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Carbon dioxide emissions from a septic tank soakaway in a northern maritime climate

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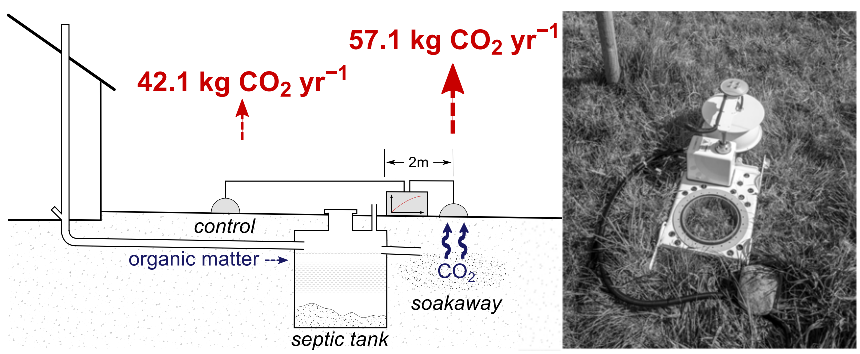
HIGHLIGHTS

- On-site wastewater treatment is a potential source of greenhouse gas emissions.
- Long-term soil flux chamber measurements recorded CO_2 emissions over a soakaway.
- Significantly higher fluxes were identified over the soakaway compared to a control.
- All CO_2 soil fluxes expressed substantial seasonal and diurnal variations.
- Soakaway fluxes showed weaker correlations in regard to environmental factors.

GRAPHICAL ABSTRACT



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ABSTRACT

Here, we present the first attempt to quantify long-term and diurnal variations of CO_2 fluxes from a soakaway of an on-site wastewater treatment system serving a single house located in a northern maritime climate (Ireland). An automated soil gas flux chamber system was deployed semi-continuously over a period of 17 months, recording hourly flux measurements from the soakaway (F_{soak}) and a control site ($F_{control}$). Soil gas fluxes expressed seasonal and diurnal variations: F_{soak} and $F_{control}$ ranged from 0.43 to 100.26 μmol CO_2 m^{-2} s^{-1} and 0.45 to 19.92 μmol CO_2 m^{-2} s^{-1} with median fluxes of 6.86 and 5.05 μmol CO_2 m^{-2} s^{-1}, respectively. While temperature, soil water content, and atmospheric pressure were identified as the most significant environmental factors correlated to the release of CO_2 from the control site, fluxes from the soakaway showed weaker correlations in regard to environmental factors. Assuming homogeneous spatial flux distributions, the soakaway emitted 15.0 kg yr^{-1} more CO_2 into the atmosphere in total compared to a similarly sized control site.

1. Introduction

On-site septic tank systems are a common choice for treating domestic wastewater in areas not connected to a centralized or decentralized wastewater treatment system. In the European Economic Area (EEA) a total of 23% of households are estimated to use on-site wastewater treatment and disposal (EEA, 2013). In particular, regions with a relatively low population density and a significant share of dispersed settlements tend to rely more on on-site septic systems as means for domestic wastewater treatment and disposal; e. g. in Ireland, where 38% of the population lives in rural areas, nearly 30% of households treat their wastewater on site (CSO, 2011). In the Nordic Countries about 34% of the population is connected to

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an on-site treatment or collection facility (Norin and Tideström, 2003) while in the United States about one fifth of the population relies on septic systems (USEPA, 2016).

Globally, there has been a shift from regarding sanitation infrastructure merely as a service for the provision of basic needs towards a more comprehensive implementation and promotion of long-term environmentally sustainable decentralized and on-site treatment systems (Massoud et al., 2009; Rosenqvist et al., 2016), particularly in regions currently underserved with basic services provision (Libralato et al., 2012; Parkinson and Tayler, 2003). Currently, with 64% of the urban population in low- and middle-income countries using on-site systems (Hawkins et al., 2014) and an estimated total of 2.4 billion people still lacking access to basic sanitation services globally (UNICEF/WHO, 2015) the total number of installed septic system is likely to rise in the future.

A conventional domestic septic system consists of two components; a septic tank (ST) and a soil dispersal system (SDS). The ST facilitates the initial collection and storage of the raw sewage from one or several households and allows the retention of settleable solids as sludge at the bottom of the tank and flocculent waste as a floating scum layer. While the settled solids are partially anaerobically digested within the tank, the effluent is ideally discharged into the vadose zone via an engineered SDS (e. g. soakaways, percolation trenches/leach fields, mound soil systems, drip line systems).

In Ireland, septic tank systems installed before 1991 had their effluent released into the soil mainly via soakaways (pits back-filled with stone or rubble for effluent disposal). In 1991, the National Standards Authority of Ireland recommended the construction of septic tank systems with larger percolation areas where the effluent would be distributed through percolation trenches – also known as leach fields, drainfields, or infiltration areas. However, of the current more than 450,000 installed on-site systems in Ireland, it is estimated that still approximately 65% remain constructed before the implementation of these revised guidelines (CSO, 2011).

