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Nitrous Oxide and N-Leaching Losses from Agricultural Soil: Influence of Crop Residue Particle Size, Quality and Placement

By

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Summary

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Incorporation of crop residues provides a source of readily available C and N, and previous works indicate that farming strategies where crop residues are used for soil fertility purposes may lead to increased emissions of N_2O. Information on the importance of different residue management on the potential for N_2O emissions, however, is missing. The objectives of this work were to determine the short-term effects of crop residue particle size and spatial distribution on soil-atmosphere fluxes of N_2O. Implications for leaching losses of inorganic N were also assessed. The work included an experiment with lysimeters incubated in the field and an experiment with soil incubated under controlled conditions. The results show that finely ground pea material (<3 mm) evolved 50 % more N_2O (33.8 mg N m^{-2}) than coarse particles (25 mm) of pea material (22.7 mg N m^{-2}) and twice as much N_2O as residue-free soil (16.5 mg N m^{-2}). Barley material, on the other hand, did not influence N_2O emissions regardless of particle size (10-17 mg N m^{-2}). The lack of N_2O evolution with barley residue was likely due to N-limitations whereas with N-rich pea material the particle size obviously controlled N-availability. Carbon dioxide evolution increased about three-fold both with barley and pea residue, but apart from a transient initial depression in CO_2 evolution with <3 mm particles there was no overall effect of particle size on CO_2 evolution. Very likely the grinding to <3 mm was inadequate to achieve soil physical protection of the crop residue material against microbial attack. Leaching of N tended to be reduced about 40 % with barley and 20 % with pea, but the numbers were not significantly different from residue-free soil,

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which leached 4.7-4.9 g N m^{-2}. When wheat and alfalfa residues were mixed into the soil N_2O emissions increased 6.5 and 1.6 times, respectively, compared with residue placed in a layer. Wheat residue in a layer evolved 3.4-times less N_2O than alfalfa in a layer, whereas when mixed the two residue types evolved similar amounts of N_2O. This difference was probably due to N-limitations in localised zones around the layered wheat. The results from this study should be extrapolated to the field situation only after very careful consideration. Nevertheless, the study emphasizes the potential for residue management to restrain N_2O emissions from agricultural soils. From a N_2O mitigation point of view, incorporating of residues with low N-contents is advantageous over a homogeneous mixing of N-rich materials into the soil.

Introduction

Emissions of nitrous oxide (N_2O), which is important for atmospheric chemical and radiative conditions, has been investigated in many studies with focus on agricultural soils under different management strategies. Emissions of N_2O are intimately linked to nitrification and denitrification activity, and production of N_2O is favoured by low oxygen tensions, for example induced by increased respiratory activity. Incorporation of crop residues provides a source of readily available C and N and therefore often stimulates N_2O emissions (e.g. COCHRAN & al. 1997, FLESSA & BEESE 1995, LEMKE & al. 1999, ROLSTON & al. 1982). Nevertheless, the magnitude of residue induced N_2O emission from agricultural soils remains largely unknown (MOSIER & al. 1998). In order to generate outlines for N_2O emission inventories MOSIER & al. 1998 suggested using a general residue N_2O emission factor equal to that for chemical fertilisers. This approximation, however, is highly uncertain since residue quality and management will likely influence the N_2O source strength. Firstly, the residue-induced emission of N_2O is related to the N content (C:N ratio) of the plant material, as is indicated by greater N_2O losses from leguminous (low C:N) material than from cereal (high C:N) material (AULAKH & al. 1991, MCKENNEY & al. 1993). Secondly, there is evidence in the literature that mechanical treatment of the residue also has an effect on the evolution of N_2O (SHELP & al. 2000). Breaking down plant residues into small particle sizes may facilitate microbial attack and accelerate decomposition rates (AMATO & al. 1984, AMBUS & JENSEN 1997, ANGERS & RECOUS 1997, SIMS & FREDERICK 1970), and possibly also increase associated N_2O production. On the other hand, fine particles may also be physically protected against decomposition by adsorption to clay and other soil constituents which would slow down the residue turnover (BRELAND 1994, JENSEN 1994a, STICKLER & FREDERICK 1959). Finally, it is also found that distribution of residue material in soils, e.g. surface application vs. incorporation, may have an influence on the N_2O evolution derived from residue applications (AULAKH & al. 1991). In addition to direct effects on N_2O fluxes, indirect fluxes e.g. from leached nitrate should also be considered assessing residue related N_2O losses (MOSIER & al. 1996). Incorporation of for example low-N cereal residues has the potential to reduce N-leaching and hence transport of N to adjacent environments thereby reducing indirect N_2O emissions derived from agriculture. Incorporation of straw from cereal production is practised by many farmers in e.g. Denmark where 30-35 % of the annual production of cereal straw is mechanically

