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DOI
10.1016/j.agrformet.2018.04.004

Publication date
2018

Document Version
Final published version

Published in
Agricultural and Forest Meteorology

Agricultural and Forest Meteorology 256–257 (2018) 516–525

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

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

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ARTICLE INFO

Keywords:
Prescribed burning
Topsoil hydrological balance
Evaporation of intercepted water
Water balance
^{2}H and ^{18}O mass balance

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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https://doi.org/10.1016/j.agrformet.2018.04.004
Received 4 August 2017; Received in revised form 8 March 2018; Accepted 8 April 2018
0168-1923/

Annex I of the Directive 92/43/EEC.

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

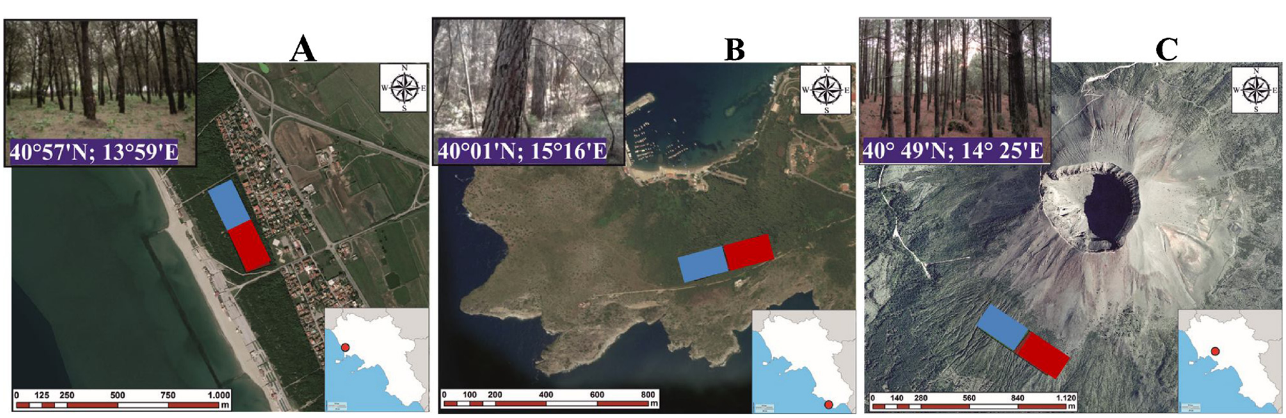

Fig. 1. Geographical location of experimental sites: *P. pinea* plantation at Castel Volturno Nature State Reserve (A; CVR), *P. halepensis* plantation at Cilento, Vallo di Diano e Alburni National Park (B; CNP) and *P. pinaster* plantation at Tirone Alto Vesuvio Nature State Reserve (C; TAV).
Control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

Fig. 2. Sampling phases (1–3) of litter and fermentation layer cores by an aluminium cylindrical collector designed to allow collecting "undisturbed" samples.

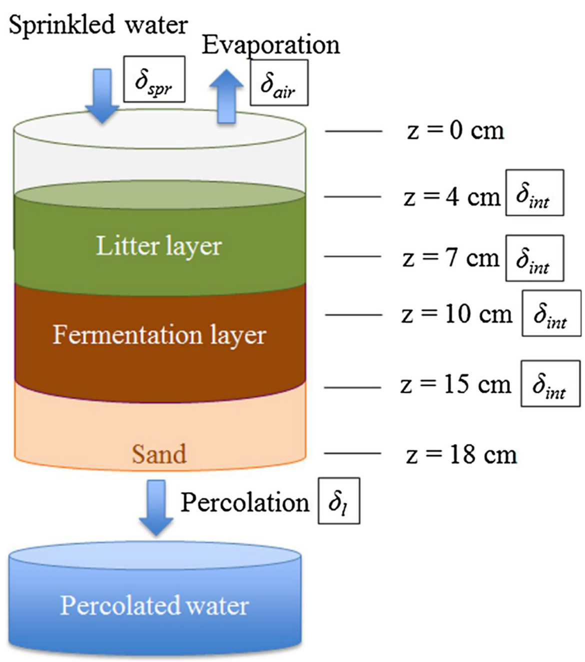

Fig. 3. Scheme of the cylindrical lysimeter used as experimental set-up (z = depth of water collecting during the experiments, δ = isotopic ratio).

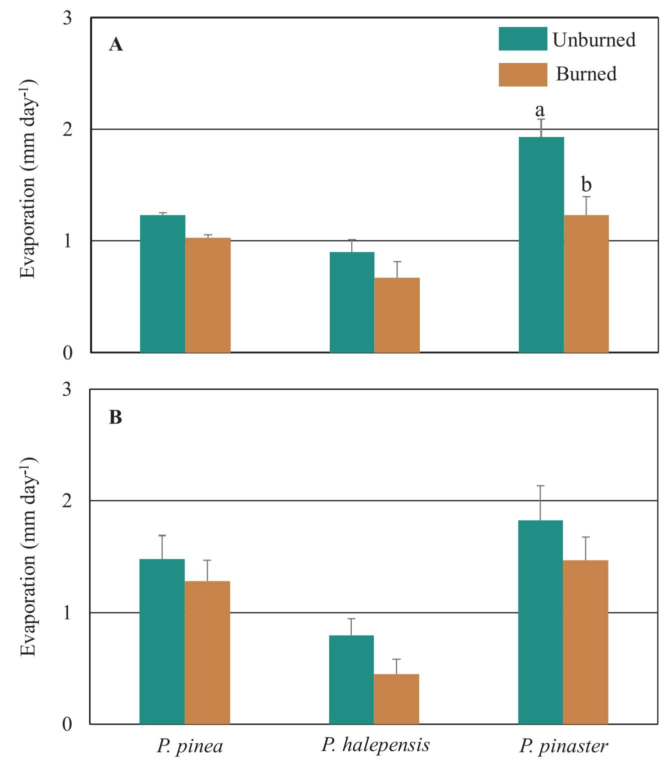

Fig. 4. Mean values (+standard error) of the evaporation flux, calculated with water balance approach (A) and water isotope mass balance approach (B) in unburned and burned areas of three pine plantations, estimated until 2 days after sprinkling. Significant ($P < 0.1$) difference between treatments are reported with different letters on bars.

Table 1
Litter and fermentation layers thickness in the three studied pine plantations.

Site	Thickness (cm)	
	Litter layer (I & II replicate)	Fermentation layer (I & II replicate)
*Pp*L-ub	5	5
*Pp*L-b	4	5
Ph-ub	5	5
Ph-b	4	4
Pp-ub	7	6
Pp-b	6	6

plantation in *Cilento, Vallo di Diano e Alburni National Park* (CNP); a *P. pinaster* plantation in *Tirone Alto-Vesuvio Nature State Reserve* (TAV). In each plantation, the fire treatment was carried out on an area of about 0.5 ha; a near untreated area with the same aspect, elevation, size and soil was used as a control.

