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Short-term effects of thinning on soil CO_2, N_2O and CH_4 fluxes in Mediterranean forest ecosystems

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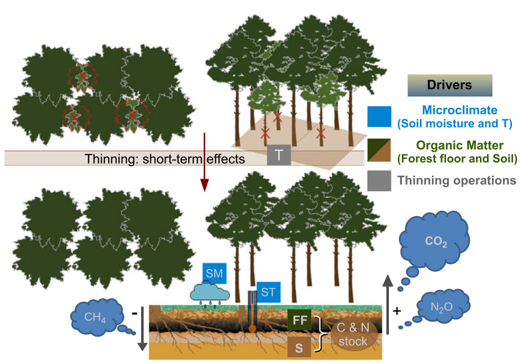
HIGHLIGHTS

- We analysed site-related GHG fluxes in two Mediterranean pine forests after thinning.
- Soil moisture content and organic matter availability affected CO_2 emission patterns.
- Short-term CO_2 emissions increased after disturbance induced by logging operations.
- Small gaps created with selective thinning increased CH_4 uptake.
- Low N_2O emissions were found in both sites and were not affected by thinning.

GRAPHICAL ABSTRACT



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ABSTRACT

In Mediterranean ecosystems an increasing demand for in situ trace gas exchange data is emerging to enhance the adaptation and mitigation strategies under forest degradation. Field-chamber green-house gas fluxes and site characteristics were analysed in two Mediterranean peri-urban pine forests showing degradation symptoms. We examined the effect of different thinning interventions on soil CO_2, CH_4 and N_2O fluxes, addressing the relationships with the environmental variables and C and N contents along forest floor-soil layers.
Soil temperature resulted as the main driving variable for CO_2 efflux and CH_4 uptake. Soil moisture content and organic matter availability affected CO_2 emission patterns in the two sites. N_2O fluxes showed a positive correlation with soil moisture under wetter climatic conditions only. GHG fluxes showed significant correlations with C and N content of both forest floor and mineral soil, especially in the deepest layers, suggesting that it should be considered, together with environmental variables when accounting GHG fluxes in degraded forests.
Short-term effects of thinning on CO_2 emissions were dependent on disturbance induced by logging operations and organic matter inputs. After thinning CH_4 uptake increased significantly under selective treatment, independently from specific site-induced effects. N_2O fluxes were characterized by low emissions in both sites and were not affected by treatments. Soil CO_2 efflux was the largest component of global warming potential (GWP) from both sites (11,553 kg ha^{-1} y^{-1} on average). Although it has a large global warming potential, N_2O contribution to GWP was about 131 kg CO_2eq ha^{-1} y^{-1}. The contribution of CH_4-CO_2 equivalent to total GWP showed a

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clear and significant CH_4 sink behaviour under selective treatment (36 kg ha^{-1} y^{-1} on average). However, in the short-term both thinning approaches produced a weak effect on total GWP.

1. Introduction

Pine species have been largely used for land restoration in the Mediterranean basin since the late nineteenth century. The traditional strategy for reforesting degraded lands was to plant fast-growing pioneer species, usually pines (Gil and Prada, 1993), to facilitate the introduction (either artificial or natural) of late-successional broadleaves able to reach a higher biodiversity and more resilient and resistant ecosystems (Barbéro et al., 1998; Pausas et al., 2004).

Nowadays, the most of these pine stands are concluding their rule of pioneers' species and the lack of timely silvicultural interventions negatively affected stands adaptability to natural processes (i.e., secondary successions). Moreover, these stands often present mechanical stability problems (Cantiani and Chiavetta, 2015; Marchi et al., 2017). From the National Forest Inventory, 31% of Italian pine forests in the Mediterranean zone show degradation symptoms with many dead, fallen and/or damaged trees for a total of 462,568 ha.

The lack of silvicultural interventions can affect the annual C sequestration rate due to a decrease in canopy cover and regeneration (Flint and Richards, 1994), reducing the potential sink capacity of these forests. In most cases these pine stands, densely overgrown with large deadwood, have become a potential source of greenhouse gases (GHGs) through decomposition of remaining plant material and soil carbon and altering the balance between gross photosynthesis and respiration (Law et al., 2004; Misson et al., 2005).

A major source of carbon and organic matter available for decomposition is represented by plant litter, with leaf litter accounting for 22% to 81% of total litter annual production and contributing up to >70% of the annual N input via litter fall (Bauer et al., 2000). Litter decomposition is an important source of CO_2 to the atmosphere; mineralization of the annual litter fall contributes to approximately half of the CO_2 output from the soil, and the average global annual CO_2 flux from the soil is estimated to be about 98 Pg C (Bond-Lamberty and Thomson, 2010), an amount comparable to that of global gross primary production.