chopped at harvest and subsequently ploughed under. The objectives of this work were to determine the short-term effects of crop residue particle size and spatial distribution in soil on soil-atmosphere fluxes of N_2O and evaluate implications for leaching losses of inorganic N. The work included an experiment with lysimeters incubated in the field and an experiment with soil incubated under controlled conditions.

Materials and Methods

The lysimeter experiment (**E1**) was conducted at the Risø National Laboratory in order to study effects of residue particle size on fluxes of N_2O and CO_2 and leaching of N. A greenhouse-incubation experiment (**E2**) was undertaken at the Kellogg Biological Station to study effects of residue placement on fluxes of N_2O and CO_2.

In **E1** we used a sandy loam soil (Typic Hapludalf) with 11.4 % clay, 13.6 % silt, 75 % sand and pH_{H2O} of 6.9. The soil was collected in the field after growing spring barley (*Hordeum vulgare* L.) and field pea (*Pisum sativum* L.), respectively. Topsoil (0 to 20 cm) and subsoil (20 to 40 cm) was sampled in each field, sieved to less than 10 mm and air-dried. Non-suction lysimeters of 30 cm diam. (JENSEN 1994b) were set up in a 1 m deep pit hole in the field, and 40 cm high soil columns were repacked in the lysimeters as follows: subsoil (23.4 kg oven dry basis) was added and compressed to a bulk density (BD) of 1.66 g cc^{-1}, then topsoil (9.3 kg oven dry basis) was added and compressed to a BD of 1.32 g cc^{-1}, and finally a similar amount of topsoil mixed with plant residues was added and compressed to a BD of 1.32 g cc^{-1}. After repackaging, the soil columns were wetted to field capacity. Treatments, all in triplicate, included residue-free controls, residue ground to less than 3 mm, and residue cut to 25 mm in combination with spring barley residue and pea (stem+pod) residue, respectively. The barley residue had 0.63 % total N, 5.641 % ^{15}N excess and C:N ratio = 68:1, and the pea residue had 1.88 % total N, 2.641 % ^{15}N excess and C:N ratio = 22:1. Application rates corresponded to 520 g dry matter m^{-2}. Barley material was mixed into the soil from the barley field, and pea material was mixed into the soil from the pea field. The lysimeters were set up in September and incubated for 218 days. Leachate was collected at least every second week and stored frozen until analysis for inorganic N and ^{15}N content. For gas flux measurements the lysimeters were covered with PVC lids, sealed gas tight by weather strips, and pierced by rubber stoppers for gas sampling using a syringe and needle. Fluxes were calculated from the change in concentration of N_2O and CO_2 in the enclosed headspace, which was measured four times during a 45 min. enclosure period. For each measurement a five-mL gas sample was withdrawn and stored in evacuated 3-mL blood collecting tubes until analysis by gas chromatography. Gas fluxes were measured at day 2, 14, 28, 49, 83, 145, and 217. On day 218, three 18-mm auger samples were taken from each lysimeter for the analysis of total and inorganic ^{14}N and ^{15}N contents. Soil samples from depths of 0-10 cm, 10-20 cm, and 20-40 cm was composited and analysed separately.