2.1.1. *P. pinea* (CVR)

In a *P. pinea* plantation (40°57′N; 13°59′E; 8 m above sea level), in Castel Volturno municipality, an experimental prescribed burning was carried out on 12th March 2014. The climate of the area is typically Mediterranean with hot and dry summers. The mean annual temperature is 13.6 °C and the mean precipitation is 761.3 mm yr^{-1} (data from meteorological station of Ischitella; Battipaglia et al., 2016). During the prescribed burning experiment in the CVR plantation the average air temperature was 18 °C, relative humidity 54%, wind speed 2.5 km h^{-1} and surface litter moisture 32%. Flame length was < 0.5 m, fire line intensity < 50 kW m^{-1} and ignition pattern was backfire, residence time of temperature above 100 °C was 139 s in the litter and 30 s in the fermentation layer (Giuditta, 2016).

2.1.2. *P. halepensis* (CNP)

Prescribed burning was applied in CNP in a *P. halepensis* coastal plantation (40°01′N; 15°16′E) on 19th March 2014. This plantation is located in Capo Palinuro municipality, at 160 m a.s.l. and 30% slope. This study site is characterized by a Mediterranean climate, with a mean annual temperature of 17.7 °C and a mean precipitation of 714 mm yr^{-1} (data from meteorological station of Capo Palinuro; Battipaglia et al., 2014). Weather conditions and prescribed burning

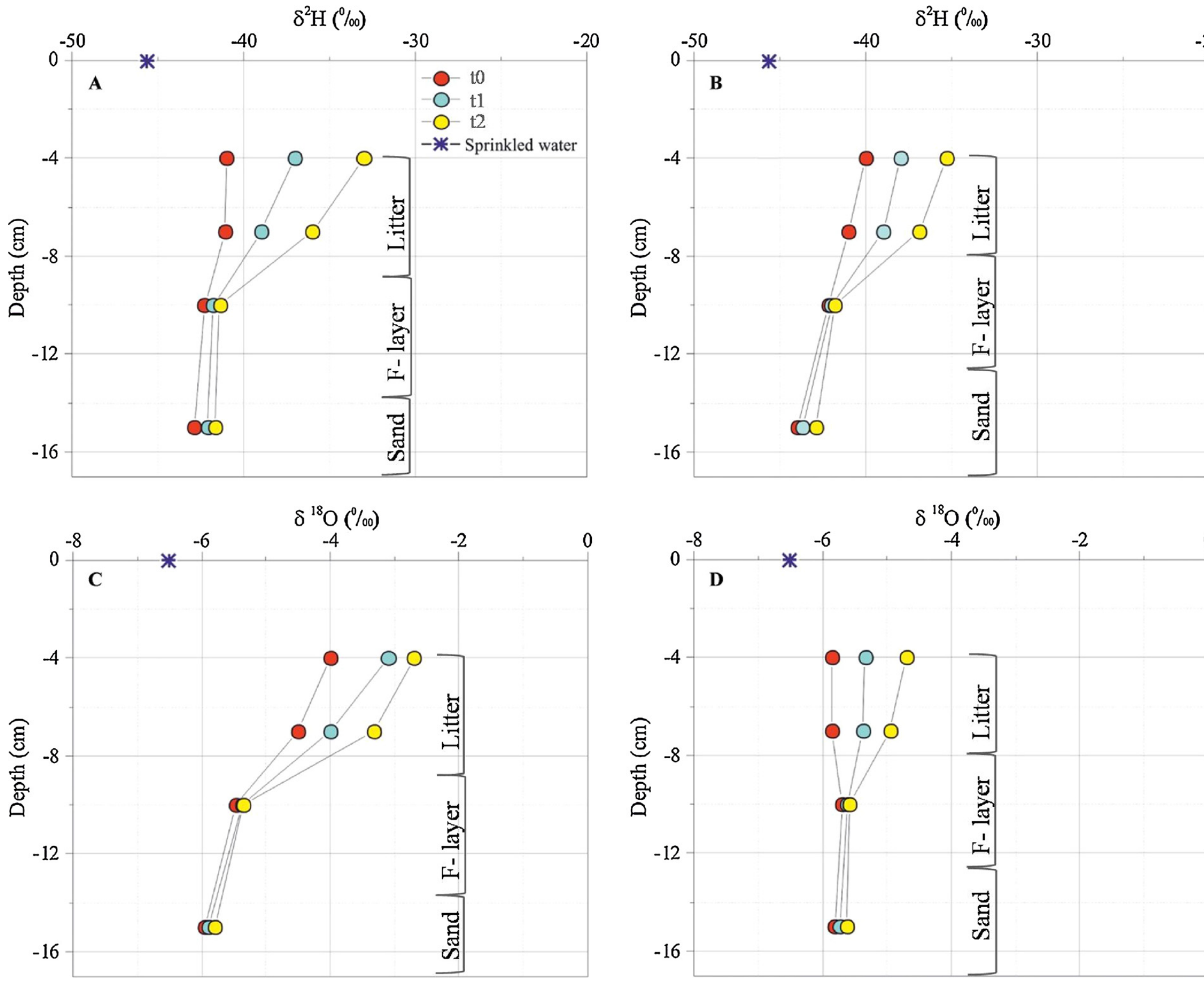

Fig. 5. Isotope depth profile in litter and fermentation layer at different days from the simulated rain (t0 = day of the sprinkling, t1 = 1 day after sprinkling and t2 = 2 days after sprinkling) in unburned (A, C) and burned (B, D) areas in *P. pinea* (CVR) plantation. F-layer = Fermentation layer.

behaviour during the experiment were: average air temperature of 14 °C, relative humidity 65%, wind speed 4 km h^{-1} and surface litter moisture 34%. Flame length range was < 1.0 m, fire line intensity < 90 kW m^{-1} and ignition pattern was backfire (Catalanotti et al., 2017), residence time of temperature above 100 °C was 290 s in the litter, whereas in the fermentation layer this temperature was not reached (Giuditta, 2016). This plantation had been also treated in 2009 with a first prescribed fire experiment.

2.1.3. P. pinaster (TAV)

Prescribed burning was applied in a *P. pinaster* plantation (40°49′N; 14°25′E) on 21st March 2014. This plantation is located in Tirone Alto Vesuvio Natural State Reserve (Torre del Greco municipality) at 640 m a.s.l. and 20% slope. The study site has a typical Mediterranean climate, with a mean annual temperature of 13.2 °C and a mean precipitation of 960 mm yr^{-1} (data from the meteorological station of Ercolano – Osservatorio Vesuviano). During the prescribed burning in TAV plantation, the average air temperature was 16 °C, relative humidity 52%, wind speed 5.5 km h^{-1} and surface litter moisture 38%. Flame length range was < 1 m, fire line intensity < 150 kW m^{-1} and ignition pattern was backfire, residence time of temperature above 100 °C was 230 s in the litter and 179 s in the fermentation layer (Giuditta, 2016).

