Consultation sur le développement durable
de la production porcine au Québec

6211-12-007

Short-term C and N dynamics in a soil amended with pig slurry and barley straw: a field experiment

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Chantigny, M. H., Rochette, P. and Angers, D. A. 2001. **Short-term C and N dynamics in a soil amended with pig slurry and barley straw: a field experiment.** Can. J. Soil Sci. **81**: 131–137. Interactions between animal slurries and crop residues can impact on soil N availability during decomposition. Our objective was to study the short-term decomposition of pig slurry and barley straw incorporated alone or in combination. A field experiment was conducted on a sandy loam unamended (control) or amended with 60 m^3 ha^{-1} **pig slurry (PS)** or 4 Mg ha^{-1} **barley straw (BS)**, or **both (PSBS)**. Surface CO_2 and N_2O fluxes, soil water content and temperature, microbial biomass C, and NO_3^- and NH_4^+ contents were monitored during 28 d in the 0- to 20-cm soil layer. Large CO_2 fluxes occurred during the first 4 h of the experiment in slurry-amended plots that were attributed to carbonate dissociation when slurry was mixed to the soil. Specific respiration activity (ratio of CO_2-C fluxes-to-microbial biomass C) was increased in slurry-amended soils for the first 7 d, likely due to the rapid oxidation of volatile fatty acids present in slurry. After 28 d, 26% more C had been evolved in PSBS than the sum of C released from PS and BS, indicating a synergistic interaction during decomposition of combined amendments. Adding straw caused a net but transient immobilisation of soil N, especially in PSBS plots where 36% of slurry-added NH_4^+ was immobilised after 3 d. Slurry-NH_4^+ was rapidly nitrified (within 10 d), but N_2O production was not a significant source of N loss during this study, representing less than 0.3% of slurry-added NH_4^+. Nevertheless, about twice the amount of N_2O was produced in PS than in PSBS after 28 d, reflecting lower soil N availability in the presence of straw. Our study clearly illustrates the strong interaction existing between soil C and N cycles under field conditions as slurry mineral N appeared to stimulate straw-C mineralisation, whereas straw addition caused a net immobilisation of slurry N.

Key words: Animal slurry, crop residues, C-N relationships, organic amendments.

Chantigny, M. H., Rochette, P. et Angers, D. A. 2001. **Évolution à court terme du carbone et de l'azote dans un sol amendé avec du lisier de porc et des pailles d'orge: expérience de champ.** Can. J. Soil Sci. **81**: 131–137. Les interactions survenant entre les lisiers et les résidus de culture peuvent avoir un impact sur la disponibilité de l'azote du sol au cours de leur décomposition. Notre objectif était de documenter la décomposition à court terme du lisier de porc et de la paille d'orge incorporés seuls ou simultanément. Une expérience de champ s'est déroulée sur un loam sableux non amendé (témoin) ou recevant 60 m^3 ha^{-1} de lisier de porc ou 4 Mg ha^{-1} de paille d'orge ou les deux. Les flux de CO_2 et de N_2O, l'humidité et la température du sol, la biomasse microbienne et les teneurs en NO_3^- et NH_4^+ du sol consécutifs aux amendements ont été mesurés pendant 28 j dans la couche 0–20 cm de sol. Les flux de CO_2 ont été très élevés au cours des 4 premières heures de mesure dans les parcelles avec lisier, et ont été attribués à une dissociation des carbonates du lisier dans le sol. La respiration spécifique (rapport entre flux de CO_2-C et C de la biomasse microbienne) s'est accrue de façon significative pendant 7 j suivant l'application de lisier et serait reliée à une oxydation rapide des acides gras volatils du lisier. Après 28 j, la quantité de C minéralisée dans le sol avec lisier et paille était 26 % plus élevé que la somme du C minéralisé dans le sol avec lisier ou paille seulement. Ceci suggère un synergisme dans la décomposition de la paille et du lisier lorsque incorporés simultanément. L'ajout de paille a causé une immobilisation nette mais transitoire du N du sol, spécialement dans le cas du sol avec lisier et paille où 36 % de l'azote minéral du lisier était immobilisé après 3 j. Malgré une nitrification rapide et presque complète du NH_4^+ du lisier après 10 j, la production de N_2O ne s'est pas avérée importante dans notre étude alors qu'elle représentait moins de 0,3 % de l'ammonium provenant du lisier. Toutefois, la quantité de N_2O produite après 28 j dans le sol avec lisier seulement a été le double de celle du sol avec lisier et paille, ce qui reflète une moins grande disponibilité d'azote dans le sol amendé avec de la paille. Notre étude illustre bien la forte interaction existant en les cycles du carbone et de l'azote du sol en conditions de champ; l'azote minéral du lisier aura stimulé la décomposition de la paille alors que l'ajout de paille aura causé une immobilisation temporaire de l'azote du lisier.