In **E2** we used a coarse loamy soil (Typic Hapludalf) with 14 % clay, 27 % silt, 59 % sand, and a pH_{H2O} of 5.7. The soil was sampled at 0-25 cm depth during the growing season of winter wheat (*Triticum aestivum* L.), sieved to less than 6 mm and air-dried. Plant residues included winter wheat (0.59 % total N; C:N ratio = 84:1) and alfalfa (*Medicago sativa* L.) with 3.64 % total N and C:N ratio = 13:1. Soil samples of 542 g (oven dry basis) were weighed out into 7.5 cm inner diam. by 15 cm high PVC cylinders with polyethylene bottom-lids, and compressed to a BD of 1.3 g cc^{-1}. Residue material, ground to less than 5 mm, was either mixed into the soil or placed in a discrete layer at 5 cm depth at rates equivalent to 600 g dry matter m^{-2}. Residue-free pots were included as controls. The soil received 110 mg NH_4NO_3-N kg^{-1}, and moisture was adjusted to field capacity (15 % H_2O w w^{-1}). Each treatment was triplicated. The pots were incubated at 16 °C and with constant soil moisture for 45 days. Effluxes of N_2O and CO_2 were measured at day 3, 7, 14, 27, and 42. The pots were placed on trays filled with 1 cm of water, and the headspace around each pot was then sealed by 15 cm inner diam. by 17 cm high metal cans placed open end down to achieve gas tight seals. The cans were pierced by rubber septa for gas sampling. Five-mL headspace samples

were stored overpressurized in a 2-mL crimp sealed vial for analysis within two days (AMBUS & ROBERTSON 1999). Pure N_2 was injected into the cans to compensate for underpressure. Headspace samples were taken every hour during three hours of enclosure, and gas fluxes were calculated from the change in concentration inside the chamber. After the 7-week incubation period subsamples of the soil in each cylinder was analysed for inorganic N.

Nitrous oxide was analysed in 0.5-mL samples on a Hewlett Packard 5730A (**E1**) or 5890 (**E2**) gas chromatograph equipped with electron-capture detector (350°C). Carbon dioxide was analysed in 0.5 mL aliquots on a gas chromatograph (Mikrolab, Århus, Denmark) by thermal conductivity detection (**E1**) or in 0.7 mL samples on a Beckman Model 865 IRGA (**E2**). Nitrate and ammonium in leachates and soil KCl extracts (1:10 w vol^{-1}; 2M for **E1** and 1M for **E2**) was analysed using a Technicon Autoanalyzer (**E1**) or Alpkem Autoanalyzer (**E2**). Total N and total C was measured on a Carlo-Erba (NA 1500) CN Analyzer. The ^{15}N enrichment of leachate, KCl extracts and total N in samples was determined on an isotope ratio mass spectrometer (Finnigan MAT DeltaE) coupled in continuous flow mode to the CN analyzer. Acidified filters wrapped in PTFE were added to leachate and KCl extracts to concentrate NO_3^- and NH_4^+ (SØRENSEN & JENSEN 1991).

For comparison of multiple means we used the Duncan Multiple Range test at P=0.05.

