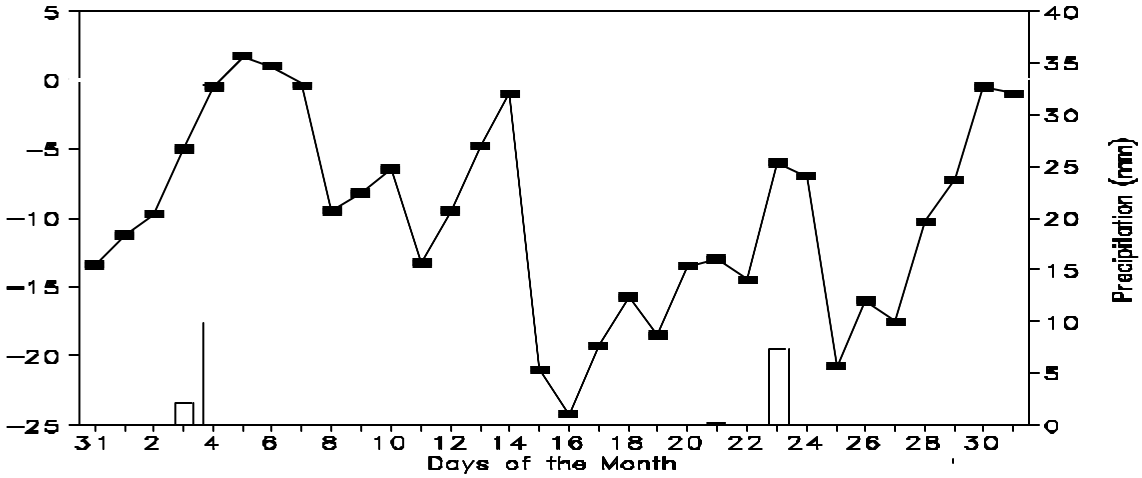

Figure 10. Temperature and precipitation at Winchester, January 1992.

Fall 1991

Soil

At the start of the experiment all plots contained approximately 80 kg N ha^{-1} as mineral nitrogen, with 50% of this being as nitrate (Table 11).

Table 11. Mineral nitrogen in the soil 3 weeks after ploughing the alfalfa hay land at Winchester, 1991.

Ammoniacal nitrogen (kg N ha^{-1})	**Nitrate nitrogen (kg N ha^{-1})**	**Total mineral nitrogen (kg N ha^{-1})**
38.3± 3.58	40.5± 3.32	78.8 ± 4.60

The effect of applying liquid cattle manure on the mineral N content of the soil was dramatic (Table 12). Twelve weeks after manure application, the mineral nitrogen content was almost double that in soil that had received no manure, and approximately 80% of that nitrogen was in the form of nitrate. Addition of the composted manure caused only a small increase in the mineral nitrogen content of the soil.

Table 12. Nitrate N and total mineral N present in soil, nitrogen in crops, and the total mineral N pool in soil by November 1991 at Winchester, 12 weeks after manure application.

Source		**No manure applied (kg N ha^{-1})**	**Composted manure (kg N ha^{-1})**	**Liquid cattle manure (kg N ha^{-1})**
Soil	Nitrate	55± 3.1	78± 19.0	134± 20.0
	Total mineral N	91± 2.5	116±23.1	171± 21.4
Plants		26± 16.0	0*	126± 28.0
Total mineral-N pool in soil		117±14.5	116±23.1	297± 34.5

* No cover crops were sown on these plots, nor did weeds grow, so there was no uptake into plants.

The total mineral-N pool that had been present in the soil over the fall period was calculated by adding the crop nitrogen content to the soil mineral nitrogen content (Table 12). Composted manure had no significant impact on the size of the nitrogen pool; the total present was not significantly greater than that in plots where no manure had been applied. However, there was an additional 180 kg N ha^{-1} mineral nitrogen in plots receiving liquid cattle manure compared with plots where no manure had been applied, and this could readily be explained by the 216 kg N ha^{-1} added in the manure. The summer of 1991 was considerably warmer and drier than expected from average climatic information, so there was no significant water movement below the rooting zone during the fall (Fig.11). Consequently no leaching of nitrogen was likely.

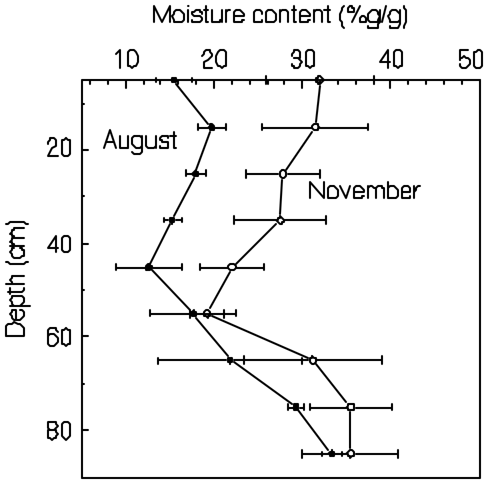

Figure 11. Soil moisture profiles at Winchester in August and November 1991. Changes below 60 cm are not significant.

Crops

The oilseed radish cover crop removed about 150 kg N ha^{-1} from the soil before it was killed by frost in early November (Table 13). Where the oat straw had been incorporated some 60 kg N ha^{-1} less nitrogen was taken up by this cover crop. Winter wheat grew much more slowly than did the oilseed radish, and it took up less than 20 kg N ha^{-1} over the same period (Table 13).

Table 13. Nitrogen taken up into the shoots of plants from emergence in September to the end of fall 1991 at Winchester. Values for plots receiving liquid cattle manure

Fall-sown crop		**kg N ha^{-1}**
Oilseed radish	**- Straw**	**151.0 ±25.70**
	+ Straw	**92.9 ±3.04**
Winter wheat		**17.4 ±1.49**

There was a significant growth of wild mustard on plots that were left unplanted over winter. Furthermore, there was a considerable growth of volunteer oats from the incorporated straw, except where oilseed radish was planted. Using results from all the sown and volunteer plant types that acted as cover crops, there was a strong correlation between the amount of nitrogen immobilized in the plant (y kg N ha^{-1}) and the dry matter produced during the fall (x t ha$^{!1}$) (Fig 12). For 1991 the relationship was given by:

$$\mathbf{y = 43x - 10.2 \quad (r^2 = 0.987,\ p< 0.001).}$$

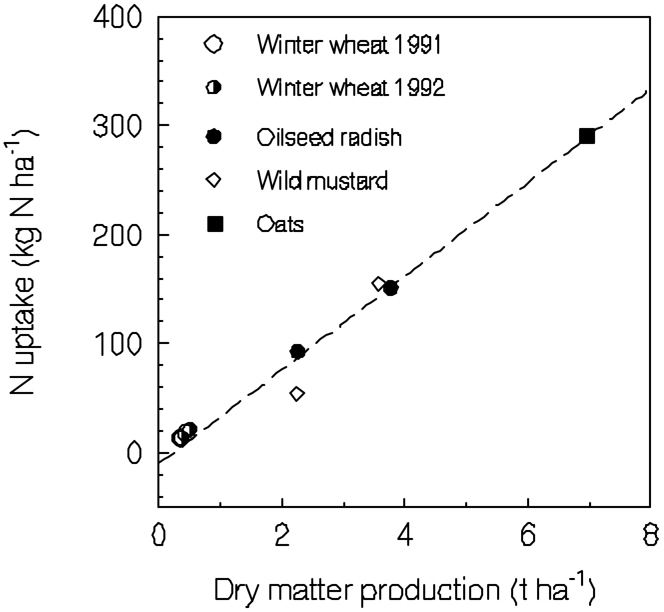

Figure 12. Relationship between nitrogen uptake and dry matter yield of cover crops.

Results for winter wheat grown in the fall of 1992 could also be described using this relationship (Fig. 12).

Fate of manure nitrogen

At Kemptville there appeared to be no significant loss of ^{15}N-labelled mineral N during the application of liquid cattle manure, composted manure or the tracer amounts of ammonium sulphate (Control), since the recovery of tracer two days after application was not significantly

Table 14. Recovery from soil of ^{15}N applied to microplots 2 days after application at Winchester in August 1991.

Source of N	**^{15}N in soil (% of applied)**
Control (soil organic matter)	**114± 21.5**
Liquid cattle manure	**92± 10.6**
Composted cattle manure	**104± 29.3**

different from 100% (Table 14). However, the difference between replicate samples was larger than expected. Polynomial regressions were fitted to the data from each microplot for each sampling occasion, and the value for those dates predicted by the regression was used for subsequent calculation of ^{15}N in the organic fraction (Appendix A).

During the fall there was little downwards movement of the mineral N from the liquid cattle manure. Even by 11 November, none of the ^{15}N applied in the cattle manure could be detected below the top 300 mm of the soil profile. This was also true for plots where ^{15}N-labelled ammonium sulphate was applied to trace the fate of nitrogen released from the below-ground alfalfa residues.

Table 15. ***Distribution of ^{15}N in soil at the end of the fall period in 1991 at Winchester.***

Nov.11. 1991	**^{15}N in organic form (% of applied)**	**^{15}N in NO_3 form (% of applied)**	**^{15}N in NH_4^+ form (% of applied)**
Treatment			
Control	**79.7**	**12.8 ± 7.70**	**0.7 ± 0.3**
LCM (Liquid Cattle Manure)	**55.8**	**22.4 ± 7.49**	**2.2 ± 1.07**
Control + winter wheat	**59.1**	**13.4 ± 10.35**	**1.8 ± 0.87**
LCM + winter wheat	**78.6**	**6.4 ± 0.94**	**1.3 ± 0.16**
LCM + Oilseed radish	**93.6**	**5.8 ± 3.29**	**1.9 ± 0.71**
LCM + Straw	**67.3**	**9.9 ± 8.55**	**0.4 ± 0.05**
LCM + Straw + Oilseed radish	**67.1**	**3.0 ± 0.56**	**0.7 ± 0.16**
Composted cattle manure	**85.8**	**13.7 ± 0.95**	**2.9 ± 0.37**

Most of the ^{15}N added to the soil in manure or directly as ammonium sulphate was still present in the soil and at least 55% had become incorporated into the organic fraction in the soil by 11 November (Tables 15 and 16). Importantly, very little ammoniacal nitrogen was found to be labelled; the majority of the ^{15}N-labelled mineral N was in the nitrate form even in the composted manure treatment. The ammoniacal-N from the manure that did not enter the organic fraction was readily nitrified during the fall, although in this experiment some was removed in the cover crops. These results are consistent with those from the general soil investigation (Table 12).

Table 16. ^{15}N remaining in soil on 11 November 1991 at Winchester.

Source of N	**15N in soil (% of**
Control (alfalfa residues)	**93± 9.4**
Liquid cattle manure	**80± 10.9**
Composted cattle manure	**102± 29.3**

Samples of the oilseed radish cover crops and the winter wheat crop taken in November showed that they had taken up about 6% of the ^{15}N applied in the manure. About one third of the N in the plants was derived from the mineral N fraction of the liquid cattle manure (Table 17). The remainder of the N in the plants must therefore have been derived from mineralization of the soil organic matter, alfalfa residues, and the organic nitrogen fraction of the manure. Only 5% of N in the wheat came from the mineral N in the soil at the time the manure was applied (Table 17). The average values for oilseed radish were similar, but more was derived from this source in the absence of added straw than where straw was incorporated. The results from analysis of ^{15}N in the winter wheat from the microplot not receiving manure suggested that just over 11% of the N in the plants was derived from the mineral N present in the soil at the time of application, the remainder presumably being derived from the mineralization of soil organic matter, particularly the residues from alfalfa (Table 17).

Table 17. ^{15}N taken up into the shoots of cover crop plants from emergence in September to the end of fall 1991 at Winchester.

Fall-sown crop		^{15}N in crop (% of applied)	N derived from mineral-N in manure (%)	N derived from mineral-N in soil when manure applied (%)
Oilseed radish	**LCM - Straw**	**8.7 ± 0.11**	**36.5± 0.04**	**7.6± 0.01**
	LCM + Straw	**6.0 ± 0.05**	**33.4± 0.19**	**4.6± 0.05**
Winter wheat	**Control**	**6.1 ± 0.15**	**-**	**11.6± 0.06**
	LCM	**4.1 ± 0.03**	**35.8± 0.63**	**5.0± 0.09**

Taking account of the ^{15}N in the crops and soil suggested that about 13% of the mineral nitrogen applied had been lost between application and the end of the fall, except on the plots where straw had been incorporated (Tables 15 and 17). As leaching was not apparent, the loss was likely to have been due to volatilization of ammonia, or denitrification. The dryness of the fall made denitrification less likely.

Growing Season 1992

Soil

The soil remained frozen until late April 1992. The period of spring runoff was short, and seeding of spring barley and corn took place in the second week of May.

Soil mineral nitrogen differed greatly between the manure treatments. Similar amounts of N were present in plots receiving composted manure and those given no cattle manure, but almost 60 kg N ha^{-1} more nitrogen was present in plots injected with liquid manure in the previous August (Table 18).