2.2. Sampling and experimental set-up

In order to assess the prescribed burning effects on evaporation of intercepted water from litter and fermentation layers, two cores were sampled in each site, both including the litter and fermentation layer. One core was collected in the unburned area, and the other one in the burned area. An aluminium cylindrical collector, with a diameter of 18 cm and a height of 21 cm, customized to extract an "undisturbed" core, was used. Sampling in the three experimental sites was performed following three steps (Fig. 2): 1) the collector was pushed into litter and fermentation layers; 2) the collector with the core was extracted without altering samples; 3) the collector was closed to store samples until measurements. The cores were sampled in September 2015, 18 months after the prescribed burning treatments. In the laboratory of Delft University of Technology (The Netherlands), each core was moved into a cylindrical lysimeter with a diameter of 20 cm and a height of 18 cm (Fig. 3). The bottom of the set-up was filled with a different amount of sand, considering the different thickness of litter and fermentation layers in the three experimental sites (Table 1), and the not neat separation between the layers, in order to align the litter and fermentation layers with the sampling locations in the laboratory lysimeter. The lysimeter is a device specifically made for the collection of water samples for isotopic analysis with Rhizon samplers, that are provided with a thin hose with a porous filter (0.15–0.2 µm) on top, and a connector to attach the syringe at the bottom. To extract water we applied a vacuum with 5 mL syringes.

In total there were six set-ups: *P. pinea* unburned (*Pp*L-ub), *P. pinea* burned (*Pp*L-b), *P. halepensis* unburned (*Ph*-ub), *P. halepensis* burned (*Ph*-b), *P. pinaster* unburned (*Pp*-ub), and *P.pinaster* burned (*Pp*-b), and each experiment was carried out in duplicate.

Each experiment lasted three days and all experiments were carried

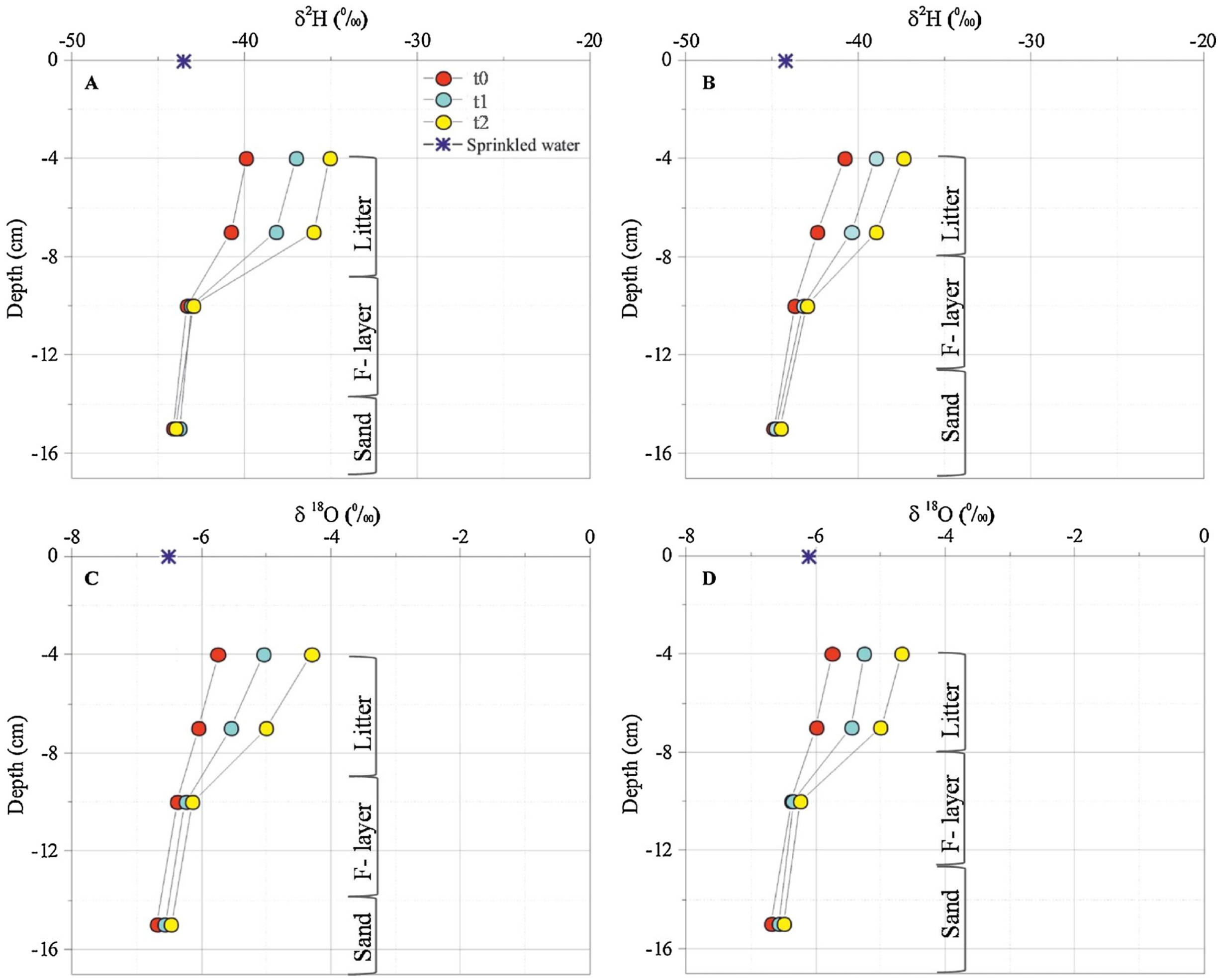

Fig. 6. Isotope depth profile in litter and fermentation layer at different days from the simulated rain (t0 = day of the sprinkling, t1 = 1 day after sprinkling and t2 = 2 days after sprinkling) in unburned (A, C) and burned (B, D) areas in *P. halepensis* (CNP) plantation. F-layer = Fermentation layer.

out in November 2015. For each experiment, the following procedure at the start to determine the initial conditions was followed:

(I) the set-up was weighed (accuracy 10 g) before the rainfall simulation (1 L of tap water, equivalent to 32 mm of rain, sprinkled uniformly on the set-up with a common plant spray);
(II) three water samples were taken from the plant spray during the simulation;
(III) after finishing sprinkling, we waited until water percolation in the lower box stopped. This was typically between 3–5 h;
(IV) the set-up was re-weighed, and a sample of the percolated water was taken with a pipette from the lower box.

After this initial sampling and weighing, water samples for isotopic analysis were taken twice per day in the morning and evening from the litter (at 4 and 7 cm), fermentation layers (at 10 cm) and at the base or just below the base of the fermentation layer (at 15 cm) with Rhizon soil moisture samplers by applying a suction pressure with 5 mL syringes. Furthermore, the total weight of the set-up was measured every day during the experiments.