Results and Discussion

In **E1** the total flux of N_2O, calculated by linear interpolation between sample dates, was not affected by the size of barley material, whereas the total N_2O flux was about 50 % greater ($P<0.06$) with finely ground pea residue than with cut pea residue (Figs. 1A-B). Compared with residue-free soil, the presence of barley material did not significantly change N_2O fluxes (Fig. 1A). Ground pea material roughly doubled ($P<0.06$) the total N_2O flux both compared with residue-free soil and soil amended with barley residue. The increase in N_2O with pea material was pronounced at the first sampling and declined rapidly hereafter (Fig. 1B). Carbon mineralisation, as expressed by the CO_2 fluxes, increased about three-fold when residue was added ($P<0.01$), but independent of residue particle size and type (Figs. 1C-D). However, time courses of CO_2 show that C in coarse particles of barley was mineralised at greater ($P<0.01$) rates during early decomposition than C in fine particles (Figs. 1C-D). A similar trend was observed with pea material, but the difference was not significant. With the initial low N content of the barley material, and since inorganic N was not added, the source of N for N_2O production was exclusively provided by the soil. This most likely explains the lack of N_2O evolution with barley material. In contrast, the high N-content of pea material stimulated N_2O production, which was clearly controlled by the particle size of the pea residue probably due to increased N-availability from the physical breakdown of the material. The greater N_2O evolution with ground pea than with coarse pea material contrasts the finding of SHELP & al. 2000 who observed more N_2O with coarse alfalfa than ground alfalfa residue. Soil physical protection of plant residues against microbial attack (e.g. BRELAND 1994) is possibly increased as the residue particle size decrease. As SHELP & al. 2000 used a more finely ground (<1mm) material than we did, soil physical protection of the ground leguminous material was probably less expressed in our study. The lack of strong soil physical

protection of the ground plant material in our study is also supported by the transient effect only on CO_2 evolution among the particle size treatments.

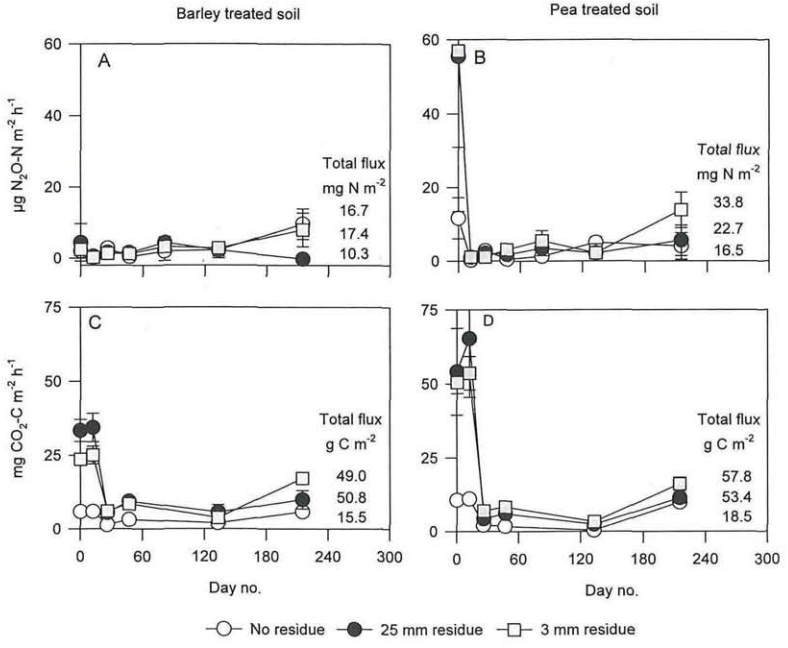

Fig. 1. Fluxes of N_2O and CO_2 from field-incubated lysimeters treated with barley (A, C) and pea (B, D) crop residues with different particle sizes. Each data point is the mean of n=3±SE. Numbers indicate total evolution during incubation period calculated from linear interpolation.

Residue size had no effect on inorganic N leached neither from the lysimeters with barley residue which averaged 2.9 g N m^{-2} nor from the lysimeters with pea residue which averaged 3.8 g N m^{-2} (Fig. 2). Residue-free lysimeters lost similar amounts of N by leaching, viz. 4.9 g N m^{-2} (barley) and 4.7 g N m^{-2} (pea), and although leaching of N tended to be smaller from lysimeters with crop residues incorporated than from residue-free lysimeters, the residue effects were not significant (Fig. 2). The amount of leached N derived from residue was independent of residue size, but only 0.5 % of the barley N was leached which is less ($P<0.05$) than the 2.3 % of residue N leached from pea (Fig. 2). These results are contrasted by the observation of JENSEN 1994b who found that a greater proportion of pea residue-N was leached from chopped pea material (15 %) than from ground pea material (7 %) in a similar setup. However, the results by JENSEN 1994b were collected in two separate experiments with varying conditions regarding precipitation and discharge amounts. This could, as pointed out by the author, explain some of the observed differences in N-leaching in response to

residue particle sizes. Analysis of the soil total N and ^{15}N contents after the 7 months incubation period indicated that 96 % (25 mm) to 98 % (3 mm) of the barley-N remained in the soil columns suggesting that no other major losses had occurred.

