Forest Ecology and Management 310 (2013) 600–611

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Greenhouse gas fluxes (CO_2, N_2O and CH_4) from forest soils in the Basque Country: Comparison of different tree species and growth stages

Iskander Barrena [a,*], Sergio Menéndez [b], Miren Duñabeitia [a], Pilar Merino [c], C. Florian Stange [d], Oliver Spott [e], Carmen González-Murua [a], José María Estavillo [a]

[a] Department of Plant Biology and Ecology, University of the Basque Country UPV/EHU, Apdo. 644, E-48080 Bilbao, Spain
[b] Institute of Agro-biotechnology (IdAB), UPNa-CSIC-GN, 31192 Mutilva Baja, Navarre, Spain
[c] NEIKER-Tecnalia, Department of Ecotechnologies, Barrio Berreaga, 1. 48160 Derio, Bizkaia, Spain
[d] Bundesanstalt für Geowissenschaften und Rohstoffe, Stilleweg 2, D-30655 Hannover, Germany
[e] Helmholtz Centre for Environmental Research – UFZ, Department of Soil Physics, Theodor-Lieser-Strasse 4, D-06120 Halle, Germany

ARTICLE INFO

Article history:
Received 11 June 2013
Received in revised form 30 August 2013
Accepted 31 August 2013
Available online 2 October 2013

Keywords:
Beech
Douglas fir
Radiata pine
Soil ammonium content
Soil porosity
Water filled pore space (WFPS)

ABSTRACT

Forest systems are considered quintessential terrestrial systems for atmospheric CO_2 sequestration to mitigate the effect of global warming. Temperate forest soils also present the highest rates of methane uptake among all the natural systems, while may represent a significant source of N_2O. Despite of the large area occupied by forest in the Basque Country, no data is yet available regarding greenhouse gas fluxes under these edaphoclimatic conditions. In this manuscript we present a 2-year study which determined the magnitude of CO_2, N_2O, and CH_4 soil gas fluxes in radiata pine, beech and Douglas fir forests using a closed chamber technique. The magnitude of these gas fluxes was additionally compared between different growth stages of radiata pine and beech forest, and the edaphoclimatic parameters that control these gas fluxes in the different forest systems and growth stages were studied. Measured greenhouse gas fluxes were in a low range as already published elsewhere for temperate forest ecosystems. A nitrogen deficit appears to be responsible for these relatively low gas fluxes. Apparently, the different forest species play a key role as controllers responsible for the differences of soil gas-exchange fluxes between the three different forest type systems. The mature pine plantation soil was emitting the most CO_2 (1.5 and 2.5 times more than the mature beech and the Douglas fir, respectively), while the Douglas fir forest soil was emitting the most N_2O (3 and 17 times more than the mature pine and the mature beech, respectively) and the mature beech forest was the soil type showing the highest CH_4 consumption rates (2 and 5.5 times more than the mature pine and the Douglas fir, respectively). The stage of growth and its usual management appear to be important concerning the soil gas-exchange behavior within one forest type. The young beech forest soil emitted 9 times more N_2O than the mature, and the new pine and the mature pine plantation soils emitted 2.5 and 2 times more CO_2 than the young, respectively. The ground vegetation cover percentage, the organic matter accumulation and the soil porosity seem to be factors which merit a closer look in future studies, as possibly responsible for the differences in gas fluxes among forest types and growth stages.