During the experiments, the following variables were measured (Fig. 3): isotopic ratio of the intercepted water (δ_{int}, ‰) from the litter and the fermentation layers (at 4, 7, 10 and 15 cm depths), isotopic ratio of the sprinkled water (δ_{spr}, ‰), of the water percolated (δ_l, ‰) and of the air moisture (δ_{air}, ‰). The δ values, represent deviations in per-mil (‰) from the Vienna Standard Mean Ocean Water (VSMOW) (Mook, 2006; Gonfiantini, 1978):

$$\delta\ (‰) = \left(\frac{R_{sample}}{R_{VSMOW}} - 1\right) \times 1000‰ \quad (1)$$

where, R_{sample} is the isotopic abundance ratio of $^2H/H$ or $^{18}O/^{16}O$ in the sample and R_{VSMOW} is the respective isotopic abundance ratio of the Vienna Standard Mean Ocean Water.

All the experiments lasted maximum three days. Temperature and relative humidity of the room were also monitored every 15 min, in order to verify controlled laboratory conditions during the experiments. The collected data indicate that the room temperature was fairly stable during the entire duration of all the experiments, ranging between 19.5 °C and 21 °C, with a maximum excursion during a single experiment of less than 1.0 °C. The relative humidity was always between 45% and 70%. Atmospheric water was sampled by condensation in order to know the isotopic composition of the air moisture. A thermostat box was filled with dry ice (−78 °C) and closed by a lid with an opening for a standard 100 mL plastic vial. Air flow was pumped through the hermetically closed plastic 100 mL vial by means of two inserted syringes. As the entire set-up was surrounded by dry ice, complete condensation was assumed to be accomplished. A sensitivity analysis of the atmospheric isotopic content on the calculated evaporation was performed. The whole system was connected to a vacuum pump and about 2 mL of water per 4 h were obtained.

2.3. Water balance

Evaporation density rate, E_a [L T^{-1}] was calculated based on the

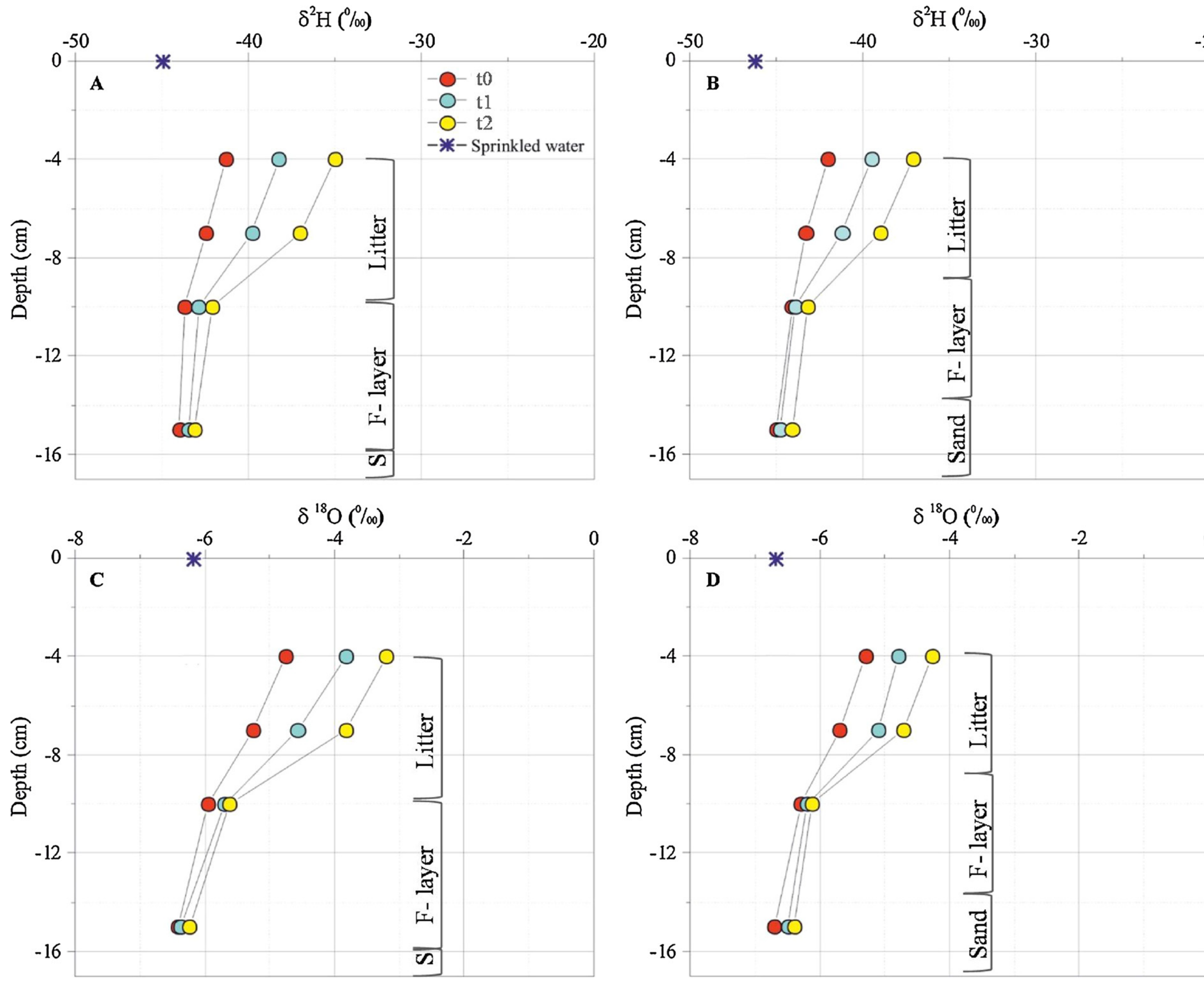

Fig. 7. Isotope depth profile in litter and fermentation layer at different days from the simulated rain (t0 = day of the sprinkling, t1 = 1 day after sprinkling and t2 = 2 days after sprinkling) in unburned (A, C) and burned (B, D) areas in *P. pinaster* (TAV) plantation. F-layer = Fermentation layer; S = Sand.

differences between precipitation P [L T^{-1}], storage changes dS/dt, and percolation L [L T^{-1}], as follows:

$$\frac{dS}{dt} = P - E_a - L \tag{2}$$

The storage changes were measured directly in the set-up. Artificial precipitation (=32 mm) was only applied at the beginning of the experiment. Since the evaporation experiment started only when percolation ceased, P and L were neglected, which reduces Eq. (1) to dS/dt = $-E_a$ during the evaporation experiment. The storage changes in millimetres per day were obtained by dividing the mass change (kg) by the surface area of the lysimeter (*i.e.*, A = 314 cm^2) and the density of water (ρ = 1000 kg m^{-3}).

2.4. Isotope measurements

Water samples were analysed with the LGR liquid water isotope analyser (LWIA) following Penna et al (2010). The analyser measures ^{2}H and ^{18}O in liquid water samples with an accuracy of ± 0.80‰ and ± 0.25‰, respectively (Penna et al., 2010). The results were reported in δ values (‰) as defined in Eq. (1).