Table 18. Nitrate-N and total mineral-N present in soil at Winchester on 12 May 1992**.**

No manure applied (kg N ha^{-1})		Composted manure (kg N ha^{-1})		Liquid cattle manure (kg N ha^{-1})	
Nitrate	**Total mineral N**	**Nitrate**	**Total mineral N**	**Nitrate**	**Total mineral N**
108 ± 14.9	**123 ± 13.9**	**110 ± 38.2**	**124 ± 37.6**	**159 ±14.5**	**181± 15.9**

The nitrate content in the top 0.6 m of the soil (values appropriate for the Ontario Soil Nitrate test) showed marked differences between treatments (Table 19). The Control treatment where no weeds were present had a soil test of 86 kg N ha^{-1}, and contained about the same amount of nitrate as the Control with winter wheat, which had taken up about 20 kg N ha^{-1} in the fall. Where weeds had been prolific, the soil test was almost 50 kg N ha^{-1} greater than that of the weed-free Control. This suggested that most of the 54 kg N ha^{-1} present in the plant residues in November had subsequently been remineralized. However, in contrast to the results on the Control treatment, the results for treatments given liquid cattle manure showed that less nitrogen was available where there had been significant ground cover in the previous fall. Treatments receiving cattle manure all contained nitrate in excess of 100 kg N ha^{-1}.

In late June the soil under spring barley contained less mineral nitrogen than did soil under corn (Table 20), probably because this was the period of maximum nitrogen demand by the barley. The soil with composted manure had a content of mineral nitrogen similar to soil that had received no manure in August 1991. On land where liquid cattle manure had been applied in 1991, there was more mineral-N present under corn than where composted manure had been applied (Table 20). Under barley the soil contained less nitrate at this June sampling than it did at planting in May, but under corn the content was greater in June than in May except on plots where composted manure was applied.

Table 19. Nitrate content in top 0.6 m of soil at time of planting at Winchester in 1992.

Treatment	Soil Nitrate (kg N ha^{-1})
Control (No manure) - fallow	**86± 11.7**
Control (No manure) - with weeds *	**129± 26.5**
LCM (liquid cattle manure) - fallow	**197± 16.5**
LCM (liquid cattle manure) - with weeds *	**141± 11.4**
Control+ winter wheat	**80 ± 14.7**
LCM+ winter wheat	**107 ± 12.6**
LCM+ oilseed radish (cover crop)	**155 ± 36.9**
LCM+ straw	**120 ± 32.1**
LCM+ straw+ oilseed radish	**134 ± 49.7**
Composted cattle manure	**105 ± 45.7**

*** Plots seeded to barley**

Table 20. Nitrate-N and total mineral N present in soil under corn and barley at Winchester, 29 June 1992.

Crop	No manure applied		Composted manure		Liquid cattle manure	
.	Nitrate (kg N ha^{-1})	Total mineral-N (kg N ha^{-1})	Nitrate (kg N ha^{-1})	Total mineral-N (kg N ha^{-1})	Nitrate (kg N ha^{-1})	Total mineral-N (kg N ha^{-1})
Corn	108 ± 1.4	131 ± 1.4	121 ±29.2	140 ±26.8	166 ±16.1	187 ± 15.9
Barley	40 ±10.0	63 ±16.0			76 ±18.9	98 ±17.6

Soil sampling carried out in late June, corresponding with the time of side-dressing for corn, also allowed values for a pre-side-dress nitrate soil test to be determined. There was little change in the test value for any treatments compared with values for May (Table 21).

Table 21. Soil nitrogen test for corn at the time for side-dressing by experimental treatment. Note treatments where barley was the test crop are not presented

Treatment	Nitrate N-Test result (kg N ha^{-1})
Control (no manure)	107 ± 10.7
LCM (liquid cattle manure)	146 ± 22.7
Control+ winter wheat	100 ± 29.1
LCM+ winter wheat	171 ± 66.4
LCM+ oilseed radish (cover crop)	161 ± 29.8
LCM+ straw	170 ± 47.1
LCM+ straw+ oilseed radish	127 ± 57.4
Composted cattle manure	114 ± 34.2

Soluble Carbon

The nitrate present in soil can be lost by leaching and, if conditions are favourable, by denitrification. One prerequisite for denitrification to occur is a source of carbon that is readily available. There also needs to be anaerobic conditions present, at least at key microsites. The organic carbon soluble in potassium sulphate is considered to be readily available. The soluble carbon in the soil was investigated at the start of the experiment in August 1991, and then at a time in June 1992 when the soil was wet and conditions might favour denitrification (Table 22). It was also measured after harvest of the barley, to identify whether the nitrate in the soil at that time could be denitrified. All values of soluble carbon in the top 0.5m of the soil exceeded 50 mg kg^{-1} (Table 22a,b), and only the two treatments where straw was incorporated showed values less than 50 mg kg^{-1} in the 0.5- 0.9 m subsoil layer (Table 22c).

Table 22a. Soluble carbon and nitrate-N extracted from soil for the different experimental treatments at Winchester. Values for topsoil layer 0 - 0.2 m

	Soluble C (mg kg^{-1})			**NO$_3$ (mg kg^{-1})**		
TREATMENT	**19/08/91**	**30/06/92**	**01/09/92**	**19/08/91**	**30/06/92**	**01/09/92**
Barley						
Control	111± 30.7	127± 47.5	174± 20.7	14± 0.7	5± 0.1	13± 1.7
LCM	129± 12.0	101± 17.4	146± 23.5	15± 2.1	8± 0.2	19± 5.5
Corn						
Control	124±12.5	91± 8.1		14± 3.8	16± 2.4	
LCM	105± 6.2	150± 11.0		11± 0.5	22± 2.6	
Control-winter wheat	112± 7.8	89± 6.4		10± 2.2	21± 1.4	
LCM-winter wheat	104± 2.9	107± 16.9		11± 0.6	25± 6.3	
LCM-Oilseed radish	132± 1.0	105± 11.0		16± 5.2	23± 6.6	
LCM-straw	100± 6.9	80± 21.6		10± 1.8	21± 2.0	
LCM+straw+ Oilseed radish	124± 31.5	92± 3.8		11± 1.8	19± 7.2	
Composted cattle manure	107± 9.4	118± 12.0		13± 5.9	22± 6.3	

Table 22b. Soluble carbon and nitrate-N extracted from soil for the different experimental treatments at Winchester. Values for subsoil layer 0.2-0.5m

	Soluble C (mg kg^{-1})			NO_3 (mg kg^{-1})		
TREATMENT	19/08/91	30/06/92	01/09/92	19/08/91	30/06/92	01/09/92
Barley						
Control	93± 13.9	75± 10.7	110± 9.0	4.± 1.1	4± 1.6	5± 0.6
LCM	102± 14.6	85± 14.6	106± 1.9	6± 2.0	9± 3.0	14± 6.0
Corn						
Control	118± 1.6	72± 5.0		8± 3.3	13.5± 1.3	
LCM	81± 9.7	88± 13.3		3± 0.7	17± 2.9	
Control-winter wheat	88± 5.0	86± 13.3		2± 0.6	9± 1.9	
LCM-winter wheat	84± 0.7	82± 13.2		2± 0.9	21± 8.6	
LCM-Oilseed radish	122± 2.0	91± 14.2		3± 1.1	24± 1.2	
LCM-straw	90± 0.7	65± 19.0		4± 2.4	21± 6.1	
LCM+straw+ Oilseed radish	106± 20.5	82± 3.7		4± 1.2	15± 5.8	
Composted cattle manure	97± 20.7	97± 6.7		4± 2.4	13± 3.1	

Table 22c. Soluble carbon and nitrate-N extracted from soil for the different experimental treatments at Winchester. Values for subsoil layer 0.5 - 0.9m

	Soluble C (mg kg^{-1})			NO_3 (mg kg^{-1})		
TREATMENT	19/08/91	30/06/92	01/09/92	19/08/91	30/06/92	01/09/92
Barley						
Control	55± 10.1	53± 13.8	89± 7.7	0.7± 0.12	2.4± 0.79	1.1±0.37
LCM	58± 3.8	54± 11.1	86± 10.2	0.3± 0.10	4.2±1.01	2.6±0.71
Corn						
Control	-	48± 2.9		1.7±0.55	6.3±1.83	
LCM	65± 9.1	73± 16.5		0.4± 0.14	6.51.49	
Control-winter wheat	45± 2.3	61± 8.7		0.5± 0.04	3.2± 0.75	
LCM-winter wheat	69±6.6	68± 13.0		0.6± 0.24	5.6± 1.65	
LCM-Oilseed radish	77± 3.1	62± 7.8		0.3± 0.04	14.3± 8.13	
LCM-straw	73± 5.2	35± 13.3		0.6± 0.21	9.8± 4.31	
LCM+straw+ Oilseed radish	69± 12.5	46± 5.2		0.8± 0.18	6.5± 1.69	
Composted cattle manure	69± 26.8	65± 10.8		0.4± 0.18	4.4± 0.82	

Nitrate leaching

Soil solution collection from samplers inserted to 0.8m only produced occasional samples until June 1992. The results for the barley plots without manure (Control-barley treatment) showed a peak in nitrate concentration in early June (Fig. 13). The maximum concentration observed was 17 mg N L^{-1}. In most plots the main peak was observed on 9 June, with a second event on June 24 giving more samples. The flush of samples had ended on all these plots by the end of the month. One plot only produced a sample at the end of July. Each of these corresponded with significant rainfall events (Fig. 13). A similar pattern was observed on the manured barley plots (LCM-barley treatment), although fewer samples were collected (Fig. 14). This probably reflected the better early growth of the crop on this treatment (see page 40). The maximum concentration recorded under this treatment was 12 mg N L^{-1}.

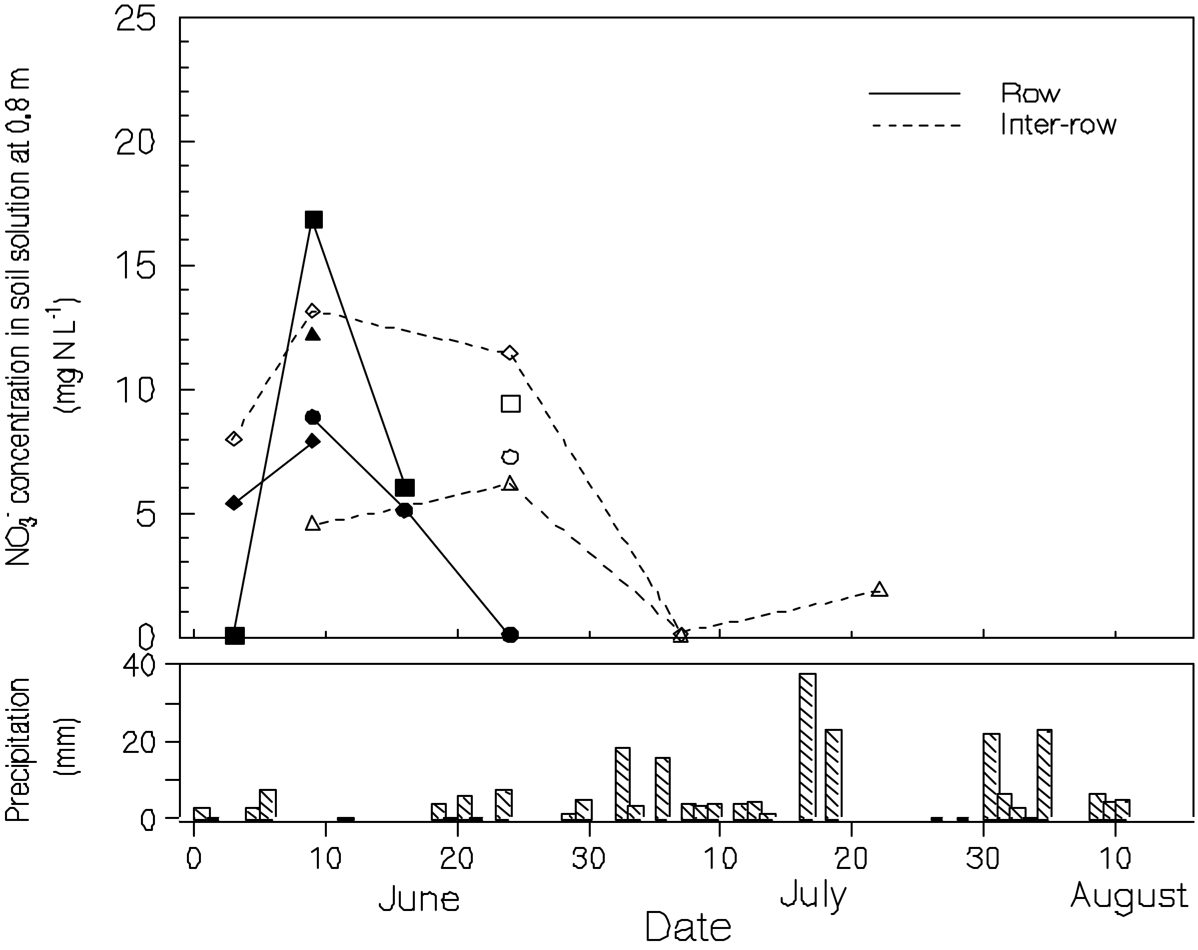

Figure 13. Solution nitrate-N concentrations for Control-barley plots at Winchester in 1992, and summer precipitation. Markers indicate data for the four replicate plots.