1. Introduction

The atmospheric concentration of greenhouse gases has increased in the last centuries, particularly since the beginning of the industrial revolution (IPCC, 2007). Carbon dioxide (CO_2) concentration in the atmosphere has risen from 280 ppm in the preindustrial era to 380 ppm in 2006, with an increment of 1.9 ppm per year during the last decade. This increment is due in large proportion to human activities such as fossil fuel combustion and land use (Dalal and Allen, 2008). In addition, nitrous oxide (N_2O) is a problematic greenhouse gas because of its high longevity in the atmosphere (about 120 years) and its high capacity of relative absorption. These characteristics make its warming potential 298 times greater than CO_2 warming potential, when a time horizon of 100 years is considered (IPCC, 2007). Approximately 70% of anthropogenic N_2O gas emissions arise from agricultural and farming practices (Mosier, 2001), mainly from its production after fertilization of soils by biological processes like nitrification and denitrification (Estavillo et al., 2002). Another environmentally risky gas is methane (CH_4), whose average longevity in the atmosphere is around 10 years and whose warming potential for a 100 year horizon is 21 times higher than that of CO_2.

* Corresponding author. Fax: +34 94 601 35 00.
E-mail address: iskander.barrena@ehu.es (I. Barrena).

0378-1127/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.08.065

Forests have several major roles in climate system. When managed sustainably, they produce wood fuels as an alternative to fossil fuels. Besides, they have the potential to absorb about one-tenth of global carbon emissions predicted for the first half of this century into their biomass, soils and products for a long time (FAO, 2012). Moreover, temperate forest soils have the highest rates of methane uptake among all the natural systems, with rates of up to 8.9 kg CH_4–C ha^{-1} y^{-1} (Bowden et al., 2000) and a mean rate of 3.6 kg CH_4–C ha^{-1} y^{-1} (Dalal and Allen, 2008). On the other hand, in the last years it has been shown that forest soils may represent a significant source of N_2O (Zhang et al., 2008). In fact, Dalal and Allen (2008) have estimated that temperate forest soils can emit around 0.01–8.07 kg N_2O–N ha^{-1} y^{-1}. Nevertheless, soil can also act as a minor N_2O sink, probably consumed by denitrifiers and, also, by nitrifiers (Chapuis-Lardy et al., 2007). Provided that forest systems are considered quintessential terrestrial systems for atmospheric CO_2 sequestration to mitigate the effect of global warming (Tate et al., 2006), it is necessary to record a wide range of data in relation to the contribution of these ecosystems to the global budget of greenhouse gases. The type of soil and climatic characteristics will be the main factors determining the seasonal pattern and the magnitude of soil greenhouse gases fluxes for a specific region (Batjes and Bridges, 1992). Additionally, two factors should be considered which have been demonstrated to have an influence on the fluxes of different greenhouse gases, i.e. the type of forest and the forest growth stage. With regard to the forest type, the effect of the different tree species on the greenhouse gas flux balance of forest systems may be significant as a consequence of the different organic matter accumulation, litter quality (C/N ratio, N content, lignin and phenolic components) and chemical, physical and biological characteristics of soils over forest types (Borken and Beese, 2005). In this sense, it has been reported that deciduous species increase nutrient turnover rates and microbiology activity comparing to coniferous species (Ambus and Zechmeister-Boltenstern, 2007). With regard to the growth stage, there are two management practices most widely used which can have an effect on soil greenhouse gas fluxes. The first is the clear-cut harvest at the end of the growing cycle of the previous plantation and the site preparation of the subsequent new plantation, and the second is the thinning procedure some years after, aimed at increasing the radial growth of the remaining trees at the expense of the total biomass (Jandl et al., 2007). The clear-cut harvest produces especially large changes in soil environmental conditions, primarily in relation to temperature, water content and soil aeration, which affect the processes of gas emission (Zerva and Mencuccini, 2005). According to Tate et al. (2006), clear-cut harvest influences organic matter decomposition and it may increase CO_2 and N_2O emissions. In addition, these authors also suggest that soil disturbance causes a temporary decrease in methane uptake. Besides, when a forest is cleared, the root system is altered and induces a change in the established microflora (Byrd et al., 2000), both in the rhizosphere and mico-rhizosphere of plants.

