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Measuring changes in forest floor evaporation after prescribed burning in Southern Italy pine plantations

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ABSTRACT

Wildfires are a growing concern in the Mediterranean area. Prescribed burning (PB) is often used to reduce fire risk, through fine fuel reduction. However, the monitoring of PB effects on ecosystem processes is mandatory before its spread. This study aims to assess hydrological effects of PB on the topsoil by controlled laboratory experiments. The evaporation flux successive to interception of a simulated rain in the litter and the fermentation layers was determined using both a water balance approach and an experimental ^{2}H and ^{18}O isotopes mass balance approach. PB was performed in spring 2014 in three Southern Italy pine plantations, dominated, respectively, by *Pinus pinea* L. (in *Castel Volturno Nature State Reserve*), *P. halepensis* Mill. (in *Cilento, Vallo di Diano e Alburni National Park*) and *P. pinaster* Ait. (in *Tirone Alto-Vesuvio Nature State Reserve*). In each study site, two cores, both including litter and fermentation layers, were sampled, 18 months after PB, in burned and in near unburned (control) areas, respectively, by means of customized collectors allowing to extract "undisturbed" cores. Afterwards, each core was moved into a lysimeter set-up in the laboratory, under controlled conditions (temperature of 22 °C, relative humidity of 50%), to carry out duplicate infiltration and evaporation experiments. To simulate rainfall, 1 L of tap water (= 32 mm of rain) was sprinkled uniformly on the litter layer in the lysimeter and intercepted water from the litter and fermentation layer was collected for isotope analysis at two different depths for each layer, two times per day until 2 days after the rain simulation. The results of the water balance and isotope mass balance showed a slightly lower evaporation of intercepted water from the forest floor in burned areas, compared to unburned ones, but in most cases not statistically significant. The isotopic profiles of ^{2}H and ^{18}O also confirmed independently this finding, since they showed more enrichment in the unburned areas compared to the areas treated with PB. This could be due to thinner litter layers in burned areas of the three plantations, at least up to 18 months after treatment.

1. Introduction

Fire is a natural or anthropogenic ecological factor affecting forest ecosystems in the world. Wildfires are a serious issue in areas with a Mediterranean climate, where the alternation of dry and rainy seasons provides ideal conditions for the spread of fire (Trabaud and Grandjanny, 2002; Turco et al., 2017). The plant fuel, accumulating during wet seasons, can easily burn during the following dry season, because of decreased moisture, if a fire ignition occurs. Despite fire is also a natural ecological factor in Mediterranean ecosystems and a lot of plant species are adapted to it (Eugenio and Lloret, 2006; Naveh, 1994), the increase in number of anthropogenic wildfires observed during the last decades (Pausas, 2004) has made it necessary to reduce fire hazard in forests. For this reason, practices as prescribed burning are spreading through Europe. Fernandes and Botelho (2003) define prescribed burning as "a deliberate application of fire in a defined area and under specific operative conditions (prescriptions) in order to obtain defined goals established in the planning phase". The main objective of prescribed burning is wildfire risk reduction. It is achieved by fuel removal and disruption of vertical and horizontal fuel continuity. This practice may also have other objectives (Fernandes et al., 2013), such as the grazing management and conservation of some natural habitats listed in

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So far, data on the effects of prescribed burning on ecosystem components mainly concern areas where this practice has been largely applied, such as Australia and USA (Bradstock et al.,1998; Fernandes et al., 2012; White, 1983), and, within Europe, especially France, Portugal and Spain (Fernandes et al., 2013; Fonturbel et al., 1995; Fontúrbel et al., 2012; Lázaro, 2010; Moreira et al., 2003; Trabaud, 1982). In Italy, the applications of prescribed burning treatment are still in an experimental phase (Ascoli et al., 2012). The research about prescribed burning mainly focuses on the effects of the practice on vegetation, soil physico-chemical characteristics and soil microbial community (Battipaglia et al., 2014, 2016; Catalanotti et al., 2010; Cookson et al., 2008; Fontúrbel et al., 2012; Hossain et al., 1993; Johnson, 1992; Moreira et al., 2003; Nardoto and Bustamante, 2003; Shen et al., 2016), but less attention is paid on the effects of prescribed burning on hydrological processes.

