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Soil Quality — Guidance on methods for measuring greenhouse gases (CO_2, N_2O, CH_4) and ammonia (NH_3) fluxes between soils and the atmosphere

Qualité du sol — Recommandations sur les méthodes de mesure des gaz à effet de serre (CO_2, N_2O, CH_4) et des flux d'ammoniac (NH_3) entre les sols et l'atmosphère

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Introduction

Greenhouse gas (GHG) emissions from soils have become a major environmental concern. Global and national emission inventories have identified soils, in particular agricultural soils, as being a major contributor to these emissions, in particular nitrous oxide (N_2O), methane (CH_4) and carbon dioxide (CO_2) related to loss of soil organic matter. Agricultural soils are also major emitters of ammonia (NH_3), which is a precursor of N_2O. Changes in soil management should take account of these emissions as part of efforts to mitigate climate change.

GHGs and ammonia fluxes from soil are complex to measure. They are variable and heterogeneous as they are governed by weather/meteorological conditions (e.g. temperature and moisture regimes), soil characteristics (e.g. soil parental material, pH, clay content, cation exchange capacity) and for managed soils by the agricultural or forestry practices (e.g. crop and wood residues management, soil tillage or no-tillage, inputs of soil conditioner and fertilizers, irrigation). These factors generally interact and their effects on GHG emissions are still poorly quantified. It results in large uncertainties for the inventories of national and global agricultural emissions. For example, Freibauer (2008)[1] has estimated an uncertainty at 80 % for European (EU27) agricultural N_2O emissions. With the reinforcement of international and regional climate policies, comparable and reliable information is needed to report on GHG emissions but also to adopt and verify mitigation options.

No standard covers the measurement of GHGs and ammonia emissions from soils. However, several measurement methods have been developed. This document provides guidance on the main methods available to quantify the exchanges of greenhouse gases (CO_2, N_2O, CH_4) and ammonia (NH_3) between soils and the atmosphere. It is intended to help users to select the measurement method or methods most suited to their purposes by setting out information on the application domain and the main advantages and limitations of each methods.

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Soil Quality — Guidance on methods for measuring greenhouse gases (CO_2, N_2O, CH_4) and ammonia (NH_3) fluxes between soils and the atmosphere

1 Scope

This document gives an overview and provides guidance on the main methods available to quantify the exchanges of greenhouse gases (CO_2, N_2O, CH_4) and ammonia (NH_3) between soils and the atmosphere.

It is intended to help users to select the measurement method or methods most suited to their purposes by setting out information on the application domain and the main advantages and limitations of each methods.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

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— IEC Electropedia: available at http://www.electropedia.org/

3.1
intrusive method
measuring method that can influence the emitting processes

3.2
mass balance approach
method based on a mass balance consisting of measuring the flux of compounds entering and leaving a volume of air above the soil surface being studied

3.3
micrometeorological method
method using analyses of the atmospheric concentration of the gas and meteorological measurements such as wind speed, wet and dry-bulb air temperatures, net radiation, and heat fluxes.

Note 1 to entry: These techniques are used for determining field-scale fluxes, and include eddy covariance, energy balance, aerodynamic and mass balance technique. They do not disturb the environmental conditions.

3.4
oasis effect
effect arising from the local environment of the field being studied and affecting emissions from a particular field depending on whether it is in an environment with a high level of emissions or a low level of emissions

Note 1 to entry: the oasis effect will only affect compounds whose fluxes result from a thermodynamical equilibrium between the surface and the atmosphere (NH_3).

4 Methods for measuring GHGs and ammonia fluxes between soil and the atmosphere

There are methods for measuring ammonia and GHG fluxes between soil and the atmosphere for a diversity of conditions and spatio-temporal resolutions (from less than an hour up to several days, from the soil sample up to several square kilometres) (this section). The main methods generally involve air sampling and determination of the concentration of the gas(es) of interest. Several concentration measurement and air sampling methods are compatible with a given flux measurement strategy (see Clause 5). The methods used and their combination depend on the purpose for which the measurements will be used, the operators' qualifications and the financial resources available (see Clause 6).

Two main strategies can be used:

a) chamber methods measuring the fluxes at source, and

b) atmospheric method used to estimate the fluxes at a distance from the source.