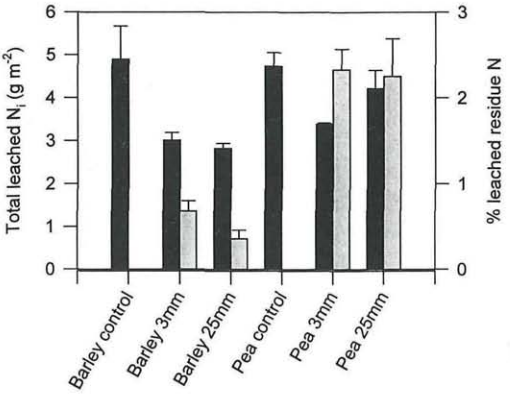

Fig. 2. Leaching of total inorganic N (N_i; black bar) and % leached residue N from total residue N (grey bar) in lysimeters treated with ^{15}N-labelled barley and pea crop residues with different particle sizes. Each symbol is the cumulated mean of n=3±SE lysimeters measured over 217 days.

With pea material the numbers were 100 % (3 mm) and 121 % (25 mm), respectively. The reason for recoveries >100 % is not obvious, but it may be related to the heterogeneous distribution of in particular coarse residue particles in the soil which is critical for representative subsampling. Cumulated effects of residue placement on N_2O and CO_2 fluxes (**E2**) are summarised in Table 1. In this experiment incorporating wheat and alfalfa residues stimulated N_2O fluxes, except when wheat was placed in a layer, and always stimulated CO_2 activity. Mixing the residue generally generated more N_2O than with layered residue, possibly due to the intimate soil:residue contact. There was no significant placement effect on CO_2, although the numbers tended to show greater CO_2 evolution with mixed residues than with layered (Table 1). These results are contrasting the hypothesis provided by BRELAND 1994 who stated that the "conservation capacity" of the soil, i.e. protection against enzymatic and microbial attacks by adsorption to clay and physical encrustment in aggregates, increases as the residues are mixed into the soil rather than situated in concentrated clumps giving rise to less C- and N-mineralization. This concept predicts, however, that the protective capacity of a soil should increase with increasing clay-content and presence of aggregates. BRELAND 1994 used a more fine-textured "loam soil" which supposedly had higher clay content than the "coarse loam" used in the present study, which may help explain the deviation of our results form the proposed model.

In particular soil mixed with residues gave off much N_2O during the first two-week incubation period after which it declined towards the baseline level (Fig. 3A). In contrast to **E1**, N_2O evolution was here increased in the presence of low-N crop residue, but only when the residue was mixed into the soil. It should be kept in mind, however, that inorganic N was added in **E2**, and not in **E1**.

Table 1. Interpolated N_2O and CO_2 effluxes and changes of inorganic N in soil incubated with wheat and alfalfa residues with different placements. Numbers are means of n=3 (SE) replicates.

Treatment	N_2O flux µg N pot^{-1}	CO_2 flux mg C pot^{-1}	Net N change mg N pot^{-1}
Control	72 (13)^{c}	77 (21)^{c}	8 (6)^{a}
Wheat layer	83 (16)^{c}	522 (22)^{b}	-13 (11)^{bc}
Wheat mixed	544 (70)^{a}	672 (40)^{ab}	-28 (4)^{c}
Alfalfa layer	282 (32)^{b}	763 (80)^{a}	7 (3)^{ab}
Alfalfa mixed	442 (20)^{a}	829 (56)^{a}	-6 (1)^{ab}

Letters indicate significant differences between treatments (Duncans Multiple Range test; P<0.05).

