Chemie der Erde xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Chemie der Erde

journal homepage: www.elsevier.de/chemer

Invited review

Greenhouse gas emissions from soils—A review

Cornelius Oertel [a], Jörg Matschullat [a,*], Kamal Zurba [a], Frank Zimmermann [a], Stefan Erasmi [b]

[a] Institute of Mineralogy, Chair for Geochemistry and Geoecology, Technische Universität Bergakademie Freiberg, Brennhausgasse 14, 09599 Freiberg, Germany
[b] Geographisches Institut, Abt. Kartographie, GIS & Fernerkundung, Universität Göttingen, Goldschmidtstr. 5, 37077 Göttingen, Germany

ARTICLE INFO

Article history:
Received 13 August 2015
Received in revised form 4 April 2016
Accepted 4 April 2016

Keywords:
Soil respiration
Carbon dioxide
Methane
Nitrous oxide
Soil emission drivers
Methodology
Flux chamber

ABSTRACT

Soils act as sources and sinks for greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Since both storage and emission capacities may be large, precise quantifications are needed to obtain reliable global budgets that are necessary for land-use management (agriculture, forestry), global change and for climate research. This paper discusses exclusively the soil emission-related processes and their influencing parameters. It reviews soil emission studies involving the most important land-cover types and climate zones and introduces important measuring systems for soil emissions. It addresses current shortcomings and the obvious bias towards northern hemispheric data.

When using a conservative average of 300 mg CO_2e m^{-2} h^{-1} (based on our literature review), this leads to global annual net soil emissions of ≥350 Pg CO_2e (CO_2e = CO_2 equivalents = total effect of all GHG normalized to CO_2). This corresponds to roughly 21% of the global soil C and N pools. For comparison, 33.4 Pg CO_2 are being emitted annually by fossil fuel combustion and the cement industry.

Contents

* Corresponding author.
E-mail address: matschul@tu-freiberg.de (J. Matschullat).

http://dx.doi.org/10.1016/j.chemer.2016.04.002

Please cite this article in press as: Oertel, C., et al., Greenhouse gas emissions from soils—A review. Chemie Erde - Geochemistry (2016), http://dx.doi.org/10.1016/j.chemer.2016.04.002

1. Main greenhouse gas source and sink aspects of soils

Political agendas of individual countries and international initiatives proclaim greenhouse gas (GHG) neutrality, e.g., by the year 2050 (G7, 2015; Law and Harmon, 2011; UBA, 2013; Willson and Brown, 2008). Whether such declarations can be and must be seen as realistic cannot be an issue in this review. Yet, it is of vital interest to properly assess soils as GHG-sources and to develop a better understanding for the source and sink strengths of this important and critical environmental compartment. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are important climate-relevant trace gases. While being highly unequally distributed (Δ of 3–4 orders of magnitude for C), about 1500 Pg of total C and 136 (92–140) Pg of total N are stored in the uppermost meter of the global soil layer, representing the largest terrestrial carbon and nitrogen pools (Batjes, 1996; Kutsch et al., 2009; Nieder and Benbi, 2008; Schaufler et al., 2010; Schlesinger and Andrews, 2000). However, soil structure changes can influence its source and sink function (Jungkunst and Fiedler, 2007) and the total storage capacity is limited. As an example, a review of the European terrestrial GHG balance (Schulze et al., 2009) showed that the fluxes (flow rate per unit area) of CO_2, CH_4 and N_2O between 2000 and 2005 were near neutral; agricultural CH_4 and N_2O emissions being largely offset by the CO_2 sink of grasslands and forests. Yet, the authors show that the trend towards more intensive agriculture and logging "*is likely to make Europe's land surface a significant source of greenhouse gases*". Bahn et al. (2010) compiled and evaluated global data across vegetation types and biomes, concluding that soils emit about 98 Pg C a^{-1} (resulting in a roughly 15-year turnover time for the reservoir). This is considerably more than emissions from fossil fuel consumption. Older sources suggest lower fluxes with 68–77 Pg C a^{-1} (Raich and Potter, 1995; Raich and Schlesinger, 1992). Bahn et al. (2010) nevertheless emphasized the still high uncertainty with various assumptions and in upscaling attempts.

GHG emissions from soils need to be better quantified for global budgets, since 35% CO_2, 47% CH_4, 53% N_2O, and 21 % nitric oxide (NO) of the respective total annual emissions relate to soil degassing (IPCC, 2007). The annual global NO emissions from soils are within the range of NO emissions from fossil fuel combustion (Butterbach-Bahl et al., 2009). The increase of GHG emissions from soils mainly stems from CH_4 and N_2O since the onset of industrialization in the mid 18th Century and has been caused by agricultural practice (Forster et al., 2007). This makes GHG emissions from soils a key topic in global change issues, in climate research, and for agricultural and forestry management.

First measurements of CO_2 emissions from soils were performed in laboratories in the 19th Century (Boussingault and Levy, 1853), motivated by the tracer function of soil respiration for soil fertility (Russell and Appleyard, 1915). Today climate change-related topics dominate the study of CO_2, N_2O and CH_4 behaviour (Cox et al., 2000). Nitric oxide (NO) has been studied because of its role in acidic precipitation, ozone formation and destruction (Kampfl et al., 2007). Field measurements with chambers were introduced at the beginning of the 20th Century (Lundegardh, 1927). Determinations of other trace gas emissions started later, as gas analyzers became available (N_2O in the 1950s: Arnold, 1954; NO in the 1970s: Galbally et al., 1987; CH_4 in the 1980s: Holzapfel-Pschorn et al., 1985).

1.1. Main gas species: properties and processes

CO_2 fluxes can be separated into three types:

1) Soil respiration includes root, anaerobic and aerobic microbial respiration. Root respiration contributes on average up to ~50% of the total soil respiration, yet may vary between 10 and 95% subject to season and vegetation type (Hanson et al., 2000),
2) Ecosystem respiration additionally includes aboveground plant respiration,
3) Net ecosystem exchange (NEE) is the difference between photosynthesis and ecosystem respiration. A positive NEE indicates a CO_2 source, whereas a negative NEE reveals a CO_2 sink.

CH_4 in soils is produced by methanogenesis under anaerobic conditions and is consumed by methanotrophic microorganisms that use O_2 and CH_4 for their metabolism under aerobic conditions (Dutaur and Verchot, 2007).

N_2O and NO releases are driven by nitrification (oxidation of NH_4^+ to NO_3^- via NO_2^-) and denitrification (reduction of NO_3^- to N_2O and N_2). Nitrous oxide (N_2O) is produced mainly by denitrification under anaerobic conditions, where the Water-Filled Pore Space (WFPS) is >50% (Ussiri and Lal, 2013). The released NO

Please cite this article in press as: Oertel, C., et al., Greenhouse gas emissions from soils—A review. Chemie Erde - Geochemistry (2016), http://dx.doi.org/10.1016/j.chemer.2016.04.002