Mots clés: Effluents d'élevage, résidus de culture, relations C-N, amendements organiques.

Spreading of pig slurry generally increases soil mineral N content (Morvan et al. 1996, 1997) and must be carefully managed to avoid environmental problems such as ammonia volatilisation (Brunke et al. 1988; Rochette et al. 2001), nitrous oxide production (Bergstrom et al. 1994; Rochette et al. 2000a), and nitrate leaching (Morvan et al. 1997). Cereal straw can cause a temporary immobilisation of mineral N shortly after incorporation in the soil (Powlson et al. 1985; Ocio et al. 1991). By promoting slurry-N retention in soil, the simultaneous incorporation of cereal straw and pig slurry could overcome some environmental problems linked to slurry spreading on agricultural soils. On the other hand, pig slurry would stimulate the decomposition of plant residues with large C-to-N ratio, such as cereal straw, by providing

mineral N to soil decomposers (N'Dayegamiye and Dubé 1986; Saviozzi et al. 1997). Carbon and N interactions in soils amended with pig slurry and straw must be characterised to predict soil N availability following the spreading of animal slurries in the field.

Most results regarding C and N interactions in the context of animal slurry application come from laboratory experiments and must be validated under field conditions. We undertook a field experiment to investigate the short-term (28 d) C and N dynamics in a sandy loam amended with pig slurry and barley straw applied separately or in combination.

MATERIALS AND METHODS

Field Site

The study site was located on the Chapais research farm of Agriculture and Agri-Food Canada, 3 km south from Québec City (46°48′N, 71°23′W), Canada. The experiment was initiated 21 June 1998 on a St-Pacôme loamy sand (Gleyed Eluviated Sombric Brunisol) that had been cropped to barley from 1993 to 1997. In summer 1998, the site was subdivided into 16 plots of 2 m × 2 m in size, which were kept free of vegetation. The treatments were: no amendment (control), pig slurry at rate of 60 m^3 ha^{-1} (PS), barley straw added at 4 Mg ha^{-1} (BS), and combined amendments (PSBS). These application rates are common in the study area. Each treatment was replicated four times. Selected characteristics of the soil and the amendments are given in Table 1. In order to simulate the soil inversion resulting from moldboard plowing, the first 10 cm of soil was removed in all plots including the control. Except for the control, organic materials were then spread over the excavated surface. The plots not amended with pig slurry were supplied with the equivalent amount of water to eliminate a treatment effect on soil water content at the beginning of the experiment. The previously removed soil was replaced on top of the plots immediately after organic materials and/or water were added. The amount of C applied was 68.4 g C m^{-2} for PS, 163.5 for BS and 231.9 for PSBS. Respective amounts of N were 14.3, 3.5 and 17.8 g N m^{-2}. The plots were prepared so that the time elapsed since amendment was the same for all plots at time of first gas flux measurement.

Table 1. Selected characteristics of soil and amendments used in the present study

Properties[z]	Soil	Pig slurry	Barley straw
Clay (g kg^{-1})	98	ND	ND
Sand (g kg^{-1})	842	ND	ND
Total C (g kg^{-1})[y]	30.0	411.8	449.0
Total N (g kg^{-1})	2.0	86.0	9.5
pH_{H2O}	5.8	7.9	ND
Dry matter (g L^{-1})	ND	2.7	ND
Dry matter (g kg^{-1})	ND	ND	910.6
SOC (% total C)	ND	32.1	ND
IC (% total C)	ND	6.5	ND
VFA-C (% total C)	ND	30.1	ND
Org N (% total N)	ND	29.4	ND
NH_4-N (% total N)	ND	69.6	ND
NO_3-N (% total N)	ND	0.7	ND
NO_2-N (% total N)	ND	0.2	ND

[z]SOC, soluble organic C; IC, inorganic C; VFA-C, C present as volatile fatty acids; Org N, organic N; ND, not determined.
[y]Total C and N contents of pig slurry and barley straw are in g kg^{-1} dry matter basis.