When the residue is concentrated in a layer, zones of N-depletion will rapidly develop in the vicinity of the decomposing material, and the N_2O production will be limited by diffusion of NO_3^- into the residue sites. Mixing the residue into the soil increases the N-availability and concomitant N_2O production. With the N-rich alfalfa material the N-supply for microbial use and N_2O production was apparently supplied in adequate amounts by the residue material.

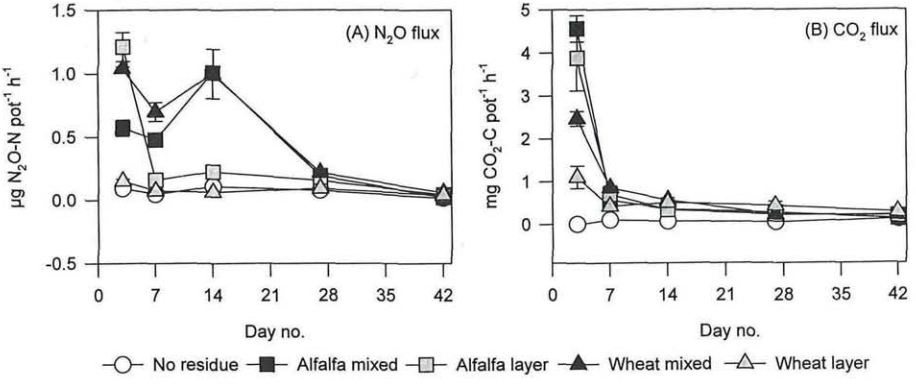

Fig. 3. Fluxes of N_2O and CO_2 from incubated soil with alfalfa and wheat crop residues with different placements. Each datapoint is a mean of n=3±SE.

The activity for CO_2 declined abrupt after the first sampling day, but residue amended soil continued to have greater respiration than control soil through day 27 (Fig. 3B). Although the average CO_2 loss was not affected by the residue

placement, there was a transient increase in CO_2 production when wheat was mixed into the soil compared with wheat placed in a layer (Fig. 3B). Incorporating wheat material gave rise to a significant decline in inorganic N, but not different between the two placements (Table 1). Alfalfa residue did not induce changes in net inorganic N dynamics as compared with control soil, regardless of placement, but more inorganic N was apparently immobilised with mixed wheat than with pea material.

Incorporation of crop residues provides a principal source of energy and nutrients for soil microbial activity and thus has a significant importance for the plant nutrient source-sink relationship. In particular in agricultural ecosystems which can be considered as open systems with respect to the organic matter (CHRISTENSEN 2000) external inputs of organic matter is of high importance in order to maintain soil fertility and physical integrity and to buffer against ecosystem perturbations. From a plant-production point of view the incorporation of low-N residues may be subject to concern by farmers due to anticipated N-limitations and consequent reductions in yields. However, depressed crop yields in response to incorporation of low-N residues are not always observed and depends on farming strategy and choose of cultivar (AMBUS & JENSEN 2001). The results from this study should be extrapolated to the field situation only after very careful consideration. Nevertheless, the study emphasizes the potential for residue management to restrain N_2O emissions from agricultural soils. From a N_2O mitigation point of view, application of residues with low N-contents and reduced mixing into the soil is advantageous over a homogeneous mixing of N-rich materials into the soil. In addition, this strategy also tends to restrain N-leaching and losses of C from the soil-residue system.

Acknowledgements

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References

AMATO M., JACKSON R. B., BUTLER J. H. A. & LADD J. N. 1984. Decomposition of plant material in Australian soils. II. Residual organic ^{14}C and ^{15}N from legume plant parts decomposing under field and laboratory conditions. - Aus. J. Soil Res. 22: 331-341.

AMBUS P. & JENSEN E. S. 1997. Nitrogen mineralization and denitrification as influenced by crop residue particle size. - Plant Soil 197: 261-270.

