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Effects of Pits and Mounds Following Windthrow Events on Soil Features and Greenhouse Gas Fluxes in a Temperate Forest

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ABSTRACT

Pit and mound micro-relief (resultant microsites from trees uprooted by windthrow) could have regimes of microclimate and soil features that differ from areas of undisturbed soil. In an attempt to provide a comprehensive evaluation of the significance of pits and mounds on soil features and also the dynamics of greenhouse gas (GHG) fluxes at local scale, this study was carried out in a reserved area of Darabkola forest in Mazandaran Province, northern Iran. The age of a pit and mound was considered equal to the degree of decay of the blown down tree. Three microsites were distinguished, consisting of pit bottom (PB), mound top (MT) and undisturbed area (UA). Soil samples were taken at 0–15 and 15–30 cm depths from all microsites and analysed for soil physical, chemical and biological features. Our findings suggested that in context of forest ecology, pits and mounds following windthrow events should be considered as an effective factor influencing soil features (*i.e.*, density, texture, water content, pH, organic C, total N, available nutrients and earthworm density/biomass) and especially GHG fluxes. Results showed that MT acted as a sink for N_2O (-0.010 mg N_2O m^{-2} d^{-1}) and CH_4 (-0.257 mg CH_4 m^{-2} d^{-1}) fluxes and also produced lower CO_2 concentrations (0.095 mg CO_2 m^{-2} d^{-1}) than PB (0.207 mg CO_2 m^{-2} d^{-1}) and UA (0.098 mg CO_2 m^{-2} d^{-1}). As a consequence, a separation into pits/mounds would be important for a precise budgeting of greenhouse gases.

Key Words: carbon dioxide, methane, microsite, nitrous oxide, oriental beech, uprooted tree

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INTRODUCTION

In forest ecosystems, carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are the major trace gases exchanged between soil and atmosphere, making significant contributions to global warming (Lavoie *et al.*, 2013). The importance of soil to the global GHG balance is hard to be evaluated precisely, as soils represent the largest terrestrial carbon sink (Lal, 2004), the largest terrestrial source of CO_2 (Livesley *et al.*, 2013), the largest source of N_2O (Smith and Conen, 2004) to atmosphere and the largest terrestrial sink for CH_4 from the atmosphere (Bousquet *et al.*, 2006). As fluxes of GHG from soil vary largely in different locations or ecosystems, for accurately estimating the inventories of GHG at local, regional or global scale, monitoring the soil-atmosphere exchange rates of these gases in different ecosystems is of fundamental importance, especially where these have not been yet studied in detail. In addition, soil GHG concentration in different locations is also of great importance, since this can provide valuable information about production, consumption and transportation of gases. A great number of soil GHG flux models on the basis of GHG concentrations across soil profile and the diffusion of gas through the soil have been presented (*e.g.*, Tang *et al.*, 2003; Han *et al.*, 2005; Jassal *et al.*, 2005). However, a better understanding of the dynamics of the GHG in soils of various ecosystems is needed for improving GHG flux modeling. Therefore, measurements of GHG fluxes may be helpful in understanding the mechanisms that control the GHG distribution and dynamics in soil and their

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losses to the atmosphere (Burton and Beauchamp, 1994).

Forest communities, in part due to disturbance, are heterogeneous at both large and small scales, which might influence the soil ecosystem development (Turner, 2010; Sebkova *et al.*, 2012; Peterson *et al.*, 2013) and also the GHG fluxes. Disturbance takes a variety of forms and occurs at varying temporal and spatial scales (Clinton and Baker, 2000; Lóšková, *et al.*, 2013). One of the most important types of disturbance in temperate forests is tree windthrows which cause direct soil ecosystem perturbations. Tree uprooting has important impacts on forest ecology and implications for forest management (Phillips *et al.*, 2008). The result of a single-tree windthrow is the creation of a number of microsites, which may strongly differ in microclimatic and pedological conditions. Temperature, humidity, soil moisture content and light regime between the closed canopy and the canopy gap differ markedly. Furthermore, uprooting affects the forest soil by the inversion of the soil profile and creation of a micro-relief with a depression or a mound containing the former rooting zone, where the former soil surface has fallen from the mound towards the stem and the soil fallen from the former root system towards the pit. The physico-chemical soil features of these microsites can be considerably different and result in a differentiation in the vegetation layer, tree regeneration, root distribution (Nachtergale *et al.*, 2002) and also GHG fluxes (Insam, 1990).

Considering that pit and mound microsites can have regimes of microclimate and soil features that differ from areas of undisturbed soil (Kooch *et al.*, 2012; Kooch *et al.*, 2014b), we assume the microsites may have more different GHG flux rates than undisturbed soil nearby. In hyrcanian beech (*Fagus orientalis* Lipsky) forests, small-scale disturbances due to canopy gap formation seem to be the prevailing natural disturbance regime (Kooch *et al.*, 2012; Kooch *et al.*, 2014a). Also, the significance of pit and mounds for ecosystem functioning further increases when considering time (Mollaei Darabi *et al.*, 2014). In most studies, the age of windthrows is established indirectly regarding to their characteristics in time (Schaetzl and Follmer, 1990). This method can be applied to a wide range of windthrows and also assess the role of windthrow dynamics even though the accuracy is low (Ilisson *et al.*, 2007).

In spite of the number of studies that focus on aspects of the pit and mound phenomenon, the overall significance of pit and mound disturbances on soil formation in natural forests has not yet been adequately assessed during different time periods, nor has, their absence in managed forests been satisfactorily evaluated. There is, however, a large potential in generalizing the results from these existing studies for broader regions, forest types and geological and soil units. Prior to this study, responses of GHG fluxes to soil disturbance by tree uprooting have not been studied in time in temperate deciduous forests of Iran. Therefore, here we attempt: i) to provide a comprehensive evaluation of the significance of pit and mound disturbances on soil physico-chemical and biological features and ii) to examine the effects of tree uprooting on the dynamics of GHG fluxes at local scale. We hypothesized that i) soil base cations (*i.e.*, available K, Ca and Mg) were greatest in pits, followed by undisturbed area and mounds, and ii) pits had significantly more GHG fluxes compared to mounds and undisturbed areas.

MATERIALS AND METHODS

Study area

With an area of 2 612 ha, the Darabkola forest is located in the north of Iran (south-east of the city of Sari, Mazandaran Province, Iran), between 36°35′56″ N and 36°29′23″ N latitudes and 53°18′39″ E and 53°27′20″ E longitudes (Fig. 1). This study was carried out in a 34 ha area of the reserve area, which is located about 900 m above sea level (a.s.l.) and covered mostly by *Fagus orientalis* Lipsky (oriental beech) mixed with *Carpinus betulus* L. (common hornbeam). The area is on uniform terrain with high slope (60%–70%) and northeast exposure. The parent material is limestone and dolomite limestone belonging to Upper Jurassic and Lower Cretaceous period. Annual mean rainfall is 750 mm, with wet months between September and February, and a dry season, from April to August, with an average monthly rainfall less than 40 mm. Average daily temperatures vary from 11.78 °C in February to 29.58 °C in August. The easily noticeable uprooted trees offered an ideal opportunity to study and monitor the pit and