Soil is a predominant component of C cycle, storing two-three times more C than the atmosphere. The significant role of soil in the global C balance depends on its potential to store C in pools with a slow turnover. Only small fractions of new C inputs into soils will become long-term SOC, whereas the largest fraction will be respired back to the atmosphere. Furthermore, soils have been reported to be a key factor for the overall response of the terrestrial biosphere to global change.

How thinning affects soil–atmospheric fluxes of GHGs is poorly understood. Contrasting results have been reported on soil CO_2 effluxes under different forest management practices (Zerva and Mencuccini, 2005). Determining how restoration thinning changes soil C fluxes is necessary to understand potential feedbacks between forest management activities and climate warming (Fang et al., 2016a, 2016b). Besides CO_2, thinning can have a significant effect also on methane (CH_4) and nitrous oxide (N_2O) fluxes by altering the environmental factors related to these fluxes, such as soil temperature, soil water content, decomposition of organic matter (Hendrickson et al., 1989), availability of substrate (Sahrawat and Keeney, 1986; Skiba and Smith, 2000), soil N dynamics (Smolander et al., 1998). Most studies assessing the impact of environmental variables and disturbances on pools and GHG fluxes from forest soil have been conducted in boreal or temperate forests and have mainly focused on CO_2, so few data are available for CH_4 and N_2O. Although the absolute quantities of CH_4 and N_2O emitted are small compared with those of CO_2, their importance depend on their larger global warming potential (GWP) that is respectively 34 and 298 times greater than CO_2 over a 100 year period (Myhre et al., 2013).

Enhanced N deposition due to increased human activity can directly promote N_2O emission by increasing inorganic N availability for microbial processes (Meng et al., 2011). Regions with elevated atmospheric N-deposition due to anthropogenic activity showed increased N_2O emissions (Butterbach-Bahl et al., 2002). However, inorganic N availability may not increase in response to increasing N deposition due to plant uptake and microbial immobilization (Edith et al., 2014). Atmospheric N deposition can be particularly important in peri-urban areas that are receiving contributions of N compounds from both urban and agricultural activities (García-Gomez et al., 2016). It is also hypothesized that increased N deposition will result in increased N_2O emissions in combination with reduced soil CH_4 oxidation and CO_2 emissions (Butterbach-Bahl et al., 2002; Ambus and Robertson, 2006).

Forest soils have also been identified as a significant sink for atmospheric CH_4, and it is estimated that CH_4 uptake of soils activities represent 3–9% of the global atmospheric CH_4 sinks (Prather et al., 1995). Well aerated forest soils seem to play a major role in this context (Papen et al., 2001). Uncertainty is associated, however, with global soil CH_4 consumption because of the few data available from Mediterranean-type ecosystems (Castaldi and Fierro, 2005), increasing the need for in situ trace gas exchange data (Butterbach-Bahl and Kiese, 2005; Rosenkranz et al., 2006). In this region warm and dry condition in summer and moderate precipitation in winter, might create favourable conditions for CH_4 oxidation throughout the year, making this area suitable for studying CH_4 fluxes dependence on meteorological parameters (Savi et al., 2016). To our knowledge, no studies in the Mediterranean basin have examined the effect of thinning practices on GHGs fluxes and their relationships with environmental factors and organic matter pools in litter and soil.

The main objectives of this study were: i) to quantify the short-term effect of different thinning treatments on soil CO_2, CH_4 and N_2O fluxes and ii) to investigate how soil temperature, soil moisture, C and N content in forest floor and soil influenced the GHGs production during and after the different thinning treatments applied. We hypothesized that thinning disturbance would significantly influence soil GHG fluxes due to modification of environmental factors, and that the response of CO_2, CH_4 and N_2O to the disturbance may differ, driven by site-specific induced effects.

2. Materials and methods

2.1. Study sites

The study sites are located in the peri-urban forests of Monte Morello (43° 51′ N–11° 51′ E, Italy) and Xanthi (41° 09′ N–24° 54′ E, Greece). Their main characteristics are shown in Table 1.

Monte Morello forest has been planted during 1910–1980 years on degraded soils affected by overgrazing, with the aim to restore the forest cover. The stands are characterized by a dominant crop layer of *P. nigra* and *P. brutia* and minor presence of *Cupressus sempervirens* and *Quercus cerris*. The understory layer is mainly occupied by *Cupressus arizonica* (with many decaying trees) and agamic regeneration of Mediterranean shade-tolerant broadleaves species such as *Fraxinus ornus* and *Acer campetris*. These stands show clear degradation symptoms with many dead, fallen and/or damaged trees, due to the absence of proper silvicultural practices. Deadwood is very widespread, reaching about 75.1 m^3 ha^{-1} divided in 80% of lying deadwood, 18% of standing dead