2.5. Isotope mass balance

The isotope mass balance calculation has been carried out to calculate evaporation. The isotope mass balance can be formulated as (Sutanto et al., 2012):

$$\delta_i \bullet m_i + \delta_p \bullet m_p = \delta_e \bullet m_e + \delta_f \bullet m_f + \delta_l \bullet m_l \tag{3}$$

where m [M] and δ stand for the water mass and (oxygen or hydrogen) isotopic composition. Subscripts i, p, e, f, and l stand, respectively, for initial measurement, precipitation, evaporation, final measurement, and percolation. In particular, in our isotope mass balance calculation, δ_i and δ_f are the average of initial and final isotopic compositions in the first 7 cm of the cores for the two experiments, at t0 (day of the sprinkling) and t2 (2 days after sprinkling), respectively. Since rainfall was not applied during the experiment and percolation stopped before the experiment started, $m_p = m_l = 0$ and since $m_f = m_i - m_e$, this simplifies Eq. (3) to:

$$\delta_i {*} m_i = \delta_e {*} m_e + \delta_f {*} (m_i - m_e) \tag{4}$$

From this m_e can be readily derived:

$$m_e = \frac{m_i(\delta_i - \delta_f)}{\delta_e - \delta_f} = E_a \bullet \rho \bullet A \tag{5}$$

and δ_e is calculated with the Craig-Gordon model. To calculate δ_e with the Craig-Gordon formulation, temperature, humidity and the isotopic composition of the ambient air should be known. The Craig-Gordon model (Craig and Gordon, 1965) makes use of the fact that evaporation from open water depends on the relative humidity of the receiving atmosphere. The higher is the air humidity, the less fractionation occurs (Craig and Gordon, 1965; Kendall and McDonnell, 2012). This conceptual method calculates the isotopic composition of open water evaporation as a function of temperature and humidity as described

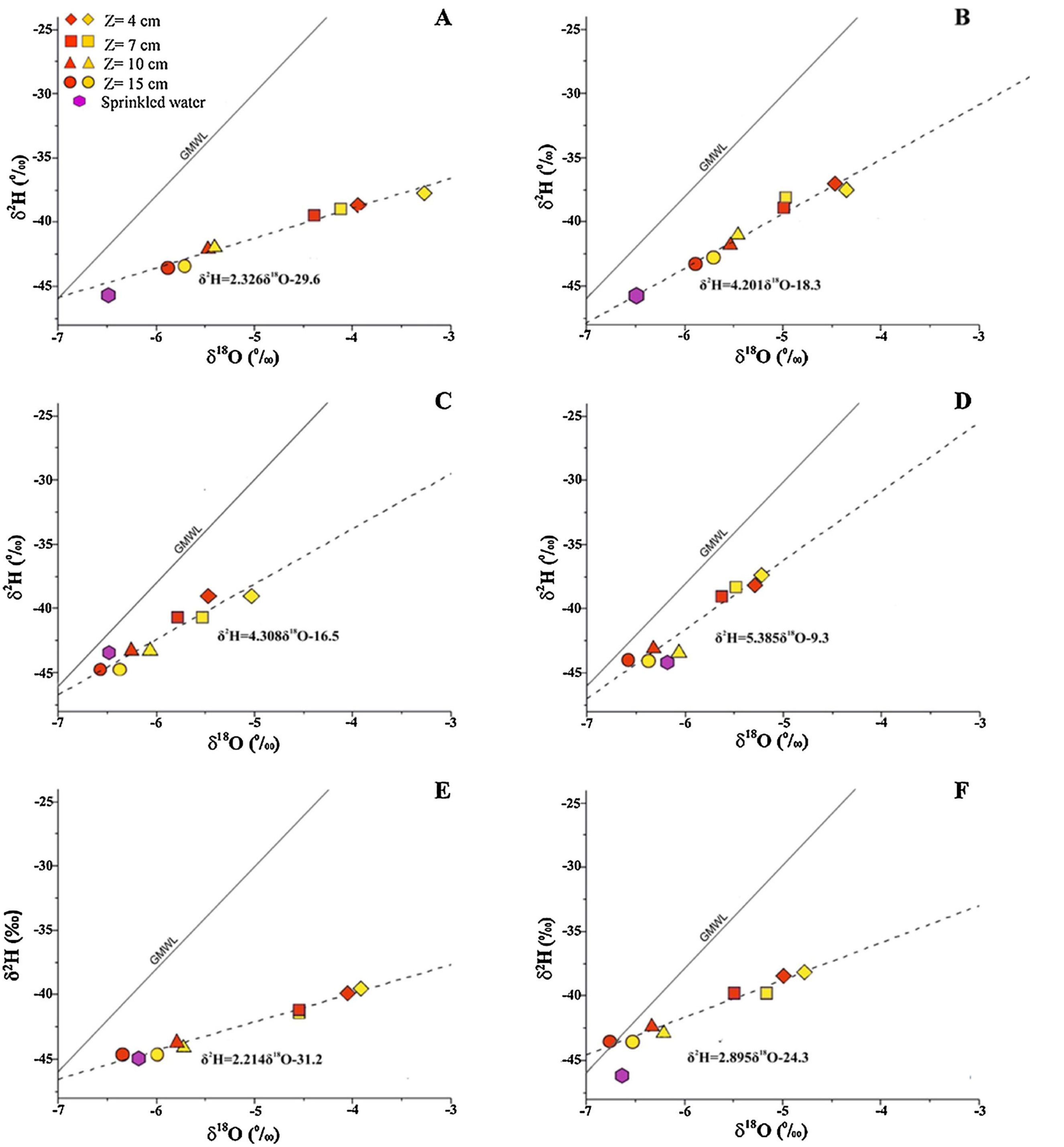

Fig. 8. Scatter plots for δ^2H (‰) *vs* δ^{18}O (‰) from t0 (immediately after percolation stopped, in red) to t2 (2 days after percolation stopped, in yellow), obtained, for each experiment, in unburned and burned areas, respectively, of *P. pinea* (A and B), *P. halepensis* (C and D) and *P. pinaster* (E and F) plantations, considering different depths in the lysimeter. GMWL: Global Meteoric Water Line (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

below:

$$\delta_e = \frac{(\delta_w - h\delta_a - \varepsilon)}{1-h} \tag{6}$$

with δ_e the isotopic composition of the evaporated moisture ($-$), h the relative humidity ($-$), δ_w ($-$), the isotopic compositions of the surface water corresponding to $\delta_i{}^2$H and $\delta_i{}^{18}$O estimated in the first 7 cm of the cores and δ_a ($-$), the vapor isotopic composition (sampled 1 m away from the lysimeter in the same room), measured with the LWIA, using water samples collected by condensation as described in Section 2.2. The enrichment factor (ε) was determined according to Kendall and McDonnell (2012), considering as exponent of the diffusivity ratio $n = 1$, as suggested by Barnes and Allison (1983). A sensitivity analysis showed that the enrichment factor (ε) has a minor effect on the calculated isotopic composition of the evaporated water and a negligible effect (< 0.01 mm day^{-1}) on the calculated evaporation. The evaporation flux calculated by isotope mass balance was reported considering the average of ^{2}H and ^{18}O mass balance results for the two experiments.