Field and Laboratory Analyses

Soil-surface Gas Fluxes

In situ N_2O fluxes (F_{N2O}) were measured by the static chamber method detailed by Lessard et al. (1994) and briefly described as follows. One acrylic frame (0.60 m × 0.60 m; 0.14 m height; 6.35 mm wall thickness) was inserted to a depth of 10 cm in the centre of each plot immediately after replacing the top soil on the plots (time 0). The average height of the frames was measured at regular intervals during the experiment, using 48 measuring points per frame, to account for variations in headspace due to soil settling. At sampling time, the frames were covered with a lid and air samples were taken through a rubber septum after 0, 10, 20 and 30 min using 7.5-mL evacuated glass vials fitted with gas-tight rubber stopper. Gas samples in vials were analysed within 10 d for N_2O concentration using a gas chromatograph (Model 5890 Series II, Hewlett-Packard, North Hollywood, CA) as described by van Bochove et al. (1996) and Chantigny et al. (1998).

Soil-surface N_2O fluxes (F_{N2O}) were calculated according to Hutchinson and Livingston (1993). The amount of N_2O evolved between two consecutive measurements was estimated by calculating the average F_{N2O} between these two measurements and multiplying by the time elapsed during this period. Cumulative N_2O-N losses were calculated by summing the previous estimates over the entire experiment period. Amendment-induced N_2O losses were estimated as the differences in cumulative N_2O-N losses between amended and control plots.

In situ CO_2 fluxes (F_{CO2}) were measured by the dynamic closed chamber method detailed by Rochette et al. (1997). The same acrylic frames as for F_{N2O} measurements were used and F_{CO2} were measured using a plexiglass chamber (15 cm height) covering the same area as the frames and equipped with a CO_2 analyser (Model LI–6200, LI-COR Inc, Lincoln, NE). For each F_{CO2} measurement, the chamber was fixed to a frame and the CO_2 concentration inside the chamber was measured once every second during four successive 20-s periods. The F_{CO2} was calculated using the equation proposed by Rochette et al. (1997). The amount of CO_2 evolved between two successive measurement points and cumulative CO_2-C losses were calculated by interpolation as described for F_{N2O}. Amendment-induced C losses were estimated as the differences in cumulative CO_2-C losses between amended and control plots.

Soil Sampling and Analyses

Soil temperature was monitored at every F_{CO2} measurements, using copper-constantan thermocouples inserted to 10-cm depth. Measurements were taken with digital thermometer (Model HH23, Omega Inc., Stanford, CT). Precipitation was recorded daily using three calibrated rain gauges. Soil bulk density was recorded to 20-cm depth in

each plot, at time 0, 3 and 7 d, and then once a week using soil cores (Culley 1993). Soil samples were collected to 20 cm depth 0, 1, 3, 7, 10, 14, 21 and 28 d after amendment, and kept at 4°C until analysed.

Soil water content was measured by weight loss upon drying at 105°C for 24 h, and soil **water-filled pore space (WFPS)** was calculated using measured soil bulk densities and soil particle density of 2.65 g cm^{-3} (Carter and Ball 1993). **Microbial biomass C (MBC)** was measured on soil samples according to Voroney et al. (1993). Briefly, a 50-g subsample of fresh soil was fumigated for 24 h with chloroform in an evacuated desiccator, and then extracted with 100 mL of 0.25 M K_2SO_4 solution. Another 50-g subsample was directly extracted with the K_2SO_4 solution. The K_2SO_4-extractable C was quantified by UV-persulphate oxidation using an automated carbon analyser (Model DC–180, Dohrmann Co., Santa Clara, CA), and the difference in C content between fumigated and unfumigated samples was corrected using a k_{EC} factor of 0.45 to estimate soil MBC (Wu et al. 1990).

Soil mineral N content was measured by shaking 30 g of soil samples with 60 mL of 2 M KCl for 30 min. The slurries were then centrifuged (16 000 × *g*, 10 min) and filtered (Whatman no. 42). Ammonium concentration in the extracts was determined by colorimetry (N'Konge and Ballance 1982), whereas NO_3^- was detected in the UV at 210 nm using a liquid chromatograph (Model 4000i, Dionex, Sunnyvale, CA). All measured soil parameters were expressed on a surface basis (m^{-2}) using measured soil bulk densities.