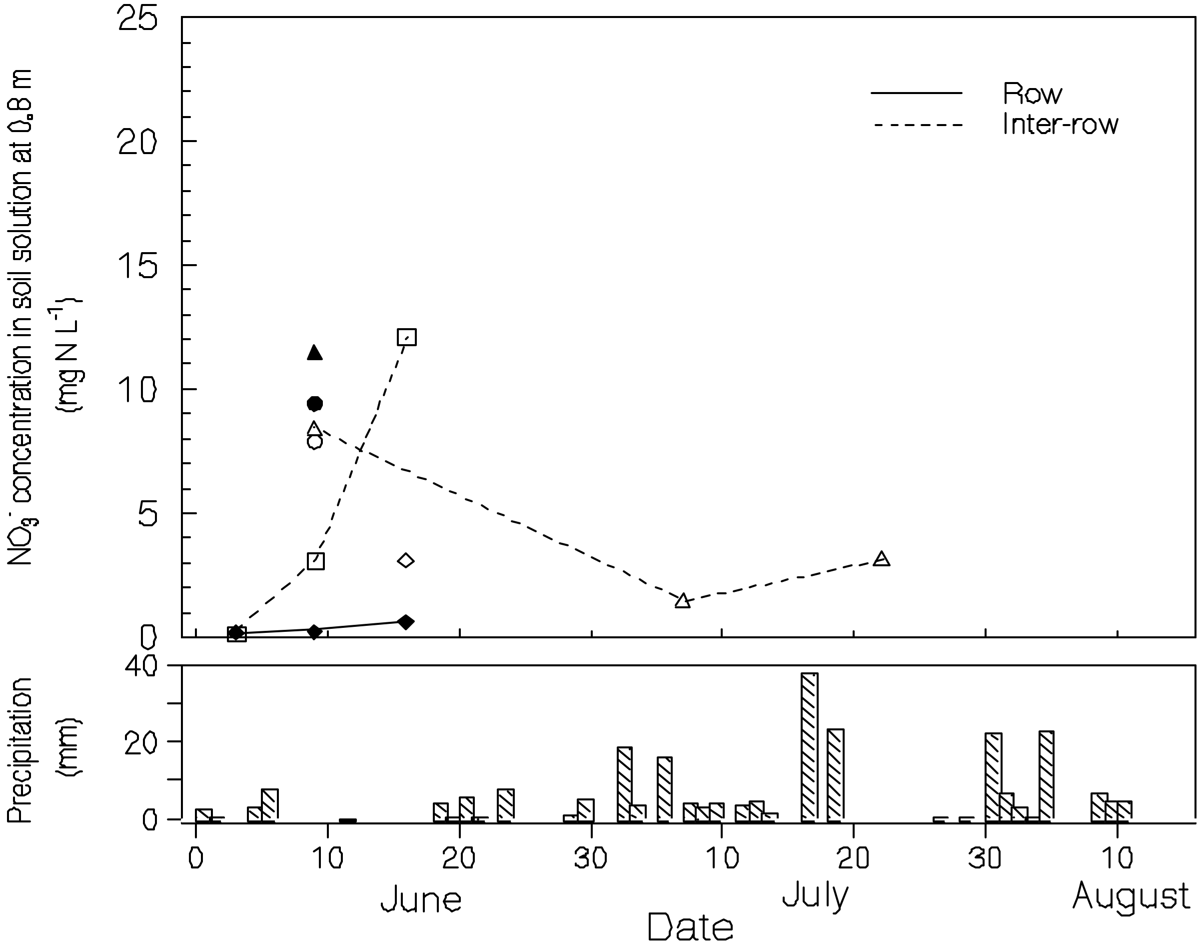

Figure 14. Solution nitrate-N concentrations for LCM-barley plots at Winchester in 1992, and summer precipitation. Markers indicate data for the four replicate plots.

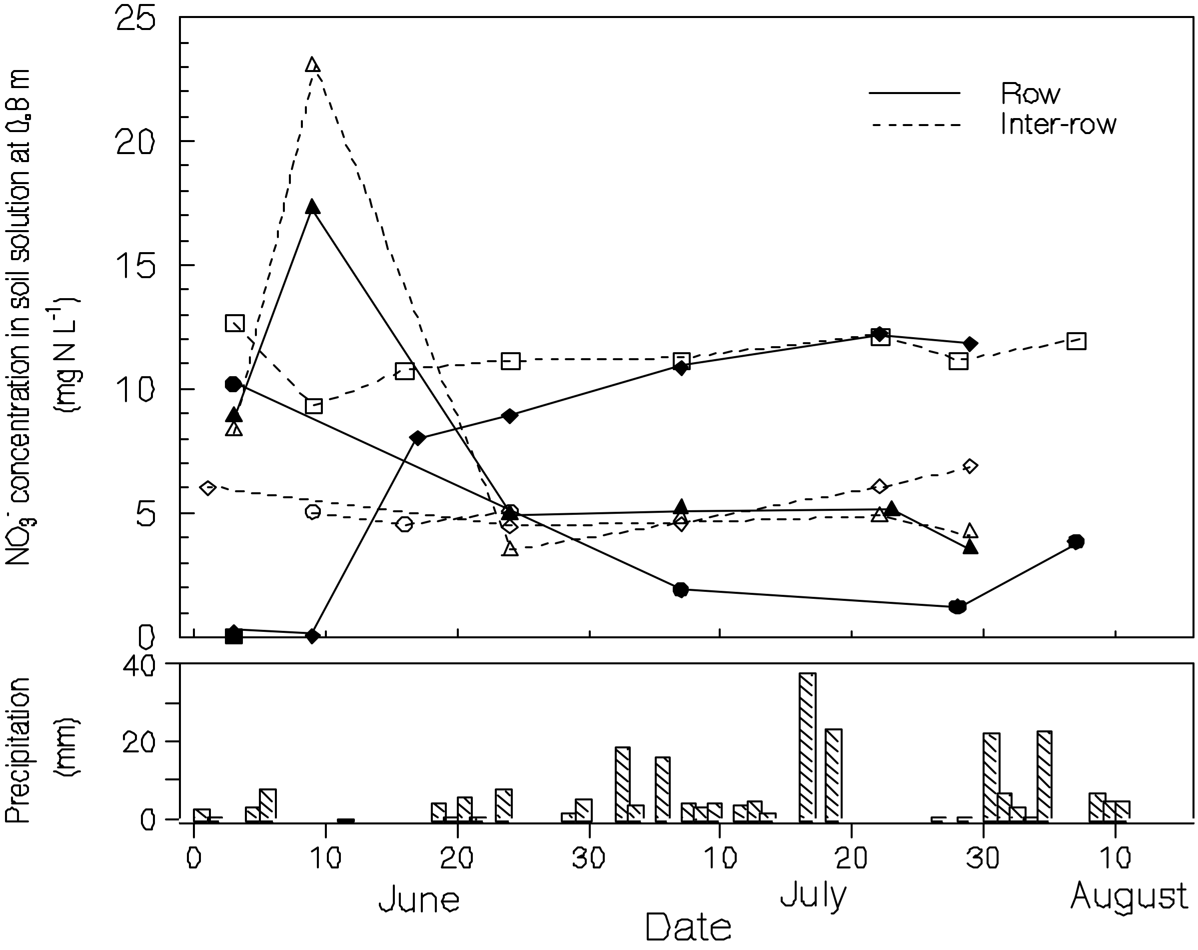

Figure 15. Solution nitrate-N concentrations for Control plots at Winchester in 1992, and summer precipitation. Markers indicate data for the four replicate plots.

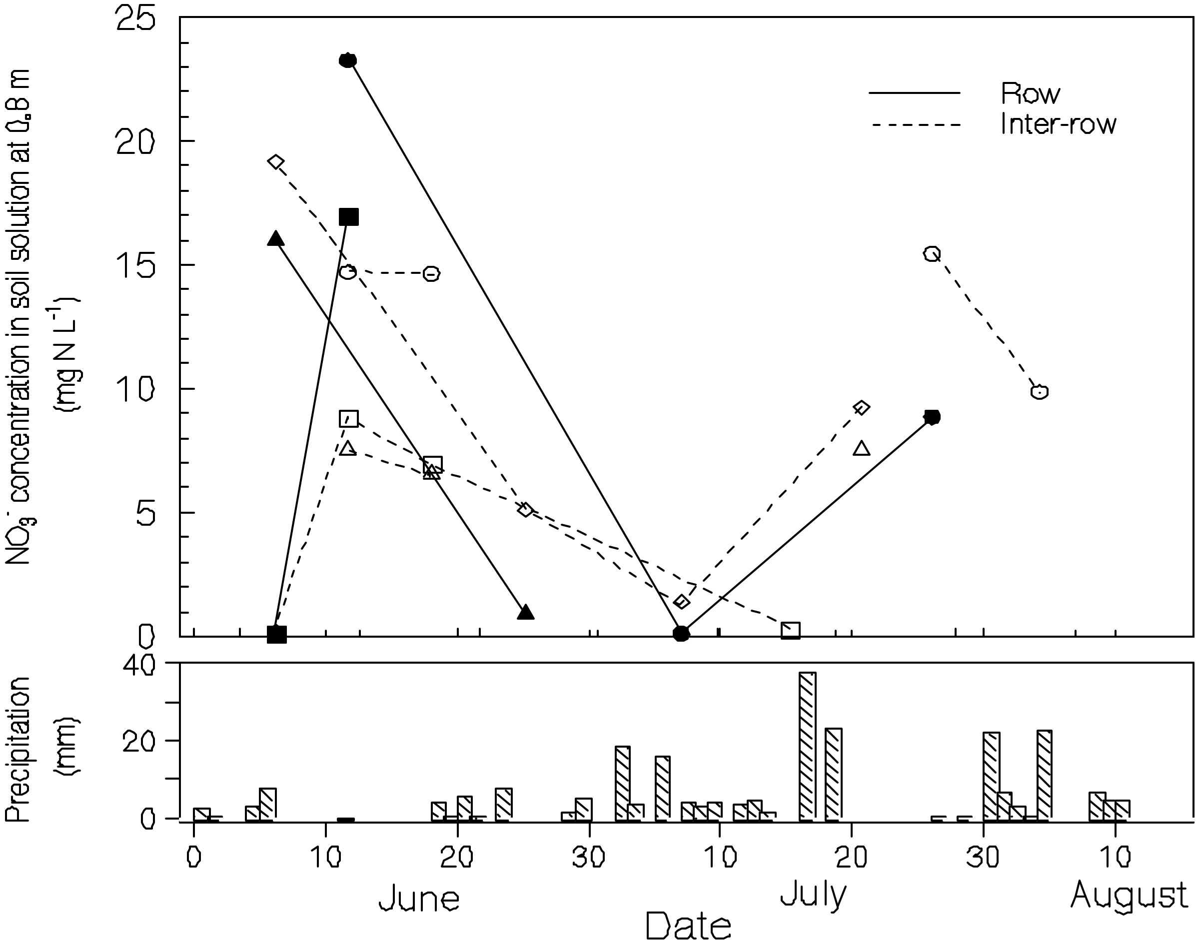

Figure 16. Solution nitrate-N concentrations for LCM plots at Winchester in 1992, and summer precipitation. Markers indicate data for the four replicate plots.

The results for the treatments under corn showed a major peak in concentration on 9 June, 1992. However some plots continued to give samples until early August. This was clearly shown for treatment 1, without manure, (Fig. 15). The maximum concentration recorded under this treatment was 23 mg N L^{-1}. In the comparable manured plots (LCM treatment), there was a clear second flush of samples at the end of July (Fig. 16). The maximum concentration recorded under this treatment was also 23 mg N L^{-1}.

The maximum possible leaching loss was calculated by assuming that all the rainfall, which fell during the period when samples were collected, actually drained through the profile. Losses could not have exceeded 21 kg N ha^{-1} under any treatment. The smallest predicted loss, 7.3 kg N ha^{-1}, was from the manured barley (LCM-barley), and the manured corn (LCM). The barley treatment without manure (Control-barley) could have lost up to 10 kg N ha^{-1}, the corn treatment without manure (Control) could have lost about 14 kg N ha^{-1}. The composted cattle manure treatment could have lost 17 kg N ha^{-1}. Treatments where oilseed radish was grown as a cover crop could have lost up to 20 kg N ha^{-1}, but about 17 kg N ha^{-1} if straw was also incorporated. The greatest loss predicted was 21 kg N ha^{-1} from the straw treatment alone.

Crops

Barley

Early growth of spring-sown barley was greater on plots that had been injected with liquid cattle manure in the fall than in the Control-barley treatment (Fig. 17). This effect lasted until mid-July when intense rain caused lodging on the manured plots, whereas damage was much less severe on the Control plots.

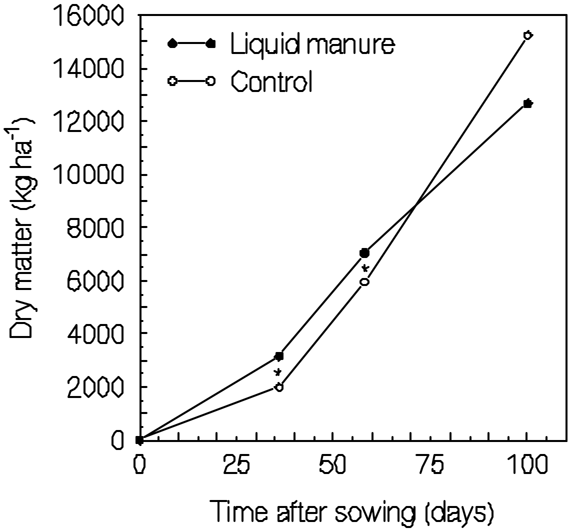

Figure 17. Effect of fall incorporated liquid cattle manure in 1991 on the growth of barley in spring 1992 at Winchester (* indicates different at p # 0.05).