2.6. Statistical analysis

The significance ($P < 0.1$) of differences among treatments (burned and unburned), for each experiment, was analyzed by one-way ANOVA, followed, if required, by Student-Newman-Keuls test (by SigmaPlot 12.0 Jandel Scientific). The choice of a relatively high significance level depends on the small number of available samples (two). Choosing a smaller P would result in a very small power of the test, *i.e.* a high probability of accepting the null hypothesis when it is false.

3. Results and discussion

The mean amount of water stored, after sprinkling, in the samples collected from *P. pinea* (CVR) plantation was 15 mm in the unburned area and 10 mm in the burned one, while in *P. halepensis* (CNP) plantation it was equal to 25 mm and 16 mm in the unburned and burned areas, respectively. In the *P. pinaster* plantation (TAV) it was 21 mm in untreated area and 14 mm in treated one.

In the *P. pinea* (CVR) plantation, evaporation of intercepted water from the litter and fermentation layers measured with water balance (Fig. 4A) was 1.23 mm day^{-1} in the unburned area and 1.03 mm day^{-1} in the burned one, while in the *P. halepensis* (CNP) plantation it was 0.90 mm day^{-1} and 0.67 mm day^{-1} in the unburned and burned areas, respectively. In the *P. pinaster* plantation (TAV) it was equal to 1.93 mm day^{-1} in untreated area and 1.23 mm day^{-1} in the treated one. Hence, all three study sites showed a reduction trend of evaporation in treated areas, compared to untreated ones, although the difference could be considered statistically significant, at the 10% significance level, only for the *P. pinaster* plantation (Fig. 4A).

The mean evaporation calculated with the isotope mass balance (Fig. 4B), was equal to 1.48 mm day^{-1} in the unburned area and to 1.28 mm day^{-1} in the burned area in *P. pinea* plantation (CVR), while in the *P. halepensis* (CNP) plantation it was 0.79 mm day^{-1} and 0.45 mm day^{-1} in unburned and in the burned areas, respectively. In *P. pinaster* plantation (TAV) it was equal to 1.82 mm day^{-1} and 1.47 mm day^{-1} in untreated and treated areas, respectively (Fig. 4B). In this case, the reduction of evaporation of intercepted water, recorded in the samples collected in the burned areas, was not statistically significant, compared to unburned ones, in all experimental sites. It has to be highlighted that our findings of the isotope mass balance showed an identical trend as the water balance results, indeed both approaches showed that the samples collected in burned areas had lower, although in most cases not statistically significant, evaporation estimates compared to those collected in the unburned areas. No significant differences occurred between evaporation values obtained, for each sample, with isotope mass balance and water balance method. The water balance approach is actually considered the most accurate method to evaluate evaporation compared to the other methods, such as the isotope mass balance, since it uses a weighing balance so directly measuring the losses of water inside the lysimeter due to evaporation and percolation (Sutanto et al., 2012). However, the results of our laboratory experiment strongly point to water stable isotope mass balance as also an effective method to calculate evaporation of intercepted water from the forest floor. Our set-up used a condensation method to determine the atmospheric water isotopic content instead of direct gas-phase measurement. A hypothetical error of the atmospheric isotopic content of 4‰ ^2H or 1‰ ^{18}O has an effect of ma × 0.2 mm day^{-1} on the calculated evaporation rate but does not change the differences of calculated evaporation between the samples. To reduce the uncertainty of the proposed method, direct sampling and measuring of isotopic composition of the atmospheric vapor in gas-phase is advised for future studies. The isotope method is in principle easily applicable also in the field, thus allowing estimates of evaporation with an easy and non-invasive experimental technique.

Isotopic profiles were obtained for each depth (from 4 to 15 cm) from the analysis of the variation of the isotopic ratios of ^2H and ^{18}O, measured in intercepted water by the litter and the fermentation layer, after the simulation of the rain. In each experimental site and condition (unburned and burned), the increase in δ values showed that evaporation of intercepted water occurred (Figs. 5–7). At t0 we can already see an evaporation front occurring, because the first samples were taken only when percolation fully stopped which took between 3–5 h. The evaporation front is located at the surface of the lysimeter and this demonstrated that the majority of evaporation came from the litter layer. This result was also found by Liu et al. (2015) in an Alpine shrub land. The isotopic profiles also showed less evaporation in the burned areas compared to unburned ones, as indicated by smaller enrichment in the litter layers of burned samples. The comparison of the results of the unburned and burned areas, showed that fractionation was higher in the unburned areas than in the burned ones, since the regression lines of the unburned areas deviated more from the GMWL (Fig. 8). If the enrichment from t0 (immediately after percolation stopped) and t2 (2 days after percolation stopped) was compared, all experiments showed similar enrichment for deuterium as for ^{18}O.

The difference in evaporation, between the burned and unburned areas, as observed by the water balance approach as well as from the stable water isotopes data, can be considered as a direct effect of a low intensity prescribed fire on the amount of litter and the fermentation layer and/or on their physico-chemical properties. Since the atmospheric conditions in the laboratory were similar during all experiments, the lower evaporation rates observed for burned samples collected in the three experimental sites, could be a consequence of a lower interception capacity. As reported, the amount of water stored in litter and fermentation layers, after percolation, that showed values comparable to Lowdermilk (1930) and Bulcock and Jewitt (2012), was lower in samples collected in burned areas, compared to unburned ones in all experimental sites. This reduction of the water storage capacity could be ascribed to the thinning of the litter in the burned areas, that had not yet recovered the pre-fire levels, at least up to 18 months after the treatment with prescribed burning, which was the case for all three plantations. This was also found by Baker Jr. (1990) and Vadilonga et al. (2008), who reported that prescribed burning treatments mainly expressed their influence on forest floor, only by reducing, temporarily, its amount of water storage capacity, at least until the amount of litter returned to pre-fire levels. Since prescribed fires generally produce lower temperatures, they have not the same effects on soil hydrological properties as wildfires, which, instead, have been reported to have marked effects on the increase of run-off (van Eck et al., 2016) and on soil erosion (Certini, 2005; Prosser and Williams, 1998; Shakesby and Doerr, 2006).

