PhD plan

The overall aim of this PhD study is to determine greenhouse gas emissions for management (storage and field application) of digestates and untreated manure. Further, the work will investigate sources of N_2O in digestate/manure-amended soil, and provide input data for a sub-model of N_2O emissions from soil. During an international exchange visit to Agriculture & Agrifood Canada, Quebec, experimental data will be analyzed to establish overall GHG balances for digestates and reference materials.

Background

Biogas treatment, by reducing waste dry matter and degradable C, may reduce decomposer activity, including methanogenesis during storage (Sommer et al., 2000) and denitrification processes after field application (Petersen, 1999). Biogas treatment also increases the mineral N content, resulting in a higher concentration of ammoniacal-N compared to untreated slurry which may promote nitrification in the soil. These treatment effects can influence the potentials for emission of methane (CH_4) and nitrous oxide (N_2O), and hence the greenhouse gas balance, of manure and co-digestates.

During storage, a floating natural crust is formed on the slurry surface which is responsible for C and N turnover. The surface crust is a source of N_2O production (Petersen et al., 2013) as it facilitates for gas exchange and regulates the microbial activities (Sommer et al., 2000). Even though, the GHG balance is dominated by methane in a storage (Petersen et al., 2013), it could be important to investigate sources of N_2O from the crusts via isotopic ratios or isotopomers of the emitted N_2O from the crust to abate the GHG.

Soil N_2O production and emission process are complex, and N_2O may be produced via nitrification, nitrifier-denitrification or denitrification processes. One new approach to identify the specific sources of N_2O is by analysis of N_2O isotopomers, including experiments with ^{15}N labeled substrates. On the basis of isotopomer composition (central and terminal ^{15}N isotope ratios), site preference (SP) may be calculated and help to determine the sources depending upon values, indicated from pure-culture studies to be 33% and ~0% for ammonia oxidation and denitrification respectively (Sutka et al., 2003, 2006, Koester et al., 2011).

Several studies have suggested that digestion of slurry could be an option to reduce N_2O emissions after field application (Petersen, 1999, Amon et al., 2006, Bertora et al., 2008). However, Oenema et al. (2005) found a consistent reduction of N_2O from digested slurry applied to sandy soil, but not when applied to clay. Similarly, Saunders et al. (2012) observed higher numbers of nitrifier and denitrifier genes, and N_2O efflux, in anaerobic digested slurry compared to untreated slurry.These results suggest that there is a complex interaction among slurry types, slurry treatments, soil moistures and textures.

In the soil, liquid manure (slurry) application alters the conditions for N_2O production by increasing soil moisture, providing easily degradable C and readily available mineral N (Koester et al., 2011). The moisture threshold for emissions of N_2O is in the range 60-80% (Machefert and Dise, 2004). Davidson (1991) presented a conceptual model on balance of N_2O and N_2 under different moisture conditions. This model was re-interpreted by Thomsen et al. (2010) to consider O_2 demand and supply ratios in the context of the field- slurry application. According to O_2 demand and supply conceptual model; N_2O emissions would increase after slurry application in relatively dry or carbon limited soil by increasing the demand for O_2, whereas N_2O emissions would reduce by further transformation to N_2 in a soil which already conducive to N_2O emissions. Application of digestates reduce the N_2O emissions compared to untreated slurry by reducing the demand for O_2 under relatively dry or carbon limited soil, whereas the increase the emissions in the soil which is already suitable for N_2O emissions. This suggests that the regulation of N_2O emissions is complex, and recommendations for application of digestates and untreated slurry must taking soil moisture and texture, as well as slurry properties, into consideration to mitigate N_2O emissions.

Objectives and hypotheses

The overall objectives are :

- ✓ To quantify emissions of greenhouse gases during storage and after field application of digestates and untreated manure .
- ✓ To investigate sources of N_2O during storage and after field application using ^{15}N isotope analyses
- ✓ To develop, based on experimental data from this project and other studies, GHG balances for digestates and reference materials (collaboration with Agriculture & AgriFood Canada).

Expected outputs

- ✓ Articles from laboratory work
    1. Effect of digestates and untreated manures on N_2O emissions with different soil moisture levels and soil types
    2. Emissions of CH_4 and N_2O during storage of digestates and manure, with special focus on N_2O dynamics
    3. Nitrogen dynamics and N_2O emissions after field application of digested and untreated slurry
- ✓ Oral and poster presentation in international conferences
- ✓ Improved submodel for estimating N_2O emissions from soil, data for validation of submodel for CH_4 emissions during storage

Project description

Part 1.