At harvest there was no significant effect of the manure application on crop dry matter (Fig. 17), but grain yield determined by hand-harvest showed a small but not statistically significant increase of 0.5 t ha^{-1} (Table 23). No significant differences between treatments were observed in combine yield at the 5% level..

Corn

The harvest of the corn was delayed until 10 November 1992 because of slow maturation. In June plant dry weight was greater on plots receiving liquid manure than on the Control treatment. By harvest there were small increases in growth of corn with liquid or composted cattle manure, but this was not observed on plots where winter wheat had been grown in the fall after injecting liquid manure (Figs. 18 and 19).

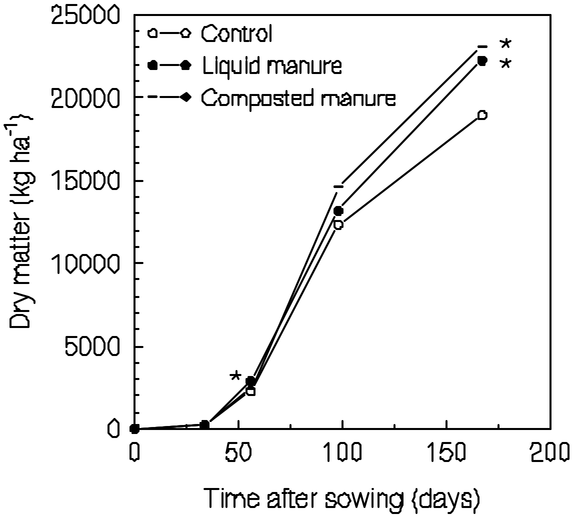

Figure 18. Effect of fall injection of liquid manure or incorporation of composted manure in 1991 on the growth of corn in 1992 at Winchester (* indicates different from Control treatment at p # 0.05).

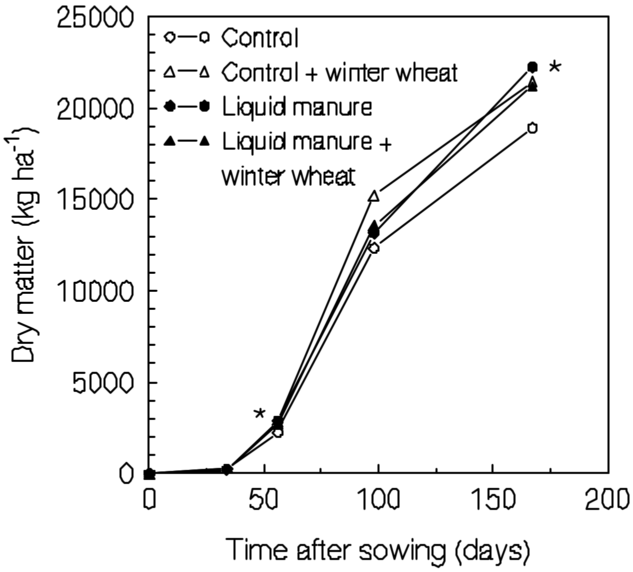

Figure 19. Effect of fall injection of liquid cattle manure in 1991 on the growth of corn in 1992 at Winchester, with and without winter wheat grown as a fall catch crop (* indicates different from Control treatment at p # 0.05).

The presence of oilseed radish or winter wheat over the fall did not have any effect on the growth of the following corn crop (Fig. 20). Nor was there any effect of the incorporation of straw in the fall (Fig. 21). Using straw or oilseed radish, singly or in combination, to immobilize nitrogen in the fall had no effect on corn growth (Fig.22).

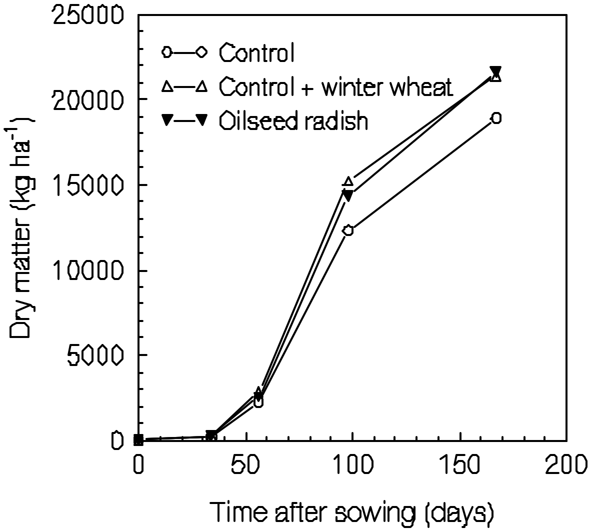

Figure 20. Effect of growing cover crops in the fall of 1991 on the growth of corn in 1992 at Winchester. (No treatment differences significant at p# 0.05).

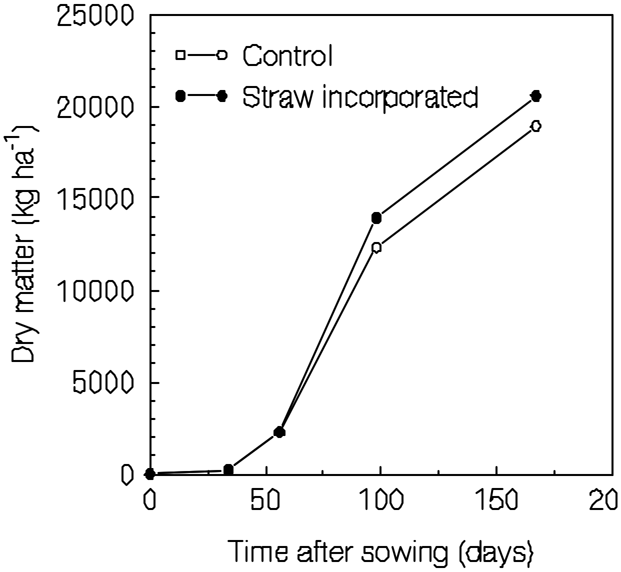

Figure 21. Effect of incorporating straw to immobilize nitrogen from liquid cattle manure applied in the fall of 1991 on the growth of corn at Winchester in 1992. (No treatment differences significant at p# 0.05).

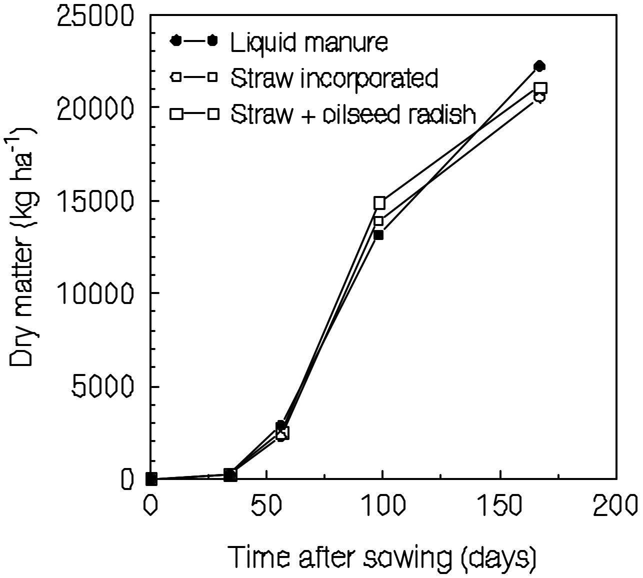

Figure 22. Effects of using straw and cover crops to immobilize nitrogen from liquid cattle manure applied in the fall of 1991 on the growth of corn at Winchester in 1992. (No treatment differences significant at p# 0.05).

Based on the results from the combine harvesting, there was no effect of the application of liquid cattle manure or composted manure on the grain yield of corn (Table 23). Nor was there any effect of any of the fall treatments to immobilize nitrogen on grain yield.

The results from hand harvesting showed a significant yield increase above the controls for all manure treatments except where straw had been incorporated or oilseed radish grown as a fall cover crop (Table 23).

Table 23. Hand-harvest and combine yields at Winchester in 1992

Treatment	Grain Yield ($t\ ha^{-1}$)	
	Hand-harvest	Combine
Barley		
Control (no manure)	4.0 ±0.29	4.6 ±0.50
LCM (liquid cattle manure)	4.5 ±0.26	4.8 ±0.34
Corn		
Control (no manure)	9.0 ±0.53	7.6±0.20
LCM (liquid cattle manure)	10.8 ±0.71	7.8±0.30
Control+ winter wheat	9.2 ±1.14	7.9±0.49
LCM+ winter wheat	10.5 ±0.43	8.0±0.37
LCM+ oilseed radish	9.6 ±0.38	7.7±0.20
LCM+ straw	8.8 ±0.26	7.8±0.51
LCM+ straw+ oilseed radish	9.7 ±0.11	7.5±0.40
Composted cattle manure	10.3 ±0.65	7.5±0.20

Fate of manure nitrogen

Between November 1991 and May 1992, the loss of ^{15}N-labelled soil nitrogen averaged about 25% of that applied in August 1991 (Tables 15 and 24). This was rather more than the change in mineral nitrogen over the same period, suggesting that re-mineralization and nitrification of ^{15}N was occurring before samples were collected in May (Tables 15 and 24). In May most of the ^{15}N in the mineral fraction in the soil was in the nitrate form, and this was consistent with the manure being the source of a significant component of the mineral fraction in the soil (Table 24).

Table 24. Distribution of ^{15}N in soil at sowing, May 1992 at Winchester.

May 14.1992 Treatment	^{15}N in organic form (% of applied)	^{15}N in NO_3 form (% of applied)	^{15}N in NH_4^+ form (% of applied)
Control - barley	50.1	11.6 ± 3.59	0.8 ± 0.04
LCM (liquid cattle manure) - barley	63.6	7.2 ± 2.68	0.8 ± 0.26
Control - corn	60.9	9.8 ± 6.46	1.6 ± 0.90
LCM (liquid cattle manure) - corn	37.2	5.4 ± 0.34	0.4 ± 0.01
Control + winter wheat	36.3	3.9 ± 0.33	0.5 ± 0.06
LCM + winter wheat	50.6	2.8 ± 1.06	0.3 ± 0.11
LCM + Oilseed radish	51.5	7.2 ± 1.55	0.2 ± 0.02
LCM + Straw	69.1	6.9 ± 0.69	0.5 ± 0.15
LCM + Straw + Oilseed radish	64.4	3.6 ± 0.50	0.4 ± 0.07
Composted cattle manure	71.6	6.0 ± 3.21	0.8 ± 0.64

The ^{15}N enrichment of the mineral fraction of the soil from Control treatments indicated that most (89.6± 5.92%) of the nitrate present at planting had come from mineralization of soil organic matter and the below-ground residues of the alfalfa. The amounts of mineral-N derived directly from the mineral fraction of the liquid cattle manure was less than 20 kg N ha^{-1}, and only about 9 kg N ha^{-1} in the treatment with straw incorporated and where oilseed radish had been grown as a cover crop (Table 25). Where composted manure had been applied in the fall of 1991, there was 1.2 kg N ha^{-1} of mineral nitrogen in the soil that was derived from the mineral fraction of the manure. The nitrogen from the mineral fraction of the liquid manure represented between 6 and 14% of the nitrate in the soil at planting, but the comparable value for composted cattle manure was only 1% (Table 25).

Table 25. Mineral-N in soil at planting in May 1992 at Winchester that was derived from mineral-N applied in the manure, and the proportion of the soil mineral-N which came from that source.

May 14.1992 Treatment	Mineral-N in soil derived from that applied in the manure (kg N ha^{-1})	Contribution of mineral-N applied in the manure to total in soil (% of total in soil)
LCM - barley	17.3 ± 6.36	12.3 ± 4.51
LCM - corn	12.6 ± 0.76	6.4 ± 0.38
LCM + winter wheat	6.7 ± 2.53	6.3 ± 2.37
LCM + Oilseed radish	16.0 ± 3.40	10.3 ± 2.19
LCM + Straw	16.0 ± 1.82	13.3 ± 1.51
LCM + Straw + Oilseed radish	8.7 ± 1.23	6.5 ± 0.92
Composted cattle manure	1.2 ± 0.65	1.0 ± 0.62

The amount of ^{15}N in the mineral fraction of soil nitrogen was much less in July 1992 compared with mid-May (Tables 24 and 26). By July the labelled mineral nitrogen in soil under barley had declined by more than 80% over the 7 week period. Under corn, the ^{15}N in the nitrate pool decreased by about 20 per cent over the same period, concomitant with the greater uptake by barley compared with corn. Only a small reduction occurred where cover crops had been grown, but where straw had been incorporated the ^{15}N in the nitrate pool increased (Tables 24 and 26). As little of the mineral nitrogen in the soil of the Control treatment at this time was labelled with ^{15}N, much of the mineralized-N must have been derived from organic matter that had not become labelled during immobilization processes. This suggests that the alfalfa residues were the likely source.

In the barley plots, the uptake of ^{15}N (Table 27) was greater than the reduction in the labelled mineral nitrogen, particularly on the LCM plots (Tables 24 & 26). This indicated that the remineralising of labelled nitrogen was the dominant process over this period. Under corn there was no clear pattern in the difference between the change in mineral-N content of the soil and uptake by the crop.