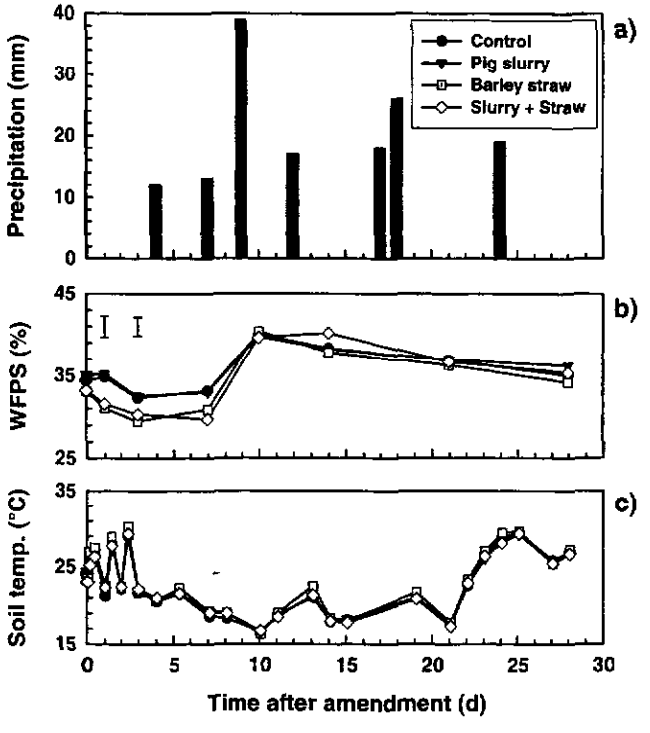

Fig. 1. Environmental and soil conditions (0–20 cm depth) during the course of the experiment. (a) precipitation, (b) soil water-filled pore space, (c) soil temperature. Bars on Fig. 1b represent protected LSD values when ANOVA was significant at $P < 0.05$.

Statistical Analyses

Statistical significance of F_{N2O} and F_{CO2} was determined according to Hutchinson and Livingston (1993) and Rochette et al. (1997), respectively. Analyses of variance were performed on soil parameters and cumulative CO_2 and N_2O production using a randomised complete block design with amendment type as the treatment and four replicates. Protected LSD test was performed when ANOVA was significant at $\alpha = 0.05$ (SAS Institute, Inc. 1989). Least significant difference values are presented directly on graphs or in the text.

RESULTS AND DISCUSSION

Environmental Conditions

Precipitation occurred at regular intervals during the experiment with one large (38-mm) rainfall on day 9 (Fig. 1a).