The effects of soil conditions, in particular texture and moisture, and manure/digestate properties on N_2O emissions and source distribution will be examined. It is hypothesized that anaerobic digestion will be most effective as mitigation strategy in situations where denitrification is the main source of N_2O (Petersen and Sommer, 2011). Factorial experiments will be conducted with: i) three water levels (60, 70, 80% WFPS); and ii) four slurry treatments (Control; cattle slurry (CS); pig slurry (PS); digested slurry (DS)); separate experiments are conducted with each of two soil types.

In these incubation experiments, the soil nitrate pool will be labeled with ^{15}N, and isotope recovery in N_2O isotopomers will be analyzed to obtain information about sources of N_2O.

Based on results from the first incubation experiments, a screening of digestates provided by WP3 during spring 2014 will be conducted under conditions where high impact of slurry properties on N_2O emissions is expected. Results from incubation experiments will be used for validation of an existing N_2O submodel (Sommer et al. 2004).

Part 2.

Digestates from biogas plants associated with the BioChain project will be stored at pilot-scale together with a manure reference. In order to simulate realistic storage conditions, the experiment will be conducted in a pilot-scale facility (Petersen et al., 2009) where emissions of GHG can be monitored during a realistic period.

Depending on organic matter content, a surface crust may form from organic matter in manure and co-digestates. This is a source of N_2O, but the importance of nitrification and denitrification processes is unknown. Using $^{15}N_2O$ analyses during both continuous ventilation and batch incubation, the sources of N_2O will be explored.

Part 3.

Stored materials will be used for a field experiment in spring 2015, where N_2O emissions and soil mineral N dynamics after application of digestates and reference materials will be quantified until emissions return to background levels. Soil moisture conditions will be monitored. These results will be used for validation of laboratory results and N_2O submodel.

Data from laboratory incubations, pilot-scale storage experiment, and field experiment will be used as input for a farm-model of GHG emissions. This work will be planned in collaboration with AAFC, Quebec (M. Chantigny), who will host an exchange visit.

Time schedule

PhD study plan

Activities	2013/14				2014/15				2015/16			
	S-N	D-F	M-M	J-A	S-N	D-F	M-M	J-A	S-N	D-F	M-M	J-A
Experimental works												
Incubation experiment with digestates, sources of N2O	🟩	🟩	🟩	🟩								
Storage experiment			🟩	🟩	🟩	🟩	🟩					
Field experiment						🟩	🟩	🟩				
Courses												
Introduction to R (1 ECTS)	▨											
Study design and analysis (5 ECTS)	▨											
Academic english for non-Denish Speaker (3 ECTS)	▨											
Isotope methods for studying carbon and nutrient dynamics (5 ECTS)	🟧											
Applied statistics with R for the agricultural, life and veterinary sciences (6 ECTS)				🟩								
scientific writing course (3 ECTS)			🟩									
Optimisation of value chains for biogas production in Denmark (2 ECTS)		🟩										
Stable isotope ecology (5 ECTS)		🟩										
Dissemination												
Conference on the Nitrogen challenge: building a blueprint for nitrogen use efficiency and food security. 18th Nitrogen Workshop, Lisbon Portugal				🟩								
Oral presentation at the Climate, Food and Farming (CLIFF) Research Network workshop 2013		▨										
Assist to Søren and Jørgen for teaching							🟩	🟩	🟩	🟩	🟩	
Assist to Søren and Jørgen for reviewing a paper						🟩	🟩	🟩	🟩	🟩		
Conference: International annual meeting of American Society of Agronomy (ASA)									🟩			
Research Environment												
Exchange visit (3 months), farm model(AAFC)									🟩			
Publication												
1. Effect of digestates and untreated manures on N2O emissions with different soil moisture levels and soil types						🟩	🟩					
2. Emissions of CH4 and N2O during storage of digestates and manure, with special focus on N2O dynamics									🟩	🟩		
3. Nitrogen dynamics and N2O emissions after field application of digested and untreated slurry											🟩	🟩
Thesis writing										🟩	🟩	🟩

▨ Finished
🟧 on going
🟩 planned

References

AMON, B., KRYVORUCHKO, V., AMON, T. & ZECHMEISTER-BOLTENSTERN, S. 2006. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. *Agriculture, Ecosystems & Environment,* 112**,** 153-162.