4. Conclusions

This is a laboratory study to evaluate the effects of prescribed burning treatments on evaporation of intercepted water from different forest floors. Three litter covers in a *P. pinea*, *P. halepensis* and *P. pinaster* plantations with different thickness were investigated. The evaporation rates were measured by a water balance and an isotope mass balance, looking at the isotope enrichment and the deviation of the regression lines from the GMWL. Both methods showed, with evaporation estimates in good agreement, that the burned areas, in all experimental sites, had a lower, but in most cases not statistically significant, evaporation rate over the study period, compared to unburned areas. The results of the isotope enrichment also indicated less evaporation in the burned areas, compared to unburned ones. The reduction trend of the evaporation flux in the treated systems could be explained by a lower interception capacity, subsequent to a lower amount of water stored in cores collected in burned areas, after percolation, probably due to a thinner litter layer at least up to 18 months after prescribed burning. However, further investigation is necessary to assess if what it was observed, performing laboratory experiments, could also hold in field conditions.

Acknowledgments

This research is part of the Ph.D. project "Effects of prescribed burning practice in Southern Italy pine plantations evaluated by a multidisciplinary approach" granted by Università degli Studi della Campania "Luigi Vanvitelli", within the Ph.D. course "Ambiente, Design e Innovazione" XXIX Cycle. This research was also partly funded by NWO Earth and Life Science (ALW), veni-project 863.15.022, The Netherlands.

Thanks are due to Campania Region and *Cilento, Vallo di Diano e Alburni National Park* (Southern Italy) for permitting the realization of this study. Thanks also to Dr. Davide Ascoli of the Università degli Studi di Napoli "Federico II" to provide weather and fire behaviour data and to Dr. Gianluigi Busico for graphical support.

References

Allen, S.T., Keim, R.F., Barnard, H.R., McDonnell, J.J., Brooks, J.R., 2016. The role of stable isotopes in understanding rainfall interception processes: a review. Wiley Interdiscip. Rev. Water 4, 1–17. http://dx.doi.org/10.1002/wat2.1187.

Aouade, G., Ezzahar, J., Amenzou, N., Er-Raki, S., Benkaddour, A., Khabba, S., Jarlan, L., 2016. Combining stable isotopes, Eddy Covariance system and meteorological measurements for partitioning evapotranspiration, of winter wheat, into soil evaporation and plant transpiration in a semi-arid region. Agric. Water Manage. 177, 181–192. http://dx.doi.org/10.1016/j.agwat.2016.07.021.

Ascoli, D., Catalanotti, A.E., Valese, E., Cabiddu, S., Delogu, G., Driussi, M., Esposito, A., Leone, V., Lovreglio, R., Marchi, E., Mazzoleni, S., Rutigliano, F.A., Strumia, S., Bovio, G., 2012. Esperienze di fuoco prescritto in Italia: un approccio integrato per la prevenzione degli incendi boschivi. Forest@ 9, 20–38. http://dx.doi.org/10.3832/efor0686-009.

Baker Jr., M.B., 1990. Hydrologic and water quality effects of fire. J.S. Krammes, Tech. Coord.. Effects of Fire Management of Southwestern Natural Resources. Gen. Tech. Rept. RM-191. US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO 31–24.

Barnes, C., Allison, G., 1983. The distribution of deuterium and ^{18}O in dry soils: 1. Theory J. Hydrol. 60, 141–156. http://dx.doi.org/10.1016/0022-1694(83)90018-5.

Battipaglia, G., Savi, T., Ascoli, D., Castagneri, D., Esposito, A., Mayr, S., Nardini, A., 2016. Effects of prescribed burning on ecophysiological, anatomical and stem hydraulic properties in *Pinus pinea* L. Tree Physiol. http://dx.doi.org/10.1093/treephys/tpw034.

Battipaglia, G., Strumia, S., Esposito, A., Giuditta, E., Sirignano, C., Altieri, S., Rutigliano, F.A., 2014. The effects of prescribed burning on Pinus halepensis Mill. as revealed by dendrochronological and isotopic analyses. For. Ecol. Manage 334, 201–208. http://dx.doi.org/10.1016/j.foreco.2014.09.010.

Bradstock, R., Bedward, M., Kenny, B.J., Scott, J., 1998. Spatially-explicit simulation of the effect of prescribed burning on fire regimes and plant extinctions in shrublands typical of south-eastern Australia. Biol. Conserv. 86, 83–95. http://dx.doi.org/10.1016/S0006-3207(97)00170-5.

Bulcock, H.H., Jewitt, G.P.W., 2012. Field data collection and analysis of canopy and litter interception in commercial forest plantations in the KwaZulu-Natal Midlands, South Africa. Hydrol. Earth Syst. Sci. 16, 3717–3728. http://dx.doi.org/10.5194/hess-16-3717-2012.

Catalanotti, A.E., Giuditta, E., Marzaioli, R., Ascoli, D., Esposito, A., Strumia, S., Mazzoleni, S., Rutigliano, F.A., 2017. Effects of single and repeated prescribed burns on soil organic C and microbial activity in a Pinus halepensis plantation of Southern Italy. Appl. Soil Ecol. http://dx.doi.org/10.1016/j.apsoil.2017.12.015.

Catalanotti, A.E., Strumia, S., Esposito, A., Ascoli, D., Marzaioli, R., Seneca, U., D'Ascoli, R., Mazzoleni, S., Rutigliano, F.A., 2010. Effects of prescribed burning on soil microbial community and vegetation in pine plantations of Southern Italy. In: Viegas, D.X. (Ed.), Proceedings of the 6th International Conference on "ForestFire Research". Coimbra, Portugal, 15–18 November, 2010.

Cawson, J.G., Sheridan, G.J., Smith, H.G., Lane, P.N.J., 2012. Surface runoff and erosion after prescribed burning and the effect of different fire regimes in forests and shrublands: a review. Int. J. Wildland Fire 21, 857–872. http://dx.doi.org/10.1071/WF11160.

Certini, G., 2005. Effects of fire on properties of forest soils: a review. Oecologia 143, 1–10. http://dx.doi.org/10.1007/s00442-004-1788-8.

Cookson, W.R., O'Donnel, A.J., Grant, C.D., Grierson, P.F., Murphy, D.V., 2008. Impact of ecosystem management on microbial community level physiological profiles of postmining forest rehabilitation. Microb. Ecol. 55, 321–332. http://dx.doi.org/10.1007/s00248-007-9278-2.

Craig, H., Gordon, L.I., 1965. Deuterium and oxygen 18 variations in the ocean and the marine atmosphere. In: Spoleto. In: Tongiorgi, E. (Ed.), Proceedings of Stable Isotopes in Oceanographic Studies and Paleo Temperatures, vol. 32. pp. 9–130.

Dietrich, O., Kaiser, T., 2017. Impact of groundwater regimes on water balance components of a site with a shallow water table. Ecohydrology e1867. http://dx.doi.org/10.1002/eco.1867.

Eugenio, M., Lloret, F., 2006. Effects of repeated burning on Mediterranean communities of the northeastern Iberian Peninsula. J. Veg. Sci. 17, 755–764. http://dx.doi.org/10.1658/1100-9233.

Fernandes, P., Botelho, H., 2003. A review of prescribed burning effectiveness in fire hazard reduction. Int. J. Wildland Fire 12, 117–128. http://dx.doi.org/10.1071/WF02042#sthash.Sd3Q4NKY.dpuf.