Table 26. Distribution of ^{15}N in soil, July 1992 at Winchester.

July 01.1992 Treatment	^{15}N in organic form (% of applied)	^{15}N in NO_3 form (% of applied)	^{15}N in NH_4^+ form (% of applied)
Barley			
Control	54.2	1.9 ± 0.64	1.3 ± 0.94
LCM (liquid cattle manure)	65.6	1.3 ± 0.78	0.9 ± 0.05
Corn			
Control	61.6	3.4 ± 0.08	1.2 ± 0.30
LCM (liquid cattle manure)	33.3	4.3 ± 3.72	0.8 ± 0.50
Control+winter wheat	29.8	3.7 ± 2.12	1.0 ± 0.54
LCM+winter wheat	45.6	1.3 ± 1.07	0.6 ± 0.44
LCM+Oilseed radish	43.2	7.0 ± 6.87	1.0 ± 0.52
LCM+Straw	65.1	9.5 ± 2.37	1.0 ± 0.33
LCM+Straw+Oilseed radish	63.0	4.3 ± 1.90	0.7 ± 0.01
Composted cattle manure	69.7	3.7 ± 3.61	0.6 ± 0.47

Table 27. Uptake of ^{15}N by barley from sowing to 2 July 1992 at Winchester.

Treatment	^{15}N in Crop (% of applied)	Contribution from mineral N in soil, August 1991 (%)	Contribution from mineral N in manure, August 1991 (%)
Control + barley	13.4 ± 0.32	8.1	-
LCM + barley	14.2 ± 0.22	3.5	25

Nitrate did leach during June (see pages 35-40), so it is possible that some of the labelled nitrate was lost by this process. Crop uptake was less than the average reduction in the mineral-^{15}N content of the soil in the Control, the LCM + winter wheat, and the composted cattle manure treatments (Tables 24, 26, 27, and 28). Assuming that changes in organic-N were due to mineralization and immobilization, and that the balance of the ^{15}N-labelled fraction of the soil-N was lost by leaching, then 3kg N ha^{-1} could have been leached from the Control plots, 6kg N ha^{-1} from LCM plots, 2kg N ha^{-1} from Control + winter wheat plots, 13kg N ha^{-1} from LCM + winter wheat plots, 17kg N ha^{-1} from LCM + Oilseed radish plots, and 0.7kg N ha^{-1} from composted cattle manure plots. The ^{15}N-labelling indicated that straw incorporation had prevented leaching loss of N from the mineral fraction of the manure. These results were consistent with those obtained by monitoring the concentration of nitrate-N in water extracted with the porous-cup samplers in that both approaches indicated a loss of N by leaching from Control (with and without winter wheat), LCM (with and without winter wheat), LCM- Oilseed Radish, and CCM treatments. However, results from the porous-cup samplers indicated that mineral-N was lost from plots under barley or plots in which straw had been incorporated. That the prediction of N-leaching based on the ^{15}N-labelling, was generally less than that based on data from the porous-cup samplers, suggested that mineralization of unlabelled organic matter could have been a significant source of the N leached. Also, it was recognized that the assumption used in calculating the loss from the porous-cup sampler data, namely that all the incident rainfall contributed to leaching loss, was unlikely.

Table 28. Uptake of ^{15}N by corn from sowing to 2 July 1992 at Winchester.

Treatment	^{15}N in Crop (% of applied)	Contribution from mineral N in soil, August 1991 (%)	Contribution from mineral-N in manure, August 1991 (%)
Control	1.7 ± 0.03	2.4	-
LCM (liquid cattle manure)	2.0 ± 0.02	1.7	13.3
Control + winter wheat	1.0 ± 0.02	1.6	-
LCM + winter wheat	0.3 ± 0.01	0.4	2.8
*LCM + Oilseed radish	0.7 ± 0.01	0.9	4.1
LCM + Straw	1.2 ± 0.06	1.6	12.3
*LCM + Straw + Oilseed radish	0.5 ± 0.04	1.0	7.5
Composted cattle manure	0.3 ± 0.04	0.2	0.2

* NB. Tops of oilseed radish were replaced in November 1991 by un-labelled material (see text), so values may be underestimated.

Nitrogen uptake by the spring-sown crops, and the source of that N, was affected by treatments imposed in the previous fall. Spring barley on the manured treatment contained more N than did un-manured treatment until harvest (Fig. 23). The greater loss of N taking place between heading and harvest from the manured treatment may have been because lodging made the crop more difficult to harvest.

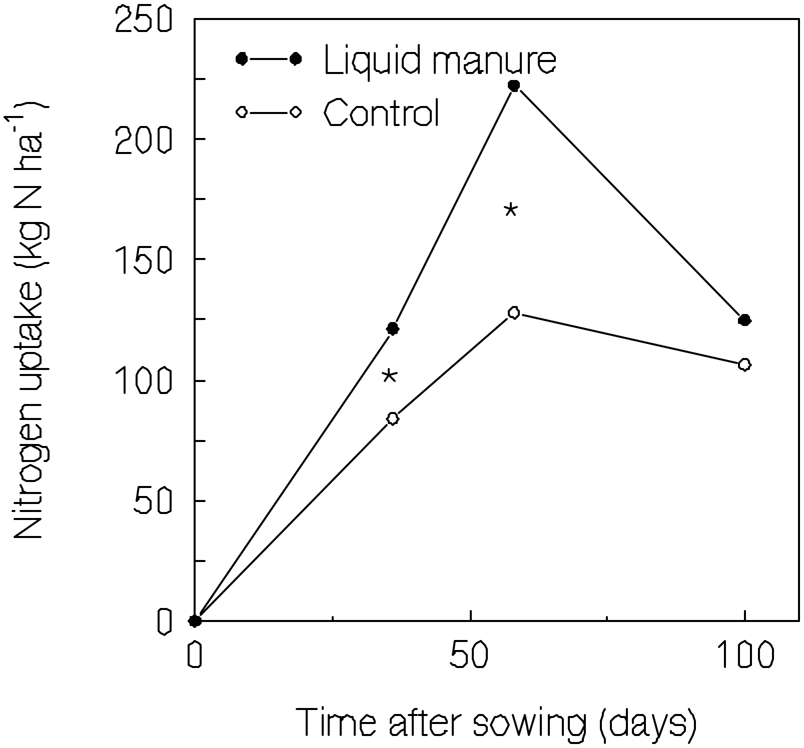

Figure 23. Effect of the injection of liquid cattle manure in the fall of 1991 on the uptake of nitrogen by spring barley grown at Winchester in 1992 (* indicates different at p # 0.05). The crop was sown on 12 May 1992.

The total ^{15}N recovered in the manured crop declined by 14% between 8 July (57 days after sowing) and harvest, whereas that of the control increased by 46% (Fig. 24), supporting the view that lodging had caused considerable leaf loss in the LCM-barley treatment (Fig. 23). The mineral N in the soil in August 1991 comprised 8% of the crop nitrogen on the Control-barley treatment at harvest, but only 3.5% on the manured plot (Table 27). Thus, most of the nitrogen came from mineralization of unlabelled organic matter. It is also notable that the ^{15}N enrichment of the manured crop declined by about 20% from 1.75± 0.017 atom per cent in early July to 1.29± 0.012 atom per cent at the harvest of the crop, whereas on the Control-barley treatment there was a reduction of about 10% from 2.65± 0.031 to 2.32± 0.004 atom per cent. The manured crop apparently obtained more nitrogen from mineralization of unlabelled organic matter over this period than did the control crop.

The recovery of ^{15}N in the corn crop by July showed that more had been taken up on the LCM treatment than on the Control treatment (Table 28). Nitrogen in the soil at the time manure was applied in 1991 comprised a greater percentage of the crop content on the Control treatment (2.4%) than where manure was applied (1.7%). Where cover crops had been grown over winter (winter wheat or oilseed radish), the contribution was only about 0.6%, but where straw was added to the soil the comparable value was 1.3% (Table 28).

At harvest in November 1992 the ^{15}N tracing showed that only 1% of the mineral nitrogen applied with the LCM passed through the cover crop into the corn (Table 29). However, about 16% of the nitrogen in the crop was derived from that present in the oilseed radish shoots in November 1991.

Table 29. Uptake by corn of ^{15}N derived from the shoot residues of oilseed radish in comparison with that derived from labelled mineral nitrogen in liquid cattle manure. Plots also had straw incorporated. Corn crop was grown at Winchester in 1992.

	Crop			
	Oilseed radish		Corn	
	^{15}N Uptake		^{15}N Uptake	
Source of ^{15}N	% of applied	N from source (% of total)	% of applied	N from source (% of total)
Manure	6.0 ± 0.05	33.4 ± 0.19	10.7 ± 2.35	11.3 ± 0.30
Shoots of oilseed radish			1.0 ± 0.22	16.1 ± 3.69

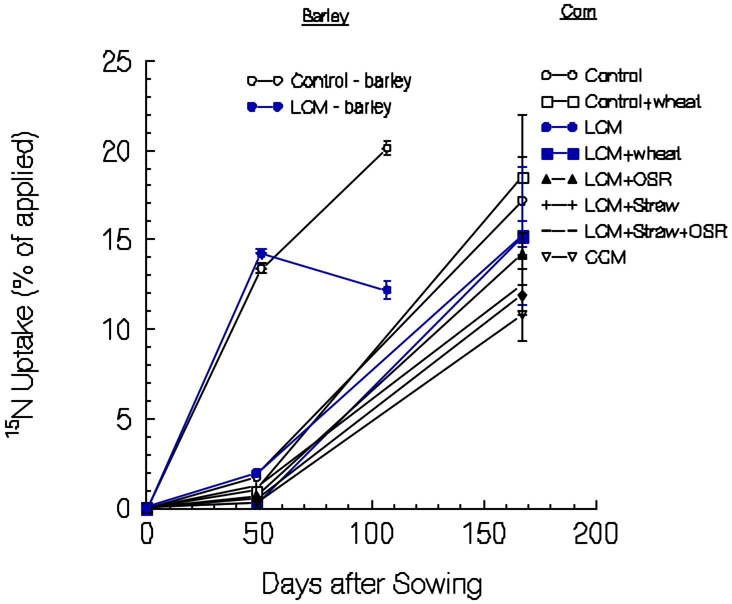

Figure 24. Uptake of ^{15}N into crops at Winchester in 1992. The results for crops growing after oilseed radish (OSR) were adjusted to include that recovered by corn growing where the cover crop tops had been applied.

Table 30. Uptake of ^{15}N by crops from sowing to harvest at Winchester in 1992.

Treatment	^{15}N in plants (% of applied)	N contribution from mineral-N in soil, August 1991 (%)	N contribution from mineral-N in manure, August 1991 (%)
Barley			
Control	20.1±0.43	7.1± 0.21	
LCM	12.1±0.25	2.7± 0.08	18.6± 0.53
Corn			
Control	17.2±1.45	3.3± 0.19	
LCM	15.3±0.73	2.0± 0.19	14.8± 0.82
Control + winter wheat	18.5± 3.53	4.0± 0.32	
LCM + winter wheat	15.2± 2.1	2.3± 0.30	16.7± 2.24
LCM + Oilseed radish	15.7± 0.85	3.1± 0.04	15.5± 0.63
LCM + Straw	12.4± 1.64	1.7± 0.21	12.5± 1.68
LCM + Straw + Oilseed radish	12.8± 1.20	3.1± 0.06	13.7± 0.79
Composted cattle manure	10.8± 1.89	1.4± 0.09	1.0± 0.07

This recovery of nitrogen from the cover crop was added to the uptake measured in plants grown where the ^{15}N-labelled oilseed radish tops had been replaced by unlabelled material so that total uptake could be calculated.Percentage recovery of ^{15}N was significantly greater from un-manured crops than from crops where liquid ($p< 0.01$) or composted ($p<0.05$) cattle manure had been applied (Figure 24, and Table 30), although the recovery indicated that only about 3% of nitrogen in the crop was derived from mineral nitrogen present in the soil in August 1991. Adding straw also reduced the recovery of ^{15}N ($p<0.05$) compared with plots where no straw had been incorporated (Table 30). The recovery of mineral N present in the soil in August 1991 by the Control treatment for corn was about half that for barley, supporting the view that after the barley matured there was some mineralization of organic residues from sources that had not been labelled by the ^{15}N during its immobilization in the fall. The LCM and LCM-barley treatments recovered less of the mineral-N in the soil in August 1991 than did the Control and Control-barley treatment, indicating that some organic-N in the manure had also mineralized (Table 30). The smallest recoveries of ^{15}N were from crops on the LCM-straw and CCM treatments. Only 2% or less of the mineral-N in the soil at the time the manure was applied on plots receiving manure was recovered in the corn crops, except where cover crops were grown.

Composted cattle manure did not result in any significant increase in total nitrogen uptake over the un-manured control (Fig. 25). The amount of nitrogen derived from the mineral nitrogen in the composted manure, as indicated by the ^{15}N recovery, was only 1% (Table 30). Under that treatment, a similar contribution was obtained from the mineral nitrogen in the soil at the time the composted manure was applied. A winter cover crop of Oilseed radish increased the contribution in the crop of the mineral nitrogen present in the soil in August 1991 from 2% to 3.1%, but the presence of straw reduced the proportion to 1.7% (Table 30). However, the cover crop only increased the amount of nitrogen in the crop at harvest relative to crops relying on the nitrogen from the alfalfa residues (Figs. 26 and 27).