— & — 2001. Crop residue management strategies to reduce N-losses - interaction with crop N supply. - Comm. Soil Sci. Plant Anal. 32: 981-996.

— & ROBERTSON G.P. 1999. Fluxes of CH_4 and N_2O in aspen stands grown under ambient and twice-ambient CO_2. - Plant Soil 209: 1-8.

ANGERS A. & RECOUS S. 1997. Decomposition of wheat and rye residue as affected by particle size. - Plant Soil 189: 197-203.

AULAKH M. S., DORAN J. W., WALTERS D. T., MOSIER A. R. & FRANCIS D. D. 1991. Crop residue type and placement effects on denitrification and mineralization. - Soil Sci. Soc. Am. J. 55: 1020-1025.

BRELAND T. A. 1994. Enhanced mineralization and denitrification as a result of heterogeneous distribution of clover residues in soil. - Plant Soil: 166: 1-12.

CHRISTENSEN B. T. 2000. Organic matter in soil – structure, function and turnover. – DIAS report Plant Production no. 30, Copenhagen. 95 pp.

COCHRAN V. L., SPARROW E. B., SCHLENTNER S. F. & KNIGHT C. W. 1997. Long-term tillage and crop residue management in the subarctic: Fluxes of methane and nitrous oxide. - Can. J. Soil Sc. 77: 565-570.

FLESSA H. & BEESE F. 1995. Effects of sugarbeet residues on soil redox potential and nitrous oxide emission. - Soil Sci. Soc. Am. J. 59: 1044-1051.

JENSEN E. S. 1994a. Mineralization-immobilization of nitrogen in soil amended with low C:N ratio plant residues with different particle sizes. - Soil Biol. Biochem. 26: 519-521.

— 1994b. Leaching in small lysimeters of nitrate derived from nitrogen-15-labeled field pea residues. - J. Environ. Qual. 23: 1045-1050.

LEMKE R. L., IZAURRALDE R. C., NYBORG M. & SOLBERG E. D. 1999. Tillage and N source influence soil-emitted nitrous oxide in the Alberta Parkland region. - Can. J. Soil Sci., 79:15-24.

MCKENNEY D. J., WANG S.-W., DRURY C. F. & FINDLAY W. I. 1993. Denitrification and mineralization in soil amended with legume, grass, and corn residues. - Soil Sci. Soc. Am. J. 57: 1013-1020.

MOSIER A. R., DUXBURY J. M., FRENEY J. R., HEINEMEYER O. & MINAMI, K. 1996. Nitrous oxide emissions from agricultural fields: Assessment, measurement and mitigation. - Plant Soil 181: 95-108.

— , KROEZE C., NEVISON C., OENEMA O., SEITZINGER S. & VAN CLEEMPUT O. 1998. Closing the global atmospheric N_2O budget: Nitrous oxide emissions through the agricultural nitrogen cycle. - Nutr. Cycl. Agroecos. 52: 225-248.

ROLSTON D. E., SHARPLEY A. N., TOY D. W. & BROADBENT F. E. 1982. Field measurement of denitrification: III. Rates during irrigation cycles. - Soil Sci. Soc. Am. J. 46: 289-296.

SHELP M. L., BEAUCHAMP E. G. & THURELL G. W. 2000. Nitrous oxide emissions from soil amended with glucose, alfalfa, or corn residues. - Comm. Soil Sci. Plant Anal. 31: 877-892.

SIMS J. L. & FREDERICK L. R. 1970. Nitrogen immobilization and decomposition of corn residue in soil and sand as affected by residue particle size. - Soil Sci. 109: 355-361.

STICKLER F. C. & FREDERICK L. R. 1959. Residue particle size as a factor in nitrate release from legume tops and roots. - Agron. J. 51: 271-274.

SØRENSEN P. & JENSEN E. S. 1991. Sequential diffusion af ammonuim and nitrate from soil extracts to a polytetrafluoroethylene trap for ^{15}N determination. - Anal. Chim. Acta 252: 201-203.