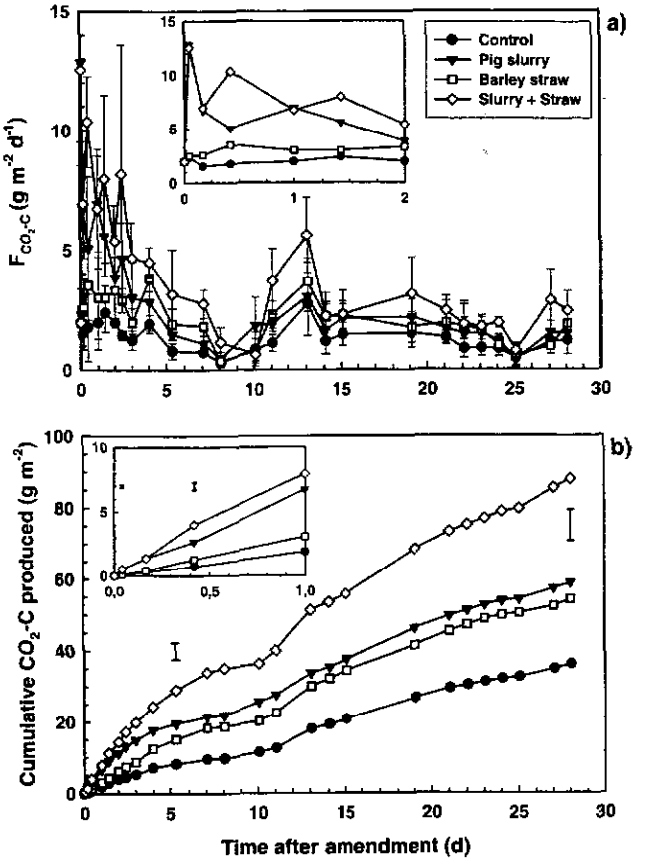

Fig. 2. Surface CO_2 fluxes (a), and cumulative CO_2-C emissions (b), recorded during 28 d following soil amendment with pig slurry, barley straw, both or none. Insets, exploded view of the first measurement points. Bars on Fig. 2a represent standard error; bars on Fig. 2b represent protected LSD values. Treatment effects were significant at $P < 0.05$ from 1 h to 28 d. However, for the sake of clarity, only selected LSD values are illustrated.

Soil WFPS varied between 32 and 41% during the course of the study (Fig 1b). The values decreased from day 0 to day 7, increased to maximum value following rainfall on day 9, and then decreased slowly until the end of the study. Soil temperature fluctuated from 16 to 30°C and was warmer (21 to 30°C) from day 0 to day 3 and from day 22 to day 27 than from day 4 to day 21 (16 to 24°C) (Fig. 1c). All those parameters were generally not significantly ($P > 0.05$) different among the treatments, indicating that soil environmental conditions were similar in all plots during the experiment.

Carbon Transformations

Large increases in F_{CO2} were recorded immediately following slurry incorporation and were of the same magnitude in PS and PSBS treatments (Fig. 2a, inset). However, this response of the soil to slurry addition was short-lived and F_{CO2} had already decreased by about 50% after 4 h, and gradually decreased thereafter. Carbonates accumulate during anaerobic storage of pig slurry (Sommer and Sherlock 1996) and should be rapidly released when the alkaline slurry is applied to an acidic soil. This phenomenon mostly explains the large but transient F_{CO2} recorded following slurry application since the total amount of C evolved during the first 10 h of the experiment represented 5% of total slurry-added C, which is close to the proportion of carbonate-C (in organic C) initially present in the slurry (Table 1). After the initial flush, F_{CO2} decreased and were most of the time largest in PSBS, intermediate in PS and BS, and lowest in the control (Fig. 2a).

Treatment effect on CO_2-C losses was already significant ($P < 0.05$) 1 h after soil amendment and remained significant until the end of the experiment. After 5 d, cumulative C losses were greatest in PSBS, intermediate in PS and BS and lowest in the control (Fig. 2b). This order remained the same and statistically significant ($P < 0.05$) until the end of the experiment. After 28 d, the fraction of CO_2-C loss attributable to the organic amendments (corrected for control) amounted to 23, 19 and 53 g C m^{-2} for PS, BS and PSBS, respectively, representing 34, 12 and 23% of total added C, respectively. Those values are in line with Dendooven et al. (1998) and Rochette et al. (2000b) who reported rapid C losses when pig slurry was added to soil. The difference in CO_2-C loss between PS and BS (4 g C m^{-2}) was mostly explained by the carbonate-induced burst in F_{CO2}, as it appeared at the beginning of the experiment (day 1) and remained constant thereafter (Fig. 2b). This result also indicates that in the short term, slurry- and straw-C were of similar lability. After 28 d, the amount of CO_2-C released in PSBS was 26% ([53 – (23 + 19)]/(23 + 19)) above the sum of C lost in PS and BS, indicating a positive interaction when slurry and straw were incorporated together. In a laboratory experiment, Saviozzi et al. (1997) reported a 23% increase in CO_2-C losses when pig slurry and wheat straw were incubated together for 230 d. However, looking at cumulative CO_2 curves presented by Saviozzi et al. (1997), it appears that the positive interaction reported between straw and slurry was already present during the first 50 d of incubation. Our findings are in accordance with the previous studies in which pig slurry application promoted decomposition of fresh organic matter (N'Dayegamiye and Dubé 1986; Saviozzi et al. 1997; Sørensen 1998). As argued in those previous studies we assume that the large amount of mineral N added through pig slurry stimulated the decomposition of C-rich residues.