BERTORA, C., ALLUVIONE, F., ZAVATTARO, L., VAN GROENIGEN, J. W., VELTHOF, G. & GRIGNANI, C. 2008. Pig slurry treatment modifies slurry composition, N2O, and CO2 emissions after soil incorporation. *Soil Biology and Biochemistry,* 40**,** 1999-2006.

DAVIDSON, E. A. 1991. Fluxes of nitrous oxide and nitric oxide from terrestrial ecosystems.In: Rogers, J.E., Whitman, W.B. (Eds.), Microbial Production and Consumption of Greenhouse Gases: Methane, Nitrogen Oxides and Halomethanes. *American Society for Microbiology,* Washington (DC), **,** 219-235.

KOESTER, J. R., CARDENAS, L., SENBAYRAM, M., BOL, R., WELL, R., BUTLER, M., MUEHLING, K. H. & DITTERT, K. 2011. Rapid shift from denitrification to nitrification in soil after biogas residue application as indicated by nitrous oxide isotopomers. *Soil Biology & Biochemistry,* 43**,** 1671-1677.

MACHEFERT, S. E. & DISE, N. B. 2004. Hydrological controls on denitrification in riparian ecosystems. *Hydrology and Earth System Sciences,* 8**,** 686-694.

OENEMA, O., WRAGE, N., VELTHOF, G., GROENIGEN, J. W., DOLFING, J. & KUIKMAN, P. 2005. Trends in Global Nitrous Oxide Emissions from Animal Production Systems. *Nutrient Cycling in Agroecosystems,* 72**,** 51-65.

PETERSEN, S., DORNO, N., LINDHOLST, S., FEILBERG, A. & ERIKSEN, J. 2013. Emissions of CH4, N2O, NH3 and odorants from pig slurry during winter and summer storage. *Nutrient Cycling in Agroecosystems,* 95**,** 103-113.

PETERSEN, S. O. 1999. Nitrous oxide emissions from manure and inorganic fertilizers applied to spring barley. *Journal of Environmental Quality,* 28**,** 1610-1618.

PETERSEN, S. O., SKOV, M., DROSCHER, P. & ADAMSEN, A. P. S. 2009. Pilot Scale Facility to Determine Gaseous Emissions from Livestock Slurry during Storage. *Journal of Environmental Quality,* 38**,** 1560-1568.

PETERSEN, S. O. & SOMMER, S. G. 2011. Ammonia and nitrous oxide interactions: Roles of manure organic matter management. *Animal Feed Science and Technology,* 166–167**,** 503-513.

SAUNDERS, O. E., FORTUNA, A.-M., HARRISON, J. H., COGGER, C. G., WHITEFIELD, E. & GREEN, T. 2012. Gaseous Nitrogen and Bacterial Responses to Raw and Digested Dairy Manure Applications in Incubated Soil. *Environmental Science & Technology,* 46**,** 11684-11692.

SOMMER, S. G., PETERSEN, S. O. & SØGAARD, H. T. 2000. Greenhouse Gas Emission from Stored Livestock Slurry. *J. Environ. Qual.,* 29**,** 744-751.

SUTKA, R. L., OSTROM, N. E., OSTROM, P. H., BREZNAK, J. A., GANDHI, H., PITT, A. J. & LI, F. 2006. Distinguishing nitrous oxide production from nitrification and denitrification on the basis of isotopomer abundances. *Applied and Environmental Microbiology,* 72**,** 638-644.

SUTKA, R. L., OSTROM, N. E., OSTROM, P. H., GANDHI, H. & BREZNAK, J. A. 2003. Nitrogen isotopomer site preference of N2O produced by Nitrosomonas europaea and Methylococcus capsulatus Bath. *Rapid Communications in Mass Spectrometry,* 17**,** 738-745.

THOMSEN, I. K., PEDERSEN, A. R., NYORD, T. & PETERSEN, S. O. 2010. Effects of slurry pre-treatment and application technique on short-term N2O emissions as determined by a new non-linear approach. *Agriculture Ecosystems & Environment,* 136**,** 227-235.