NOTE 1 Chamber methods are intrusive methods based on using static or dynamic flux chambers. Static and dynamic flux chambers can only quantify emissions for a small area of the source. Fluxes generally vary in time (variations in the parameters for weather and season) and in space (different soils and climatic conditions). For spatial extrapolation at field-scale, a sampling strategy using several chambers is required to reflect the variations in emissions over the area. Flux spatial structure could be determined by exploratory measurements prior to monitoring, or by assuming that flux will vary according to soil properties (e.g.: texture, organic matter content) or landscape features (e.g.: position in a slope). These methods can also be applied under laboratory conditions to determine the emissions of gases from soil samples, but hard to scale-up to field scale.

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NOTE 2 Atmospheric methods are non-disruptive. The net exchange is estimated by measuring concentrations at a distance from the source together with micrometeorological measurements (e.g.: wind, air temperature). The fluxes are then estimated on the basis of these measurements, with a mass-balance approach or with models. Some of these methods are fairly difficult to implement and are highly dependent on weather conditions. Some knowledge of micrometeorology is generally required. They can be used to characterize global fluxes from heterogeneous, diffuse sources within a given area, without being able to distinguish the contribution of each particular source. In particular, atmospheric methods measure both soil and vegetation contributions, if there is active vegetation.

Table 1 presents the different methods and their main advantages and limitations.

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Table 1 — The different methods and their main advantages and limitations

	Application domain	Main advantages	Main limitations
Chambers methods			
Static flux chambers	— Applicable to low fluxes — Mainly used for comparison of treatments — Applicable in field and in laboratory — Small area (~m^2) — Can be automated for monitoring dynamics over short periods — Non-reactive gases (CO_2, CH_4, N_2O)	— Easy to implement — High sensitivity even with low instrumental precision — Evaluation of spatial variability with several chambers — Most common flux measurement methods with many methodological references	— Intrusive method modifying emissions conditions. Chambers may alternate between locations (provide multiple chamber bases) to limit the impact of the chamber on the soil environment and hence emissions. — Spatial extrapolation of measurements requires a sampling strategy using several chambers with spatial and temporal extrapolation models.
Dynamic flux chambers and wind tunnels	— Comparison of treatments — Applicable in field and in laboratory — Small area (~m^2)	— Possible control of wind speed — Preferred for reactive gas such as NH_3	— Intrusive method modifying emissions conditions — Very difficult to extrapolate results to representative field emissions — The oasis effect can increase or decrease the apparent flux

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Table 1 *(continued)*

	Application domain	Main advantages	Main limitations
Atmospheric methods			
Mass-balance methods	— Continuous monitoring — Real conditions — Comparison of treatment	— Easy to implement and not expensive — Non-intrusive method — Can be used for small areas (few tens of square metres)	— Need a large number of measurement points — Background concentration should be measured accurately
Inverse modelling		— Easy to implement and not expensive — Non-intrusive method — Small numbers of measurement points — Can be used to estimate emissions from several sources simultaneously, if there is a sufficient number of sensors (n+1 where n is the number of sources).	— Suitable for uniform, major emissions sources with low and fairly constant background concentrations — Not suitable for areas with hedges or scattered trees or with significant changes in surface roughness — Deployment over extended periods with changes in wind direction requires multiple measurement points to cover all wind directions.
Aerodynamic gradient	— Continuous monitoring — Real conditions — Allows measuring atmospheric deposition	— Non-intrusive method — Measures the flux from the surface directly — Can be used to monitor multiple sources	— Difficult to implement and expensive — Assumes a large uniform emitting surface
Eddy-covariance		— Applicable to large areas (>1 ha) — Non-intrusive method	— Very difficult to implement and expensive — Assumes a uniform emitting surface. Methodologies are in development to distinguish different emitting surfaces through flux footprint analysis (see for example Cowan et al. 2016[2]; Bureau et al. 2017[3]). — Requires high speed sensors for wind and gas concentrations, but method derived from eddy-covariance such as disjunct eddy-covariance (DEC) have been developed for measuring fluxes without high speed analysers — In development, for reactive gases such as NH_3 — Flux underestimation when turbulence is low, particularly during nights.

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5 Concentration measurements and air sampling

5.1 General

Methods for measuring soil-atmosphere exchange of GHGs and ammonia involve the determination of gas concentrations in volumes of air. There are various methods to determine the concentrations, involving air sampling if necessary. They are characterized by the chemical species which they can detect and the associated limits of detection, the acquisition frequency, their precision, their cost and by the ease of use.