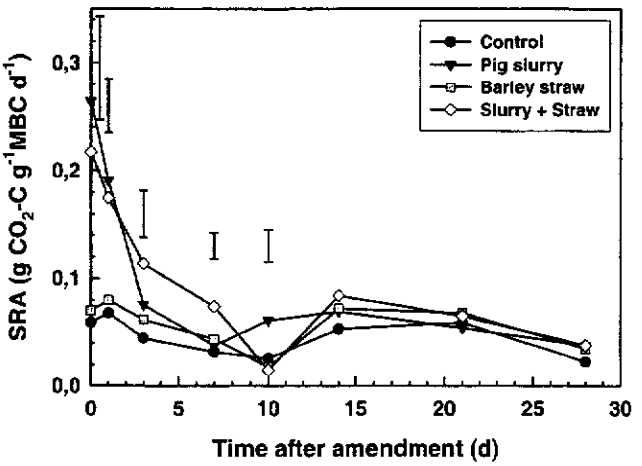

Fig. 3. Specific respiration activity as calculated during 28 d following soil amendment with pig slurry, barley straw, both or none. Bars on the graph represent protected LSD values when ANOVA was significant at $P < 0.05$.

Incorporation of slurry and straw in the soil did not result in significant increases in MBC, although the values were most of the time larger in soil amended with straw (data not shown). The specific respiration activity (SRA; ratio of daily mean F_{CO2}-to-MBC) was significantly ($P < 0.05$) increased in soil following the application of slurry with or without straw (Fig. 3). As discussed earlier for F_{CO2}, large SRA values in slurry-amended soils during the first day of the experiment were mostly caused by the release of CO_2 from carbonates. However, SRA values recorded after day 1 were assumed to be mostly of biological origin. The SRA decreased sharply during the first 3 d in slurry-amended soils, and was not significantly different among treatments after 10 d. It has been previously demonstrated that volatile fatty acids present in anaerobically stored pig slurry are metabolised within a few days after soil amendment (Kirchmann and Lundvall 1993; Sørensen 1998). In our study, 30% of total slurry-C was accounted for by volatile fatty acids (Table 1). Excluding the first 10 h of the experiment, to avoid the carbonate-induced F_{CO2}, 28% of slurry-added C had been mineralised after 7 d in PS plots (Fig 2b). We thus assume that SRA values following slurry application reflected the response of soil microbes to the addition of volatile fatty acids. Because MBC was little influenced by the addition of slurry, increased soil CO_2 fluxes following amendment was likely the reflect of higher respiration rate per unit biomass rather than the increase in number of microorganisms.

Nitrogen Transformations

Soil NH_4^+ content was drastically ($P < 0.05$) increased by slurry addition (Fig. 4a). However, this effect was short-

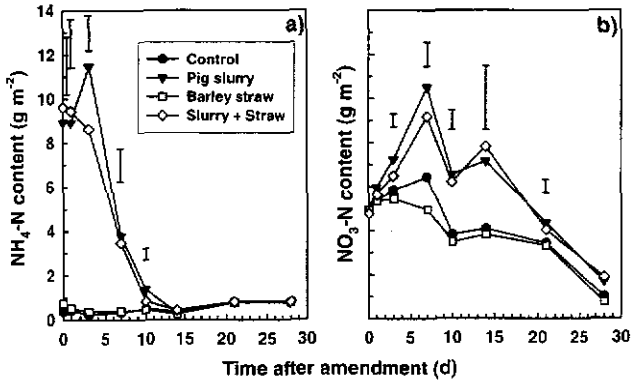

Fig. 4. Soil ammonium and nitrate contents during 28 d following soil amendment with pig slurry, barley straw, both or none. Bars on graphs represent protected LSD values when ANOVA was significant at $P < 0.05$.

Table 2. Treatment-induced changes in soil mineral N (NO_3^- + NH_4^+) content during the experiment[a]

Time after amendment (d)	Pig slurry (g N m^{-2})	Barley straw (g N m^{-2})	Slurry + straw (g N m^{-2})	LSD
0	8.62*a*	0.42*b*	9.11*a*	2.9
1	9.05*a*	0.06*b*	9.27*a*	2.4
3	12.62*a*	−0.24*c*	9.02*b*	1.9
7	7.56*a*	−1.39*c*	5.91*b*	1.4
10	3.56*a*	−0.39*b*	2.70*a*	0.9
14	3.01*a*	−0.37*b*	3.79*a*	2.9
21	0.89*a*	−0.13*b*	0.61*a*	0.7
28	0.68*a*	−0.26*b*	0.90*a*	0.9