Microbial processes in the ST mainly follow anaerobic pathways for the degradation of organic matter via hydrolysis, acidogenesis, and methanogenesis resulting in the production of CH_4 and CO_2 gas. In the SDS a clogging zone forms at the infiltrative surface for the liquid ST effluent over time. Initial clogging occurs due to an accumulation of suspended solids, organic matter, and chemical precipitation resulting in potentially saturated conditions and ponding of effluent at the infiltrative surface (Beach and McCray, 2003). The increasing impedance to flow, in turn, allows for the formation of a mature biological clogging zone – also known as a microbial biomat – providing significant treatment and attenuation of contaminants before the wastewater reaches the underlying groundwater aquifer (Gill et al., 2007). Bacteria forming the biomat utilize an efficient defense mechanism, producing extracellular polymeric substances (EPS) to create anaerobic microenvironments to protect their bacterial cells. EPS have been characterized as containing significant concentrations of humic substances and polysaccharides and can cause soil clogging leading to lower infiltration rates (McKinley and Siegrist, 2010). Site specific parameters such as system design, mineral subsoil composition, subsoil permeability, hydraulic and organic loading rates, and further environmental factors such as soil temperature and rainfall patters influence the extend and microbial composition of the clogging zone (Beach and McCray, 2003; Gill et al., 2009; Winstanley and Fowler, 2013). A continuously fed biomat acts as a potential source of CO_2, CH_4, and N_2O emissions from transformation and degradation of organic and inorganic contaminants in the soil.

Considering the large number of on-site septic systems in use internationally, potentially constituting a significant source of GHG emissions, there has been a surprising lack of direct field measurements of these fluxes to the atmosphere. Most of the existing septic system emission models rely on load-based calculations or estimated emission factors. The IPCC provides guidelines on national GHG inventories following an organic load-based approach to estimate septic system emissions (IPCC, 2006). These guidelines only consider CH_4 emissions from anaerobic degradation in STs, disregarding the potential emissions from microbial degradation processes in the SDS. Direct CO_2 emissions from septic systems are omitted in the GHG inventories as they are of biogenic origin.

Numerous recent studies on septic systems mainly focused on the attenuation of chemical and biological pollutants and the risk for contamination of groundwater (Gill et al., 2007; Godfrey et al., 2007; Katz et al., 2010; Keegan et al., 2014), wells (Hynds et al., 2014; Lu et al., 2008), or surface waters (Dubber et al., 2016; Ockenden et al., 2014; Rosario et al., 2014; Withers et al., 2012) from septic systems. However, there is a limited number of studies with a scope on quantifying gas emissions from septic systems. Kinnicutt et al. (1910) reported gas emissions of 39 L m^{-3} treated sewage, of which 75.2% were CH_4 and 5.9% were CO_2, from a closed municipal septic tank in Worcester (MA, USA) fed with sewage from domestic and industrial sources. More recent studies by Leverenz et al. (2010) and Diaz-Valbuena et al. (2011) identified, for the first time, emissions of all three major GHGs (CH_4, CO_2, and N_2O) from eight septic systems and two SDSs in CA, USA. The studies noted that the septic tank itself would be the primary source of CH_4 emissions while most of the CO_2 is emitted from the SDS with negligible overall N_2O emissions. Emissions from direct flux measurements over the SDSs were deemed negligible. In the latest study, Truhlar et al. (2016) quantified CH_4, CO_2, and N_2O emissions from SDSs, sand filters, and vents for a period of three months at eight septic systems in NY, USA. While the majority of GHG emissions escaped through the roof vent, interpreted as proxy for direct emissions from the ST surface itself, the SDS was found to be a negligible source of CO_2 but potentially releases N_2O.

The existing studies on soil gas fluxes from septic systems have a limited temporal (September to December 2009 in Diaz-Valbuena et al. (2011), June to August 2014 in Truhlar et al. (2016)) and spatial span, thus, not being able to fully capture the expected seasonal variability of the emission rates.

Here, we are presenting the first attempt of measuring the CO_2 soil flux from a soakaway and a control area semi-continuously using an automated in-situ flux chamber measurement technique with hourly measurements over a 17-month period. The objective of this study was (i) to quantify the CO_2 emissions of a soakaway receiving domestic septic tank effluent under a normal load in order to detect potential seasonal and diurnal variations, and (ii) to identify potential environmental factors that drive the release of CO_2 over such a system.

2. Materials and methods

2.1. Study site

CO_2 soil flux measurements were conducted at an on-site wastewater treatment system receiving effluent from a single house in Co. Westmeath, Ireland (N53° 24′ W7° 30′). The system, consisting of a single-chamber septic tank and subsequent soakaway, was constructed more than 20 yr ago. The septic tank has a total capacity of 2.6 m^3 with a theoretical hydraulic retention time of 7 d and is fed by a single gravity flow effluent pipe from the household with a fluctuating number of occupants averaging 2. The septic tank was last desludged 3 yr before the start of this study. The subsequent soakaway distributes an average 360 L d^{-1} of effluent over a total area of approximately 6 m^2.

Co. Westmeath lies in central Ireland and its climate is classified as maritime Cfb (warm temperate, fully humid, warm summer) after Köppen-Geiger (Kottek et al., 2006). The mean annual temperature is 10 °C with mean seasonal minimum and maximum between