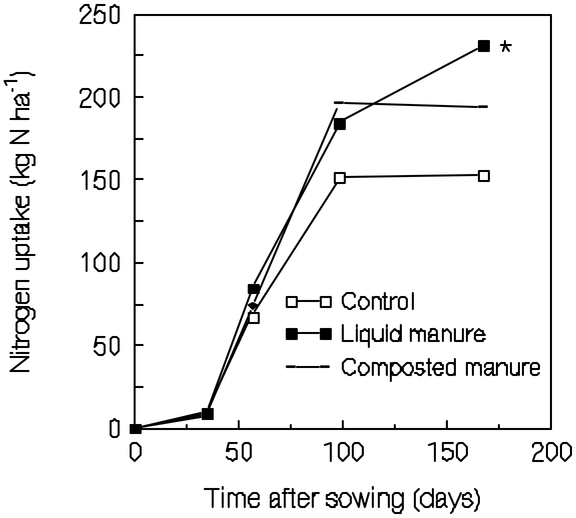

Figure 25. Uptake of nitrogen by corn from land where liquid cattle manure or composted cattle manure was applied in fall 1991. Corn crop sown 14 May 1992 at Winchester (* indicates different from control treatment at p # 0.05).

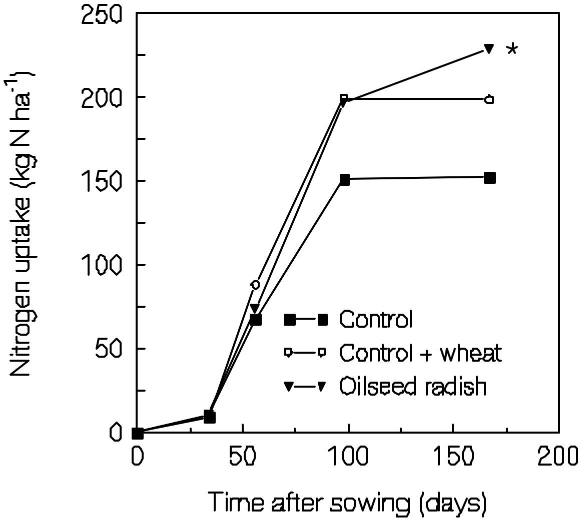

Figure 26. Uptake of nitrogen from land with and without cover crops grown in the fall of 1991 by corn sown 14 May 1992 at Winchester (* indicates different from control treatment at p # 0.05).

Results for total uptake of nitrogen on the main plots suggested that there was no difference between the straw treatment and the treatment with straw and oilseed radish as the winter cover crop (Fig. 27), and this was consistent with the results from the microplots where the ^{15}N-tracer was applied (Fig. 24). Thus despite the release of ^{15}N from the cover crop, this did not result in more of the mineral nitrogen that was present in the manure at the time of application, being taken up by the corn crop. Although straw increased the total nitrogen in the crop compared with that in the crop receiving no liquid cattle manure (Fig. 28), a smaller proportion of the ^{15}N applied in the previous fall was taken up by the crop (Fig. 24). Where the oilseed radish had been grown as a cover crop, the presence of straw reduced the proportion of nitrogen in the crop derived from the mineral nitrogen in the manure.

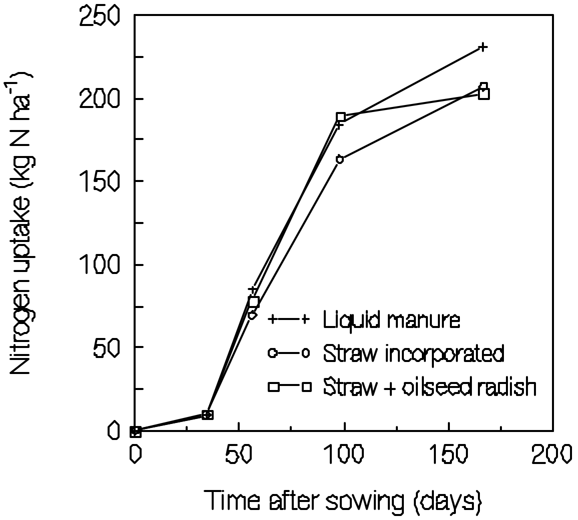

Figure 27. Effects on uptake of nitrogen by corn of using straw and cover crops to immobilize nutrients from liquid cattle manure applied in the fall of 1991. The corn crop was sown 14 May 1992 at Winchester. Treatment differences are not significant at p#0.05.

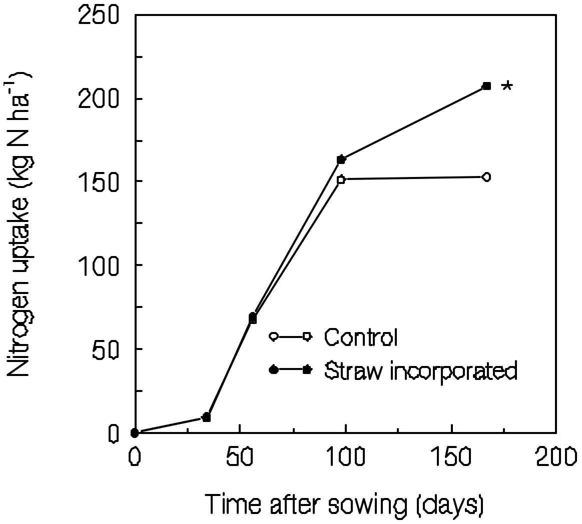

Figure 28. Uptake of nitrogen by corn from soil where straw was incorporated in the fall of 1991 to immobilize nutrients from liquid cattle manure. The corn crop was sown 14 May 1992 at Winchester (* indicates different from Control treatment at p # 0.05).

The ^{15}N taken up by the winter wheat in the previous fall did not result in significantly more being present in the corn crop, either where liquid manure had been applied or where it had not. Similarly, the total uptake of nitrogen on the main plots was not significantly affected by growing winter wheat in the previous fall, whether or not manure had been applied (Fig. 29).

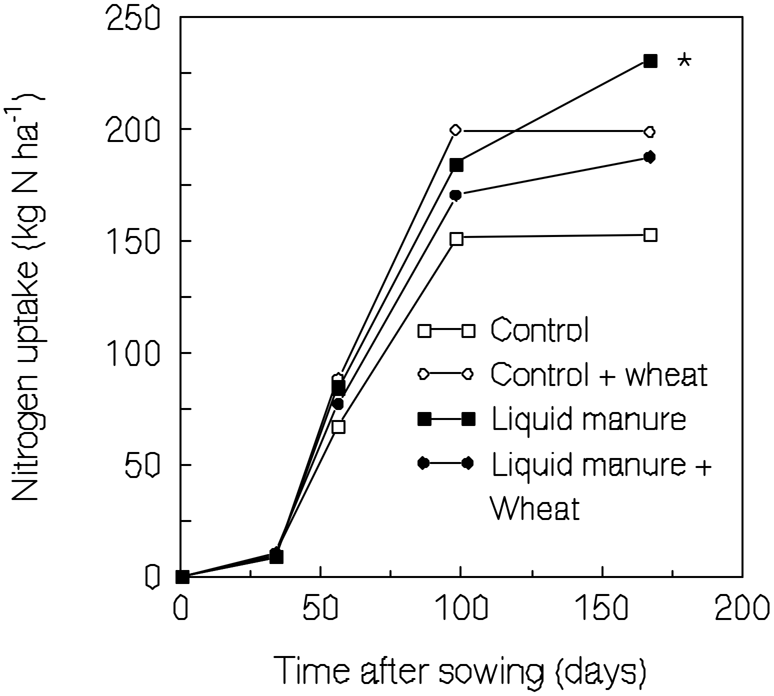

Figure 29. Uptake of nitrogen by corn grown on land with or without liquid cattle manure applied in fall 1991, and with or without growing winter wheat as a fall catch crop. The corn crop was sown 14 May 1992 at Winchester (* Significant difference from Control treatment at $p = 0.05$; no other treatment comparisons are significantly different at $p = 0.05$).

Fall 1992

Soil

The soil was sampled separately at the time of harvest for the barley and corn crops. After barley there was nearly twice as much mineral nitrogen in plots that had received liquid manure in 1991 as in plots left un-manured (Table 31). Between 60% and 80% of this mineral nitrogen was present in the mobile nitrate form. The un-manured plots still contained about 90 kg of mineral nitrogen per hectare, similar to the value found in all un-manured plots following the ploughing of the alfalfa hay the year before.

On average there was less than 60 kg N ha^{-1} mineral nitrogen in un-manured plots after the harvest of corn. Plots receiving liquid manure in 1991 contained about 90 kg N ha^{-1}, as did the plots receiving composted cattle manure. Nitrate comprised about 80% of the total mineral nitrogen in the manured treatment soils, but closer to 60% in the un-manured plots.

Table 31. Soil mineral nitrogen at harvest of the crops at Winchester, 1992.

Treatment	Mineral Nitrogen (kg N ha^{-1})	
	Nitrate	Total
Barley		
Control - barley (no manure)	56.4 ± 6.51	93.2±16.16
LCM - barley (liquid cattle manure)	132.6 ± 23.36	162.0±26.02
Corn		
Control (no manure)	35.3 ± 4.82	55.1± 5.75
LCM (liquid cattle manure)	73.2 ± 10.02	89.2±10.64
Control + winter wheat	40.6 ± 19.18	60.3± 8.75
LCM+winter wheat	71.0 ± 12.0	90.8±12.69
LCM+Oilseed radish	82.7 ± 11.55	97.6±14.36
LCM+ straw	90.3 ± 27.43	108.7±21.17
LCM+ straw+Oilseed radish	67.8 ± 19.07	87.4±21.24
CCM (composted cattle manure)	65.9 ± 36.55	84.5±35.08

Crops

The treatments where spring barley was grown in 1992 were sown with winter wheat on 17 September 1992 to act as a fall catch crop. Growth was significantly greater on the treatment where liquid cattle manure had been injected in fall 1991, than on plots where no additional nitrogen had been applied (Table 32). The nitrogen in the plant represented only about 14% of the soil mineral nitrogen content at the time the crop was sown.

Table 32. Growth and nitrogen uptake into the shoots of wheat plants from emergence in September to 19 November 1992 at Winchester.

	Control	Liquid manure
Dry matter produced (kg ha^{-1})	362 ± 26.8	503 ± 47.2
Nitrogen in shoots (kg N ha^{-1})	13.3 ± 1.48	21.3 ± 1.83

Fate of manure nitrogen

Table 33. Distribution of ^{15}N in soil, November 1992 at Winchester.

NOV 11/92	^{15}N in organic form (% of applied)	^{15}N in NO_3 form (% of applied)	^{15}N in NH_4^+ form (% of applied)
Treatment			
Barley			
Control (winter wheat 1992-3)	41.3	1.3 ± 0.20	0.7 ± 0.14
LCM (winter wheat 1992-3)	58.5	1.0 ± 0.22	0.6 ± 0.32
Corn			
Control	51.5	0.4 ± 0.30	1.1 ± 0.84
LCM	30.1	0.2 ± 0.04	0.4 ± 0.08
Control +winter wheat	21.9	0.4 ± 0.35	0.6 ± 0.46
LCM +winter wheat	34.6	0.2 ± 0.06	0.5 ± 0.12
LCM +Oilseed radish	35.8	0.7 ± 0.31	0.6 ± 0.21
LCM Straw	70.0	1.0 ± 0.75	0.7 ± 0.65
LCM +Straw +Oilseed radish	66.0	0.8 ± 0.02	0.8 ± 0.03
Composted cattle manure	64.2	0.1 ± 0.07	1.1 ± 0.57

Very little of the mineral nitrogen was labelled with ^{15}N (Table 33), although ^{15}N was present in both the ammoniacal and nitrate fractions. On the Barley plots (planted to winter wheat in September) there was an indication of more ^{15}N in the nitrate than in the ammonium fraction. Under all treatments there was less ^{15}N in mineral form than in July (Table 26), reflecting the uptake by the crops over the period. In addition to this immobilization of mineral-N by the crops, the main trend was for the labelled nitrogen added to the ammoniacal fraction of the manure to be re-mineralized from organic forms.

Growing Season 1993

Fate of manure nitrogen

Only small amounts of the ^{15}N applied in August 1991 were present in the mineral nitrogen fraction of the soil at seeding time in 1993, and most was in the ammoniacal fraction (Table 34). There may have been losses by leaching, and on plots where winter wheat was grown over fall and winter some would likely have been taken up in the crop. With the exception of the Control and Control+winter wheat treatments, the mineral-N content of the soil was less in May than in the previous November (Tables 33 and 34). However, there was no clear difference in the mass of labelled mineral nitrogen between treatments, and values for plots under wheat were similar to those being planted with corn (Table 34).

Table 34. Distribution of ^{15}N in soil, May 1993 at Winchester.