[a]Values were corrected for soil mineral N content in control soil.
a–c Values on the same line followed by different letters are significantly different at $P < 0.05$.

lived since soil NH_4^+ content returned to background levels 10 d after slurry addition. In the absence of N uptake by plants, NH_4^+ disappearance can be explained by NH_3 volatilisation, nitrification or immobilisation (Morvan et al. 1996, 1997). Ammonia volatilisation was likely small in our case, because the slurry was incorporated at 10-cm depth, which strongly reduces volatilisation (Brunke et al. 1988; Rochette et al. 2001).

Compared with the control, slurry application immediately increased soil mineral N content by 8.6 g N m^{-2} in PS and 9.1 in PSBS (Table 2). Because total mineral N brought by the slurry amounted 10.0 g N m^{-2}, recovery of slurry-NH_4^+ varied from 86 to 91%. Although not significant, soil mineral N content was slightly lower in BS than in control plots from days 3 to 28. Soil mineral N content was significantly ($P < 0.05$) lower in PSBS than in PS plots at days 3 and 7. These results indicate that part of the soil N was immobilised following straw addition, as previously reported (Powlson et al. 1985; Ocio et al. 1991). The maximum N immobilisation occurred in PSBS at day 3 and represented 36% of slurry NH_4-N added to the soil. The amount of N immobilised was greater in PSBS than in BS, likely because mineral N availability was limiting microbial activity in BS. The amount of N immobilised in BS and PSBS decreased after 7 d until the end of the study. Because there was no significant difference in soil organic N among treatments at the end of experiment (data not shown), we assume that the net immobilisation phase due to straw incorporation was only transient.

Nitrification of NH_4^+ has been found to occur rapidly after spreading of pig slurry (Flowers and O'Callaghan 1983; Morvan et al. 1996). This was also the case in our study, as shown by an increase in NO_3-N content (5 g m^{-2}) in slurry-amended soils during the first 7 d of the present study (Fig. 4b). In addition, this increase in NO_3-N accounted for about 90% of net NH_4-N disappearance (5.6 g m^{-2}) during the first 7 d of study (Fig. 4a). Maximum NO_3^- contents were recorded after 7 d in all treatments and ranked as follows: PS > PSBS > control > BS ($P < 0.05$; Fig. 4b). In the absence of plant uptake, the decrease in soil NO_3^- in all plots after 7 d may have been caused by gaseous emissions (Rochette et al. 2000a) or leaching below the sampled soil layer (Morvan et al. 1996, 1997). The rapid accumulation of NO_3^- in slurry-amended soils indicates that pig slurry should preferably be applied to soil in the presence of an actively growing crop to reduce potential risk of N loss through denitrification and leaching.

The F_{N2O} were generally low in the sandy loam studied, and most losses were recorded in slurry-amended soils from days 7 to 11 (Fig. 5a) when soil WFPS was around 40%. It thus appears that N_2O production was not a significant mechanism of N loss in our study. This is in agreement with Chantigny et al. (1998) who did not report significant denitrification and N_2O production in sandy soils at WFPS < 45%.

Cumulative N_2O-N losses were significantly ($P < 0.05$) larger in slurry-amended soils than in BS or control soil after 2 d (Fig. 5b), which is in line with previous studies reporting increased N_2O production following spreading of animal slurries (de Klein and van Logtestijn 1994; Clough et al. 1998; Rochette et al. 2000a). From day 8 until the end of the experiment, cumulative N_2O-N losses in PSBS were significantly ($P < 0.05$) less than in PS (Fig. 5b) likely because of N immobilisation during the initial phase of straw decomposition, which decreased N availability to soil microbes.