In the Basque Country, forestry is economically and environmentally one of the most important activities of the primary sector, being a traditional activity in rural areas. The 55% of the total area of the Basque Country is covered by forest, mainly occupied by plantations for wood production of radiata pine (*Pinus radiata* D. Don) and native beech forest (*Fagus sylvatica* L.), representing 48% and 15% of the total forest area, respectively (Inventario Forestal CAE, 2005). In order to minimize pathogen infections on monospecific coniferous plantations of radiata pine, Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) is another forestry valuable plantation, representing 2% of the total forest area. In the case of radiata pine the rotations have the duration of 35–40 years and in the case of Douglas fir the duration is of 55–60 years.

There is no data available regarding forest soils greenhouse gas fluxes in the edaphoclimatic conditions of the Basque Country. Due to the large forest areas in this region and its usefulness as carbon sink, it is important to quantify these gas fluxes with the ultimate purpose of estimating regional soil fluxes of these gases. Therefore, the aims of this work were (1) to determine the magnitude of CO_2, N_2O, and CH_4 soil gas fluxes in three different forest types (radiata pine, beech and Douglas fir), (2) to compare the magnitude of these gas fluxes in three specific growth stages for the radiata pine and two growth stages for the beech, and (3) to determine the edaphoclimatic parameters that control these gas fluxes in the different forest systems and growth stages.

2. Materials and methods

2.1. Site description

The experiment was carried out in three different forest types: radiata pine (*Pinus radiata* D. Don), Douglas fir (*Pseudotsuga mensiezii* Mirb.) and beech (*Fagus sylvatica* L.). Besides, two stages for the beech forest (young and mature) and three stages for the radiata pine (new plantation, young, and mature) were included (Table 1). Both radiata pine and Douglas fir stands are located at Artzentales (43°13′ 38″ N, 3° 11′ 54″ W, 350 m) within a distance of not more than 200 m, while the beech stands are at the Natural Park of Gorbea (43° 6′ 27″ N, 2° 48′ 16″ W, 400 m) also within a short distance of 50 m. Both locations are situated in the Atlantic region of the Basque Country. The young beech stand is characterized by a considerable cover of ground vegetation dominated by bracken (65–75%), while the new and mature radiata pine stands were dominated by grasses and heather (80–90%). The young radiata pine soil is covered by around 30%, while both the mature beech and Douglas fir soils show <20% of ground vegetation cover.

The management history of the studied coniferous stands was as usual in the Basque Country. It involved harvesting of the previous plantation with chainsaws and skidders, and mechanical site preparation with a bulldozer which includes the removal of residues from the previous plantation and the competing vegetation with a front-mounted straight-blade. After this site preparation, the new plantation was hand planted at a density of 1600 trees ha^{-1}. The first four years of the plantation the competitive vegetation was cut with a brush cutter. Thinning was performed with chainsaws and skidders at 13, 18 and 23 years after planting, and the residues were piled and left in the stands. In each thinning procedure 200–400 trees ha^{-1} were removed.

Mean annual rainfalls for the 1971–2000 period were 904 and 1353 mm for Artzentales and Natural Park of Gorbea, respectively, while mean annual temperatures were 10.9 and 9.8 °C. The monthly precipitations and average monthly temperatures during the two years of study are shown in Fig. 1.

2.2. Soil greenhouse gas flux measurements

N_2O, CO_2, and CH_4 gas fluxes were measured using a closed chamber technique (Menéndez et al., 2008) with a frequency of measurement of every 2 weeks from January 2010 to December 2011. In each stand, six PVC cylinders (15 cm diameter and 8 cm height) were placed as replicates within a 10 × 15 m area inserted approximately 2 cm into the soil. All cylinders were located randomly and open in the same place during the two years of the study. To determine gas fluxes the cylinders were covered and hermetically closed with a PVC lid. Soil gas exchange rates were calculated based on gas concentration changes during 90 min of closing. Gas samples (15 mL) were collected from the inlet of the cylinders and stored in vials of 12 mL. Gas samples were then analyzed