MAY 05.1993 Treatment	Mineral-N (kg N ha^{-1})	^{15}N in NO_3 form (% of applied)	^{15}N in NH_4^+ form (% of applied)
Barley			
Control (winter wheat 1992-3)	67.7± 0.41	0.1±0.02	0.7±0.06
LCM (winter wheat 1992-3)	51.9± 1.33	0.1±0.01	1.2±0.05
Corn			
Control	114.9± 0.21	0.2±0.16	0.3±0.02
LCM	82.2± 0.60	0.2±0.01	0.7±0.05
Control +winter wheat	144.4± 15.92	0.5±0.34	0.9±0.02
LCM +winter wheat	68.6± 0.80	0.3±0.01	0.5±0.10
LCM +Oilseed radish	76.3± 1.17	0.1±0.01	0.6±0.09
LCM +Straw	98.3± 1.17	0.4±0.03	0.5±0.01
LCM +Straw +Oilseed radish	62.1± 1.00	0.3 ±0.01	0.7±0.03
CCM (Composted cattle manure)	127.2± 2.00	0.4±0.02	1.2±0.04

Although there was less mineral N in the soil than on the previous sampling occasions, its ^{15}N-enrichment declined on the plots that did not receive animal manures, but showed little or no change on plots given liquid cattle manure. Thus, on the control treatments, mineralization was releasing nitrogen from a source not participating in mineralization-immobilization turnover with the original labelled mineral nitrogen applied in 1991. On the plots treated with liquid cattle manure, sufficient labelled nitrogen was being mineralized to maintain the level of enrichment of the mineral-N.

By November 1993 there was no detectable enrichment in the mineral nitrogen fraction of the soil nitrogen under the corn crops.

At harvest, the yield of wheat was significantly greater on the LCM treatment than on the Control. There was no effect of treatment on the yield of corn. About 4% of the ^{15}N applied in 1991 was recovered in the corn crops, and there was no clear differences between treatments in the mass recovered (Table 35). The contribution made by the mineral nitrogen in the composted manure to the crop nitrogen content was only 0.5% (Table 35). In contrast, the contribution from the mineral nitrogen in the liquid manure was almost 7% from the LCM treatment, and ranged from 6.0% to 3.8% in other treatments. In the control treatments the contribution from the mineral fraction in the soil in August 1991 was 1%, and there was a contribution of 1.3% from this source from plots where oilseed radish had been grown in the fall of 1991. The contribution from this source on the remaining treatments was about 0.7%.

Table 35. Crop grain yield and uptake of ^{15}N by corn at Winchester in 1993 , and total uptake for the two experimental years combined.

Treatment	Grain yield in 1993 (t ha^{-1})	^{15}N in 1993 Crop (% of applied)	Contribution from mineral N in soil, August 1991 (%)	Contribution from mineral N in manure, August 1991 (%)	Total Uptake in 1992 & 1993 (% of applied)
Winter wheat					
Control	2.9± 0.08				
LCM	3.5± 0.15				
Corn					
Control	5.0± 0.13	4.4 ± 0.83	1.0±0.13	-	21.6±2.28
LCM	6.0± 0.23	4.5 ± 0.37	0.9±0.07	6.8±0.53	19.8±1.10
Control + winter wheat	5.4± 0.62	2.6 ± 0.52	0.8±0.16	-	21.1±4.06
LCM + winter wheat	5.0± 0.69	3.3 ± 0.81	0.7±0.10	4.7±0.73	18.5±2.94
LCM + Oilseed radish	5.7± 0.37	5.3 ± 0.44	1.3±0.27	5.6±1.32	28.0±3.94*
LCM + Straw	4.8± 0.81	5.3 ± 1.08	0.8±0.05	6.0±0.41	17.8±2.72
LCM + Straw + Oilseed radish	5.3± 0.56	4.0 ± 2.32	0.6±0.20	3.8±1.52	21.9±3.56*
Composted cattle manure	5.2± 0.40	4.5 ± 0.35	0.7±0.06	0.5±0.05	15.3±2.24

* Includes uptake by oilseed radish cover crop removed in 1991.

Over the two seasons, the greatest recovery of the ^{15}N applied in the manure was from the plots where oilseed radish was grown as a cover crop in 1991 (Table 35). The smallest recovery was from the composted cattle manure.

Table 36. Effect of agronomic treatment at Winchester on total losses of ^{15}N from 1991-1993 computed from recoveries of label in soil and crop.

Treatment	^{15}N apparently lost (% of applied)
Barley[†]	
Control	27.3
LCM	27.7
Corn[‡]	
Control	39.0
LCM	39.7
LCM +oilseed radish	23.4
LCM +Straw	29.1
LCM +Straw +Oilseed radish	8.8
CCM (composted cattle manure)	15.2

[†] 1 year [‡] 2 cropping years

Adding straw and growing oilseed radish as a cover crop was the only treatment that had a major impact on the loss of ^{15}N (Table 36). Use of composted manure did not result in the smallest loss in percentage terms, but was least overall given the small amount of mineral N traced by the ^{15}N. The spring barley resulted in a loss over one year similar to that of corn in the same period.

DISCUSSION

In this study the fate of nitrogen from liquid dairy cattle manure and from composted cattle manure was investigated in two field experiments. In the first experiment liquid cattle manure was applied in spring before planting corn. Both types of manure were applied to alfalfa forage during late summer in the second experiment. In the latter experiment a range of practical agronomic practices were tested for their potential to immobilize nitrogen over the fall, winter and spring without impairing the productivity of the land.

The magnitude of the fluxes of nitrogen was investigated by chemical analysis of the nitrogen forms in the soil, and the nitrogen balance in the crops. ^{15}N was used to trace over time the fate of the nitrogen present in the mineral fraction of the manures. The ^{15}N-tracer was also applied directly to the soil to identify the fate of mineral nitrogen produced by mineralization of soil organic matter prior to the application of manure, and to help identify the potential sources of the nitrogen that was mineralized after manure application.

The injection of liquid cattle manure at Winchester was a successful means of application. There was no increase in the variability of mineral-N in soil samples from plots to which this source of nitrogen was applied. A similar variability also related to samples from plots which had received composted manure until the final sampling date in November 1992 when the coefficient of variation increased from 34% to 53%. Combining the results for soil nitrogen and plant nitrogen for November 1991, allowed the addition of mineral nitrogen to the soil in the manure to be determined. Approximately 17 kg N ha^{-1} of mineral nitrogen was applied in the composted manure, and this small addition could not be identified against the background of 117 kg N ha^{-1} present in the Control plots. About 180 kg N ha^{-1} of the additional 216 kg N ha^{-1} mineral nitrogen applied in the liquid manure appeared to be present in the soil and plants. On average 134 kg ha^{-1} nitrate-N remained in the soil and so was at risk of leaching. However, from analysis of the ^{15}N present in the soil it appeared that only about 25% of this (60 kg N ha^{-1}) had been derived from the mineral fraction of the manure, at least 50% of that fraction had already transferred into the organic pool of the soil by November, less than three months after application.

In neither experiment were there climatic conditions conducive to extensive leaching or for major denitrification events. Losses reported should therefore be considered as conservative. Nonetheless, losses of nitrogen from the manured plots over two years ranged between 35 and 40% of the ^{15}N applied, equivalent to 52 kg N ha^{-1} lost from the spring-applied liquid manure at Elora, and 81 kg N ha^{-1} lost from the fall-application at Winchester.

At Winchester, the growth of the cover crops in the fall was good in both seasons, except that the Timothy grass failed to establish in 1991, most probably because of the dry conditions. The amount of nitrogen immobilized in these plants was proportional to the dry matter produced. There was no evidence of differential concentration in the tissue of the cruciferous or grass species. In total, winter wheat immobilized about 20kg N ha^{-1} during fall period, and since it failed to survive the winter of 1991-92 there was no information gained as to its ability to reduce leaching loss of nitrogen in the spring. The oilseed radish and the winter wheat took up approximately 19 and 9 kg N ha^{-1} respectively from the mineral fraction of the liquid cattle manure. Uptake by the oilseed radish was reduced by about one third where straw had been incorporated. These amounts of nitrogen were small compared to the total mineral nitrogen added to the soil, and left considerable amounts of mineral nitrogen in the soil. Only about 2 kg N ha^{-1} of the nitrogen originating from the manure was re-mineralized from the tops of the oilseed radish and taken up by the following corn crop. The oilseed radish grew as well in Eastern Ontario, and took up as much nitrogen as did the cover crops grown at Ayr and Woodstock in Ontario, Canada (Miller et al.,1992). The wild mustard that developed from the soil weed seed bank also grew as well as the sown oilseed radish.

The weed control on treatments 1 and 2 where Timothy grass was sown, but failed to establish, was very effective so that these acted as true controls for the other treatments. Incorporation of composted manure acted as an effective inhibitor of weed seed germination, and there was no measurable plant development on the plots.

There was considerable dry matter production by the volunteer spring oats where large numbers of seeds must have been introduced with the straw. This suggested that densely-sown oats could be used as a cover crop if the tops could be harvested for forage late in the fall.

In the first year at Winchester on the Control treatment there was an increase in the soil mineral nitrogen between the last sampling date in the fall and planting time in spring. This was consistent with the view that little or no leaching occurred as a result of the snow melt because the soil was not fully rewetted after the previous dry summer. The loss of ^{15}N over this period indicated that about 50 kg N ha^{-1} of the nitrogen present in the mineral fraction was lost from the soil over winter. There was 40 kg N ha^{-1} more nitrate in the soil that had received liquid cattle manure than where oilseed radish had been grown. However, where the straw was incorporated and oilseed radish grown, there was only 20 kg ha^{-1} less nitrate-N than where no straw was incorporated. These results suggest that there was more nitrate returned to the soil from the cover crops where immobilization had been greatest. The results from the ^{15}N tracing did not support this conclusion. There was much more variation in the ammonium ion content of the soil at this time than in the total mineral nitrogen content. This is consistent with mineralization of organic matter taking place. The combined results support the view that considerable mineralization took place in the spring prior to mid-May.

The yield results for spring barley were probably influenced by the lodging that took place preferentially on the manured plots. This probably limited light interception by the flag leaves, and resulted in less grain production than would have been expected from the dry matter yield. The reduction in plant nitrogen observed between the sampling in July and at harvest was probably attributable to the leaves that were detached from the plants and could not be sampled adequately.

As the growth and yield of the corn were largely unaffected by treatment, it was evident that the nitrogen released by the ploughing of the alfalfa hay soil provided sufficient nitrogen for the corn crop. The corn crop on land injected with liquid manure (LCM -treatment) contained 225 kg N ha^{-1}, but this was not converted into significantly more combinable yield than the control which only contained 150 kg N ha^{-1}. About half of the additional nitrogen was present in the grain, but the remainder was in the harvest residues that will contribute to the organic matter pool of the soil and be remineralized in the future. The increase in the nitrogen content of the corn crops grown on land where cover crops were grown in the previous fall, took place after 20 August. This suggests that the main period for release of nitrogen from the cover crop residues only took place late in the season. If cereals rather than corn had been the test crop it strongly suggests that most of this nitrogen would have remained in the soil where it would have been at risk of leaching.

The soil N test, which only takes account of nitrate-N, clearly underestimated the amount of mineral nitrogen available in the soil at sowing in 1992 on all treatments. The results of the soil N test (Table 19) suggested that most treatments that had not been manured in the fall would benefit from the addition of 40 kg N fertilizer ha^{-1} to obtain the maximum economic yield of corn. The exception to this was the Control treatment with weeds where there had been significant growth of wild mustard that had immobilized about 50 kg N ha^{-1}. However,the LCM treatment with weeds also had a considerable growth of mustard over the fall, but the N test result was less than that of the LCM fallow treatment. This suggested that the contribution of mineral nitrogen from the below-ground residues of the alfalfa hay was not adequately assessed. Since yields were unaffected by the treatments imposed, this further indicated that adjustments are needed to the N test to ensure that the nitrogen from crop residues (straw or cover crop) is included before fertilizer recommendations are made.

At the time the alfalfa-hay forage was ploughed-down at Winchester, little mineral-N would have been expected to be in the soil. Subsequent mineralization on the Control treatment would therefore be 105 kg N ha^{-1} (mineral-N in the soil at planting in 1992), plus the 150 kg N ha^{-1}(N removed in the corn crop at harvest in 1992), less the 55 kg N ha^{-1} (mineral-N remaining in the soil), a total of 205kg N ha^{-1}. As about 100 kg N ha^{-1} would be expected to be mineralized in the absence of a previous legume crop, this suggests that about 105 kg N ha^{-1} was an appropriate credit for the alfalfa-hay residues.

Two periods of leaching were identified at Winchester in late spring and early summer of 1992. The maximum concentration of nitrate-N recorded in the water draining from the rooting zone for all treaments exceeded the Ontario Drinking Water Objective of 10 mg L^{-1} during one or both periods. The soluble organic carbon content of the soil at this time was large, and the potential energy source for denitrification was high. Some of the nitrogen leaving the rooting zone might have been lost in gaseous form rather than enter the groundwater.

At Elora, the growth of the corn crop on the microplots was good in both years, and there was no significant benefit to yield from application of manure compared with control plots in either season. Previously corn had been grown continuously on the site, so the lack of any effect on yield due to manure application in the first season was probably due to residual nitrogen from the management of those crops. The crops at Winchester grown on land injected with liquid manure produced significantly greater grain yields than the Control treatment when harvested by hand, except where straw had been icorporated or oilseed radish planted, but this was not converted into significantly more combinable yield.