5.2 Concentration measurement methods

There are two families of concentration measurement methods (Table 2) that can be used for any type of gas targeted:

- Physical methods (absorption spectroscopy). The main characteristics of these methods are their very short response time, their sensitivity and the possibility of monitoring the concentration dynamics in real time (possibly monitoring several gases with different levels of concentration at the same time). Open path technologies exist for measuring integrated gaseous concentrations over a path directly in the atmosphere.
- Chemical methods (gas chromatography, laboratory assays, chemiluminescence). These methods are suitable for ad hoc measurements or for measurements integrated over periods from a few minutes to a few weeks. They are, therefore, less suitable for monitoring concentration dynamics. Furthermore, most of these methods are selective and cannot be used to measure several gases at the same time using the same equipment.

Annex B provides concentration measurement methods.

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Table 2 — Concentration measurement methods

Method	Application domain	Advantages	Limitations
Chemical methods			
Gas chromatography	— Gaseous CO_2, CH_4, N_2O, NH_3 — Suitable with chamber and atmospheric methods, except eddy-covariance	— Technique is well understood, commercial equipment is available — High sensitivity and low limit of detection (of the order of ppm for CO_2 and ppb for N_2O, NH_3 and CH_4) — Can be used to quantify several chemical species at the same time — Can be used where there are high concentration fluctuations — Suitable with small sample volumes — Easily automated	— May be used in the field for continuous measurements but has logistical limitations and high operating costs (bottles of carrier gas, reference gases, daily intervention by operators and maintenance of ambient conditions).
Chemiluminescence	— Gaseous NH_3 — Suitable with both dynamic chamber and atmospheric methods	— High sensitivity of a few ppb for NH_3 — Fast response time (down to 0,1s) with rapid data acquisition — Particularly suitable for use with eddy covariance method	— Frequent calibration — Interference may be problematic for low concentrations in rural areas
Laboratory assay of ammonium (NH_4^+) in solution - Continuous flow analysers (CFA)	— NH_4^+ trapped in solution (passive diffusion sampler, denuders and trapping of ammonia in acid solution)	— High speed analyses (40 to 60 samples per hour) — Robust — Good reproducibility	— Allowance should be made for interference with other gases if the samples are very acidic (e.g.: having been trapped in an acid solution)
Laboratory assay of ammonium (NH_4^+) in solution - Liquid chromatography		— Can be used to assay all the major cations at the same time as ammonium — Reproducible	— Long analysis time (4 samples per hour) — Interference with other gases if the sample contains a large number of cations
Laboratory assay of ammonium (NH_4^+) in solution - Conductivity		— Easy to implement — Low cost — Small samples — Wide measurement range and low limit of detection — Good reproducibility	— Long analysis time (5 to 12 samples per hour)

[a] TDLAS : Tunable Diode Laser Absorption Spectroscopy; OA-ICOS : Off-Axis Integrated Cavity Output Spectroscopy; CRDS : Cavity Ring-Down Spectroscopy.

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Table 2 *(continued)*

Method	Application domain	Advantages	Limitations
Physical methods			
Fourier-transform and photoacoustic infrared absorption spectroscopy	— Gaseous CO_2, CH_4, N_2O, NH_3 — Closed path and open path technologies — All chamber and atmospheric methods	— High sensitivity depending on the instrument and the gas (e.g. <1 ppb for N_2O and CO_2) — Can measure several compounds at the same time — Fast response time and rapid data acquisition — Standard equipment for greenhouse gases — Can be used where there are high concentration fluctuations	— Risk of interference — Sensitive to ambient conditions — Frequent calibration for some analysers but low annual drift for others
Laser absorption spectroscopy (TDLAS, OA-ICOS, CRDS)[a]		— Standard method for quantitative evaluation of trace gases — Fast response time (down to 0,1 s) with rapid data acquisition — Very high sensitivity (typically, 0,01 ppb for N_2O, 2 ppb for CH_4, 1,5 ppb for NH_3 at 1 Hz) — High selectivity and low risk of interference, in particular with Quantum Cascade Laser (QCL)	
Differential optical absorption spectroscopy	— Gaseous CO_2, CH_4, N_2O, NH_3 — Open path technologies (ambient air) — Atmospheric methods	— Fast response time (<1 s) with rapid data acquisition — Very high sensitivity (<1 ppb)	— Measurements are affected by poor visibility (ex: fog, snow), and clouds if the light source is the sun — Risk of interference

[a] TDLAS : Tunable Diode Laser Absorption Spectroscopy; OA-ICOS : Off-Axis Integrated Cavity Output Spectroscopy; CRDS : Cavity Ring-Down Spectroscopy.

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5.3 Air sampling

In many cases, the determination of gaseous concentration involves sampling of a volume of air before analysis. There are various gas sampling methods which depend on the strategies adopted and the methods used to determine the concentrations.

Table 3 presents the different methods and their main advantages and limitations.

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