It is well known that wildfires could influence the system's ability to retain rainwater (Baker Jr., 1990; Certini, 2005; Fernandes et al., 2013). They could create a discrete layer with enhanced water repellence on the soil surface or a few centimetres below, parallel to the mineral soil surface (Knicker, 2007), increasing the overland flow (Baker Jr., 1990). However, a small increase in water repellence was observed for soil heating lower than 175 °C and the hydrophobic layer resulted destroyed at temperatures of 280–400 °C (Knicker, 2007). The wildfires could also affect the water interception by litter and fermentation layers and the successive evaporation flux after rainfall ends (Baker Jr., 1990). However, prescribed burns are usually applied with less intense burning conditions, so their effects on forest floor interception and successive evaporation flux are less severe than during intense wildfire (Baker Jr., 1990). Interception is the amount of rainfall that is temporarily stored on a canopy or forest floor and evaporates during or shortly after a rainfall event (Lankreijer et al., 1993; Savenije, 2004). Gerrits (2010) showed that in a beech forest 7% of the rainfall in winter, and 15% in summer, was intercepted by the canopy. The forest floor intercepted another 22% of throughfall in both seasons. For a pine forest floor, where canopy interception was not determined, 16–20% of throughfall was intercepted in summer and winter, respectively (Gerrits, 2010). Hence, canopy and forest floor interception and the successive evaporation flux are important parts of the total water balance (Herbst et al., 2008; Murray, 2014) and, for this reason, especially forest floor interception has to be considered if one wants to know the effect of prescribed burning on soil water balance. To measure evaporation from the topsoil often lysimeter-like set-ups are used (Dietrich and Kaiser, 2017; Gerrits et al., 2007; Li et al., 2000; Magliano et al., 2017; Schaap and Bouten 1997; Stumpp et al., 2007) or field samples are weighted in wet and dry conditions (Helvey, 1967; Pathak et al., 1985; Putuhena and Cordery, 1996). The disadvantages of these methods are that the litter and fermentation layers are disturbed and/or that the "measuring device" is disturbing the measurement (*e.g.*, edge effects for wind, drainage problems) (Gerrits and Savenije, 2011; Pruitt and Angus, 1960). Isotopic techniques, on the other hand, do not suffer from these drawbacks (Aouade et al., 2016). By analysing the hydrogen and oxygen stable isotopic compositions of the water stored on and in the litter and fermentation layers, evaporation can be measured with fewer disturbances (Aouade et al., 2016; Michener and Lajtha, 2008). Furthermore, sampling of water samples is easy, quick, and non-destructive. Although sometimes it can be difficult to take representative samples and for smaller set-ups the sample volume can influence the available moisture (and thus the physical processes), this effect vanishes when the set-up is large enough and/or when unconstrained field conditions are considered. Furthermore, an additional benefit of water stable isotopes is that they provide useful information in hydrological studies on the physical processes and water routing (Allen et al., 2016; Reckerth et al., 2017; Wang et al., 2015). Isotopes are also widely used, as ideal tracers (Koeniger et al., 2010), to track water through the soil (Sprenger et al., 2016) and to derive quantitative information, such as the soil evaporation flux (Rothfuss et al., 2015; Rothfuss and Javaux 2017). In literature, to best knowledge of the authors, there are no studies that have considered the effects of a prescribed burning on the forest floor interception and the successive evaporation flux. Indeed, some studies (González-Pelayo et al., 2010; Johansen et al., 2001) mainly focus on the effects of prescribed burning on the surface run-off, soil hydrophobicity, infiltration and soil erosion phenomena associated with it. Cawson et al. (2012) and Vega et al. (2005), for example, showed a significant increase in the run-off surface and in the erosion of the soil as a result of a prescribed fire of medium-high intensity, similar to wildfire, due, mainly, to the high temperatures reached to the ground during the treatment.

This research aims to investigate the effects of prescribed burning on evaporation of intercepted water from the litter and fermentation layers in three different pine plantations using both the classic water balance technique and the stable water isotope approach. The hypotheses of this study are: i) stable isotopes can be used to quantify the evaporation flux from interception and ii) prescribed fire may affect evaporation of intercepted water from topsoil at least until this does not reach its original thickness.

2. Materials and methods

2.1. Study areas and fire treatments

The prescribed burning experiments were carried out in March 2014 in three pine plantations of Southern Italy (Fig. 1): a *P. pinea* plantation in *Castel Volturno Nature Reserve* (CVR); a *P. halepensis* coastal

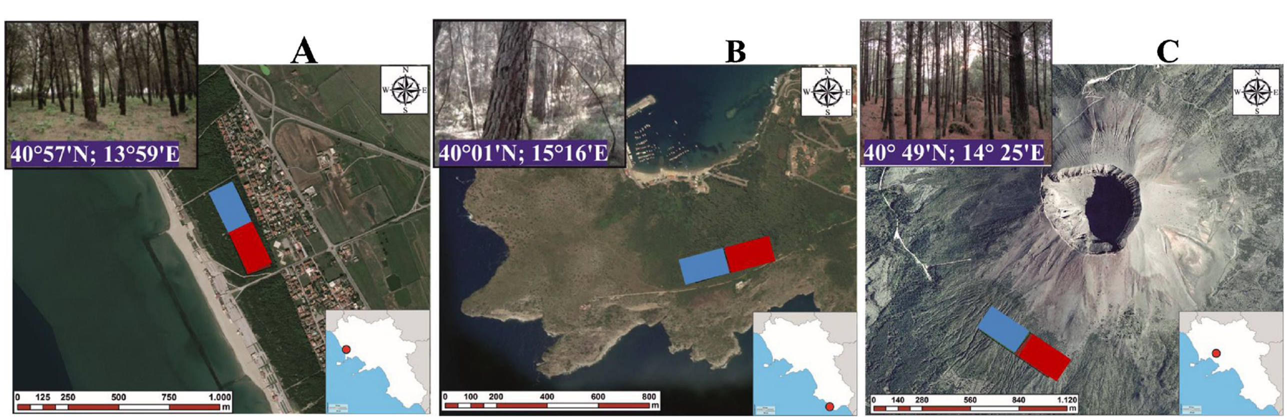

Fig. 1. Geographical location of experimental sites: *P. pinea* plantation at Castel Volturno Nature State Reserve (A; CVR), *P. halepensis* plantation at Cilento, Vallo di Diano e Alburni National Park (B; CNP) and *P. pinaster* plantation at Tirone Alto Vesuvio Nature State Reserve (C; TAV).
Control and burned plots in each experimental sites are reported in blue and red, respectively on Google Earth maps (https://earth.google.com/web/).