After 28 d, cumulative N_2O-N losses accounted for 26, 15, 3 and 3 mg m^{-2} for PS, PSBS, BS and control, respectively (Fig. 5b), representing less than 0.3% of total NH_4^+ added in PS and PSBS. Nitrous oxide production following spreading of animal slurry largely depends on nitrification, which produces some N_2O and supplies NO_3^- to denitrifiers (Hutchinson and Davidson 1993; Bergstrom et al. 1994). Given the sensitivity of nitrification and denitrification to soil conditions, the proportion of added N that can be lost as N_2O in slurry-amended soils varies widely ranging from < 0.1% (Coyne et al. 1995) to > 15% (de Klein and van Logtestijn 1994), with values generally below 5% (Stevens and Laughlin 1997; Clough et al. 1998). N_2 and NO production were not investigated in our experiment and may have been important mechanisms of gaseous N loss. In a

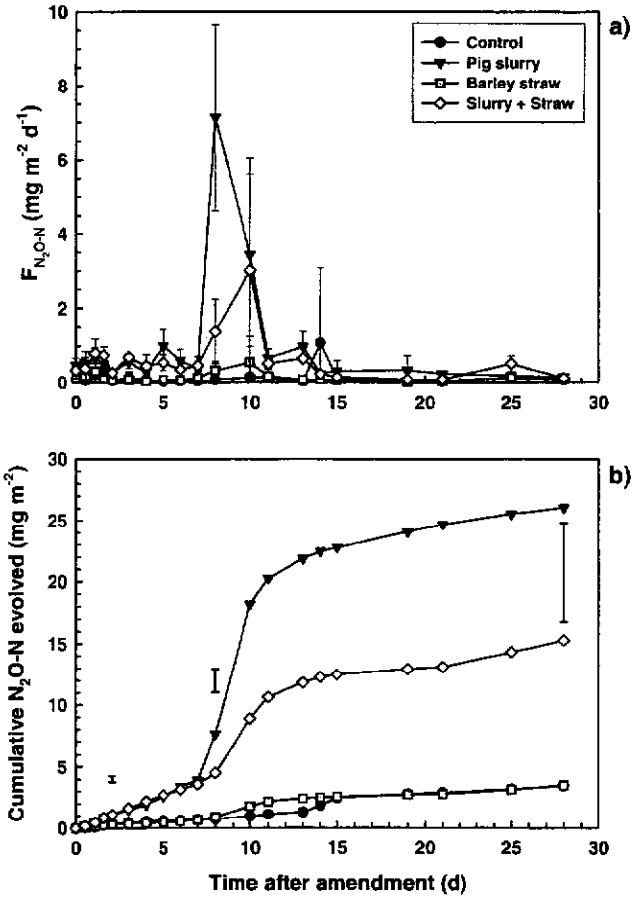

Fig. 5. Surface N_2O fluxes (a), and cumulative N_2O-N emissions (b), recorded during 28 d following soil amendment with pig slurry, barley straw, both or none. Bars on Fig. 5a represent standard error; bars on Fig. 5b represent protected LSD values. Treatment effects were significant at $P < 0.05$ from days 2 to 28. However, for the sake of clarity, only selected LSD values are illustrated.

sandy soil, Watanabe et al. (1997) reported a NO to N_2O ratio of up to 13, especially at WFPS below 60%. On the other hand, Clough et al. (1998) reported N_2 to N_2O ratios up to 33 in sandy soils. Even when using these large ratios, estimations of total gaseous N losses would not exceed 11% of total added N in slurry-amended soils. Considering that most mineral N had disappeared at 28 d (Fig. 4), it appears that gaseous emissions were not the major pathway for N losses in our study, and N losses were most likely due to NO_3^- leaching below 20-cm depth. Leaching can be important in well-drained soils because of high hydraulic conductivity, and might represent a significant way of N loss when rapid nitrification (Morvan et al. 1996, 1997) and large precipitation occur such as observed in our study.

In conclusion, our field study clearly illustrates the strong interaction existing between soil C and N cycles when C-rich (BS) and N-rich (PS) residues are incorporated at the same time. A synergistic effect was found between pig slurry and cereal straw as slurry-NH_4^+ appeared to stimulate the mineralisation of straw-C, whereas addition of barley straw resulted in a transient immobilisation of 36% of slurry-NH_4^+, and markedly reduced N_2O production. However, the rapid accumulation of soil NO_3^- indicate a possible risk of N losses though denitrification and leaching when pig slurry is applied to a bare soil.

ACKNOWLEDGEMENTS

This project was supported by the PERD-Climate Change Program of AAFC. We thank M. Duval and N. Bertrand for field work, N. Bissonnette and P. Jolicoeur for technical assistance and J. Tremblay for statistical analyses.

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