About 32% of the ^{15}N applied was taken up by the two following corn crops at Elora, and almost 21% was found in the two corn crops grown at Winchester. These were equivalent to 47.4 kg N ha^{-1} taken up at Elora, and 42.2 kg N ha^{-1} taken up at Winchester. About 9 kg N ha^{-1} was taken up by the second corn crop. The grain contained 60% of the ^{15}N taken up at Elora (28.4 kg N ha^{-1} from the mineral N in the manure), and 62% (26.2 kg N ha^{-1} from the mineral N in the manure) was in the grain at Winchester. The remainder of the nitrogen would normally be returned to the soil. In the first year at Winchester, spring barley took up 14% of the ^{15}N applied in the liquid cattle manure, equivalent to 28.8 kg N ha^{-1} from the mineral fraction of the manure. Some 52% of the nitrogen was in the grain of the spring barley and the remainder would commonly be returned to the soil.

At Elora the recovery of nitrogen in the corn crops during 1991 was similar on plots given cattle manure, and those treated with labelled ammonium sulphate. The ^{15}N enrichment of the manured crop was similar from July onwards. This suggested that the dilution of the ^{15}N in the mineral fraction of the soil was similar for both the manured and Control plots until August, when most of the ^{15}N was taken up. The spring barley plots at Winchester showed a different trend. Although there was a loss of ^{15}N from the crop with LCM, probably due to the loss of leaves during lodging, the average enrichment in the crop also declined. It appeared that during the rapid phase of nutrient uptake in July, there was more dilution of the ^{15}N in the plants from those plots than from the Control plots. At harvest at Winchester, the ^{15}N enrichment of corn was least on the plot with composted manure, and greatest on the control plot. These results suggested that some of organic nitrogen in the manure was mineralized during the first growing season after application, and that this only occurred after the main period of uptake for corn at Elora. There was more nitrogen in corn crops grown on land where cover crops were grown in the previous fall compared to that in unmanured controls. However, the increase only occurred after 20 August. Much of the nitrogen released by the cover crops also appeared to take place after the main period of uptake by the corn.

The composted cattle manure did not pose a significant hazard in the fall after application at Winchester when the mineral nitrogen content of the soil was similar to the control treatment. Only 0.46 kg N ha^{-1} from the mineral nitrogen in the composted cattle manure was removed in the corn grain. However, in the fall of the following year an average of 85 kg ha^{-1} of mineral nitrogen remained in the soil after the harvest of the corn. Nitrate leaching from solid beef manure at Elora was also less than in other treatments during the 1992 growing season.

The study strongly indicated that applying liquid manure in the fall was potentially hazardous to water resources. The risk from leaching was high in the fall immediately after application, in the following spring, and in the next fall period, especially if cereals were grown in the spring. None of the fall treatments to immobilize nitrogen were adequate to reduce the risk significantly. Spring application of manure resulted in similar losses over two cropping seasons, but volatilization of ammonia may have been particularly important.

CONCLUSIONS

The injection of liquid cattle manure in the early fall resulted in a large amount of mineral nitrogen in the soil, much of it in the mobile nitrate form that is at risk of leaching. Incorporating composted cattle manure did not have a significant impact on the soil pool of mineral nitrogen.

The loss of mineral nitrogen from manure, as indicated using ^{15}N as a tracer, was greater during surface spreading and mechanical incorporation in spring than after early fall application to recently cultivated land followed immediately by hand-digging.

Cover crops sown after manure application in the fall immobilized nitrogen proportional to the dry matter produced before the first killing frost. Incorporation of straw reduced the amount of nitrogen incorporated in the cover crops because the growth of these crops was impaired.

In the first cropping year the uptake by corn of nitrogen derived from the mineral-N in manure was greater from a spring application (39 kg N ha^{-1}) than from a fall application (31 kg N ha^{-1}). Uptake in the second season was about 5% of the mineral nitrogen in the manure at application in both cases. Total loss over two cropping years, estimated as ^{15}N not present in soil or crop, were 35% for the spring application and 40% for the fall application. The potential for leaching loss to occur in the period following the fall application was considerable. The application of manure in the early fall resulted in a large amount of mineral nitrogen in the soil, much of it in the mobile nitrate form. In that experiment, the prevailing weather conditions were not conducive to leaching, but the loss over winter was still about 25%; less where cover crops were grown on land where straw had been incorporated. Incorporating composted cattle manure at the same time of year did not have a significant impact on the soil pool of mineral nitrogen.

At least 49% of the mineral-N labelled with ^{15}N was incorporated in the organic-N fraction of the soil before mid-November. Remineralization of a small part of this fraction appeared to take place in early spring. But much of the ^{15}N was still retained in the soil organic matter after two years. Only small amounts became available even in the second year.

The cover crops removed less than 10% of mineral-N applied in liquid cattle manure, and only about one tenth of this was transferred to the following corn crop. Evidence from crop sampling indicated that much of the nitrogen from the cover crop did not become available until late in the season, and this was also true for nitrogen from the organic fraction of the manure. Lack of variation in enrichment of the corn crop at Elora with ^{15}N indicated that mineralization of organic-N from the manure applied in May did not take place before August. Evidence from spring barley suggested that the mineralization of organic-N from the fall-applied manure became available in the following July. Much of the nitrogen would be at risk of leaching after harvest of spring-sown small-grained cereals. Composted manure did not result in a significant loss of mineral-N, nor did it provide much nitrogen to the corn crop in the first year. There was evidence that some of the organic nitrogen in manure became mineralized in the late summer, twelve months after application, when it was at risk to leaching over winter.

Combining straw incorporation and growing a cover crop that would be removed for forage in late fall appeared to offer the best solution to minimize loss of nitrogen from manure applied in early fall. However, in a wet fall the impact of this treatment might not be as great as the results for a relatively dry fall.

The results of the study were consistent with the generally accepted nitrogen credit of 110 kg N ha^{-1} being appropriate for calculating the availability of N from the underground residues of alfalfa hay.

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LITERATURE CITED

Anon. 1993. Summary Proceedings of the Manure Systems Workshops. March, 1993, Woodstock, Port Perry, Kemptville, Ontario. Centre for Land and Water Stewardship, University of Guelph, Guelph, Ontario.

Beauchamp, E.G. 1986. Availability of nitrogen from three manures to corn in the field. Canadian Journal of Soil Science 66, 713-720.

Beauchamp, E.G. 1983. Response of corn to nitrogen in preplant and sidedress applications of liquid dairy cattle manure. Canadian Journal of Soil Science 63, 377-386.

Bernal, M. P. and H. Kirchmann. 1992. "Carbon and Nitrogen Mineralization and Ammonia Volatilization from Fresh, Aerobically and Anaerobically Treated Pig Manure During Incubation with Soil." Biology and Fertility of Soils 13:135-141.

Brooks, P.D., J.M. Stark, B.B. McInteer, and T. Preston. 1989. Diffusion method to prepare soil extracts for automated nitrogen-15 analysis. Soil Sci Soc. Am. J. 53:1707-1711.

Burford, J.R., Greenland, D.J. & Pain, B.F. 1976. Effects of heavy dressings of slurry and inorganic fertilizers applied to grassland on the composition of drainage waters and the soil atmosphere. In: Agriculture and Water Quality. Technical bulletin, Ministry of Agriculture, Fisheries and Food. No. 32. H.M.S.O., pp. 432-443.

Chescheir, G. M., P. W. Westerman & L. M. JR Safely. 1986. "Laboratory Methods For Estimating Available Nitrogen in Manures and Sludges." Agricultural Wastes 18:175-195.

Dean, D.M. & Foran, M.E. 1991. The Effect of Farm Liquid Waste Application on Receiving Water Quality. Final Report RAC Projects 430G and 512G. Ausable-Bayfield Conservation Authority, Exeter, Ontario.

Fleming, R. J. 1988. An expert system for the selection/design of swine manure handling methods. *M.Sc. Thesis, Univ. of Guelph*

Foran, M.E., Dean, D.M. 1991. Comparison of liquid manure spreading practices on the tile drain water quality. In: Proceedings - Environmental Research: 1991 Technology Transfer Conference, Volume I. Toronto, Ontario, November 1991, Research and Technology Branch, Environment Ontario, pp. 241-248.

Goss, M. J. 1990. The effects of soil and crop management on the leaching of nitrates. In Nitrates-Agriculture-Eau: Intern. Symposium Instit. Nat. Agron., Paris-Grignon, R. Calvert, (ed). Instit. Nat. Recher Agron, Paris.

Kelly, K.A., D.C. Ditsch., and M.M. Alley. 1991. Diffusion and automated nitrogen-15 analysis of low mass ammonium samples. Soil Sci. Soc. Am. J. 55:1016-1020.

Keeny, D.R., and D.W. Nelson. 1982. Nitrogen - Inorganic Forms, pp. 643-698. In: A.L. Page et al., (eds.). Methods of Soil Analysis, Part 2. American Society of Agronomy, Madison, Wisconsin.

Liu, Y.P., and R.L. Mulvaney. 1992. Use of diffusion for automated nitrogen-15 analysis of soil extracts. Commun. Soil Sci. Plant Anal. 23: 613-698.

Meisinger, J. J. and Randall G.W. (1991) Estimating nitrogen budgets for soil-crop system. In Managing nitrogen for ground water quality and farm profitability. R.Follett, D.R. Keeney and R.M. Curse, (Eds.). Soil Sci. Soc. Amer. Madison WI. USA.

Miller, M.H., Beauchamp, E.G., Vyn, T.J., Stewart, G.A., Lauzon, J.D. and Rudra, R. 1992. The Use of Cover Crops for Nutrient Conservation. Soil and Water Environmental Enhancement Program, Report 43. Agriculture Canada.

Mulvaney, R.L. 1992. Mass Spectrometry. In: R. Knowles and H.T. Blackburn, (eds.). Nitrogen Isotope Techniques.1993. p.11-54.

Paul, J.W. 1991. Corn Yields and Potential for Nitrate Leaching From Manures and Inorganic N Fertilizer. Ph.D. thesis. University of Guelph, Guelph, Ontario.

Power, J.F. and J.W. Doran. 1988. Role of crop residue management in nitrogen cycling. In Cropping Strategies for Efficient Use of Water and Nitrogen. W.L. Hargrove, (ed.), Am. Soc. Agron. Special Publ. No. 51.

Power, J.F. and J.O. Legg. 1978. Effect of crop residues on the soil chemical environment and nutrient availability. In Crop Residue Management Systems, W.R. Oschwald, (ed.), Am. Soc. Agron. Special Publ. No. 31.

Thompson, R.B., J.C. Ryden and D.R. Lockyer. 1987. Fate of nitrogen in cattle slurry following surface application or injection to grassland. *J. Soil Sci.* 38, 689-700.

Van der Molen, J., H.G. Chardon, M.Y. LeClerc, R. Vriesema and W.J. Van Faassen. 1990. Ammonia volatilization from arable land after application of cattle slurry. 1. Field estimates. *Neth. J. Agric.* Sci 38: 145-158.

Smith, J.L and M.H. Um. 1990. Rapid procedures for preparing soil and KCl extracts for ^{15}N analysis. Commun. Soil Sci. Plant Anal. 21: 2173-1279.

APPENDIX

A. Regressions for calculating the percentage of ^{15}N remaining in the soil (Y) with time in days after application (X) at Winchester.

Date (Days after application)		0	76	260	308	441	627	781	Regression
Treatment									
Control	Predicted Measured	121.7 57.9	104.2 44.3	72.3 79.3	66.0 76.5	53.0 30.9	45.6 19.6	49.0 33.4	Y= 121.7 -0.23*X +0.00012*X^2
Control-barley	P M	90.1 87.5	82.1 85.0	62.5 78.8	57.4 42.4	43.3 55.3			Y= 90.1 -0.11*X +3.7E-05*X^2
LCM	P M	84.9 60.3	69.7 102.3	43.0 53.4	38.4 20.8	30.7 27.0	32.4 25.0	44.9 47.4	Y= 84.9 -0.22*X +0.0002*X^2
LCM-barley	P M	101.6 109.2	91.1 82.0	71.6 70.8	67.8 63.2	60.1 68.4			Y= 101.6 -0.15*X +0.0001*X^2)
Control+wheat	P M	92.8 96.3	74.3 68.5	40.7 38.3	34.5 40.2	22.9 17.5	20.3 45.2	30.3 14.9	Y= 92.8 -0.26*X +0.0002*X^2
LCM+wheat	P M	103.9 98.8	86.3 89.4	53.7 73.1	47.5 31.1	35.3 32.7	30.6 37.2	37.5 40.1	Y= 103.9 -0.25*X +0.0002*X^2
LCM+OSR	P M	124.8 144.4	101.3 68.8	58.9 69.5	51.2 58.0	37.1 32.3	35.3 51.6	49.6 49.2	Y= 124.8 -0.33*X +0.0003*X^2
LCM+straw	P M	76.9 66.9	77.6 88.9	76.5 79.5	75.6 79.4	71.7 61.3	63.1 62.1	53.1 48.7	Y= 76.9 +0.012*X -5.5E-05*X^2
LCM+straw+OSR	P M	72.2 68.0	70.8 69.0	68.4 88.7	68.0 67.7	67.6 50.3	68.5 65.0	70.5 82.5	Y= 72.2 -0.02*X +2.4E-05*X^2
CCM	P M	115.4 104.0	102.4 114.6	78.4 107.7	74.0 40.3	65.4 67.4	62.9 108.1	69.3 32.0	Y= 115.4 -0.18*X +0.0002*X^2