Fernandes, P.M., Davies, G.M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., Stoof, C.R., Vega, J.A., Molina, D., 2013. Prescribed burning in southern Europe: developing fire management in a dynamic landscape. Front. Ecol. Environ. 11, 4–14. http://dx.doi.org/10.1890/120298.

Fernandes, P.M., Loureiro, C., Botelho, H., 2012. PiroPinus: a spreadsheet application to guide prescribed burning operations in maritime pine forest. Comput. Electron. Agric. 81, 58–61. http://dx.doi.org/10.1016/j.compag.2011.11.005.

Fonturbel, M.T., Vega, J.A., Bara, S., Bernardez, I., 1995. Influence of prescribed burning of pine stands in NW Spain on soil microorganisms. Eur. J. Soil Biol. 31, 13–20.

Fontúrbel, M.T., Barreiro, A., Vega, J.A., Martín, A., Jiménez, E., Carballas, T., Fernández, C., Díaz-Raviña, M., 2012. Effects of an experimental fire and post-fire stabilization treatments on soil microbial communities. Geoderma 191, 51–60. http://dx.doi.org/10.1016/j.geoderma.2012.01.037.

Gerrits, A.M.J., 2010. The Role of Interception in the Hydrological Cycle. Dissertation. Delft University of Technology978-90-6562-248-8.

Gerrits, A.M.J., Savenije, H.H.G., Hoffmann, L., Pfister, L., 2007. New technique to measure forest floor interception—an application in a beech forest in Luxembourg. Hydrol. Earth Syst. Sci. 11, 695–701. http://dx.doi.org/10.5194/hess-11-695-2007.

Gerrits, A.M.J., Savenije, H.H.G., 2011. Forest floor interception. In: Levia, D.F., Carlyle-Moses, D.E., Tanaka, T. (Eds.), Forest Hydrology and Biogeochemistry: Synthesis of Past Research and Future Directions. Springer-Verlag, Heidelberg, Germany pp. 3–27.

Giuditta, E., 2016. Effects of Prescribed Burning Practice in Southern Italy Pine Plantations Evaluated by a Multidisciplinary Approach. PhD Thesis. .

Gonfiantini, R., 1978. Standards for stable isotopes measurements in natural compounds. Nature 271, 534–536. http://dx.doi.org/10.1038/271534a0.

González-Pelayo, O., Andreu, V., Gimeno-García, E., Campo, J., Rubio, J.L., 2010. Effects of fire and vegetation cover on hydrological characteristics of a Mediterranean shrubland soil. Hydrol. Process. 24, 1504–1513. http://dx.doi.org/10.1002/hyp.7612.

Helvey, J.D., 1967. Interception by eastern white pine. Water Resour. Res. 3, 723–729. http://dx.doi.org/10.1029/WR003i003p00723.

Herbst, M., Rosier, P.T., McNeil, D.D., Harding, R.J., Gowing, D.J., 2008. Seasonal variability of interception evaporation from the canopy of a mixed deciduous forest. Agric. For. Meteorol. 148, 1655–1667. http://dx.doi.org/10.1016/j.agrformet.2008.05.011.

Hossain, A.K.M.A., Raison, R.J., Khanna, P.K., 1993. Effects of fertilizer application and fire regime on soil microbial biomass carbon and nitrogen, and nitrogen mineralization in an Australian subalpine eucalypt forest. Biol. Fertil. Soils 19, 246–252. http://dx.doi.org/10.1007/BF00336167.

Johansen, M.P., Hakonson, T.E., Breshears, D.D., 2001. Post-fire runoff and erosion from rainfall simulation: contrasting forests with shrublands and grasslands. Hydrol. Process. 15, 2953–2965. http://dx.doi.org/10.1002/hyp.384.

Johnson, D.W., 1992. Effects of forest management on soil carbon storage. Water Air Soil Pollut. 64, 83–120. http://dx.doi.org/10.1007/BF00477097.

Kendall, C., McDonnell, J.J., 2012. Isotope Tracers in Catchment Hydrology. Elsevier, The Netherlands.

Knicker, H., 2007. How does fire affect the nature and stability of soil organicnitrogen and carbon? A review. Biogeochemistry 85, 91–118. http://dx.doi.org/10.1007/s10533-007-9104-4.

Koeniger, P., Leibundgut, C., Link, T., Marshall, J.D., 2010. Stable isotopes applied as water tracers in column and field studies. Org. Geochem. 41, 31–40. http://dx.doi.org/10.1016/j.orggeochem.2009.07.006.

Lankreijer, H.J.M., Hendriks, M.J., Klaassen, W., 1993. A comparison of models simulating rainfall interception of forests. Agric. For. Meteorol. 64, 187–199.

Lázaro, A., 2010. Development of prescribed burning and suppression fire in Europe. In: In: Montiel, C., Kraus, D. (Eds.), Best Practices of Fire Use-Prescribed Burning and Suppression Selected Case-Study Regions in Europe, vol. 24 European Forest Institute Research Report, Joensuu pp. 17–31.

Li, X.Y., Gong, J.D., Gao, Q.Z., Wei, X.H., 2000. Rainfall interception loss by pebble mulch in the semiarid region of China. J. Hydrol. 228, 165–173. http://dx.doi.org/10.1016/S0022-1694(00)00152-9.

Liu, Y., Liu, F., Xu, Z., Zhang, J., Wang, L., An, S., 2015. Variations of soil water isotopes and effective contribution times of precipitation and throughfall to alpine soil water, in Wolong Nature Reserve, China. Catena 126, 201–208. http://dx.doi.org/10.1016/j.catena.2014.11.008.

Lowdermilk, W.C., 1930. Influence of forest litter on run-off, percolation, and erosion. J. For. 28, 474–490.

Michener, R., Lajtha, K., 2008. Stable Isotopes in Ecology and Environmental Science, second ed. John Wiley & Sons, Hoboken, NJ.

Magliano, P.N., Giménez, R., Houspanossian, J., Páez, R.A., Nosetto, M.D., Fernández, R.J., Jobbágy, E.G., 2017. Litter is more effective than forest canopy reducing soil evaporation in Dry Chaco rangelands. Ecohydrology e1879. http://dx.doi.org/10.1002/eco.1879.

Mook, W.G., 2006. Introduction to Isotope Hydrology Stable and Radioactive Isotopes of Hydrogen, Carbon and Oxygen. Taylor & Francis Group, London, Great Britain p. 226.

Moreira, F., Delgado, A., Ferreira, S., Borrahlo, R., Oliveira, N., Inacio, M., Silva, J.S., Rego, F., 2003. Effects of prescribed fire on vegetation structure and breeding birds in young *Pinus pinaster* stands of northern Portugal. For. Ecol. Manage. 184, 225–237. http://dx.doi.org/10.1016/S0378-1127(03)00214-7.

Murray, S.J., 2014. Trends in 20th century global rainfall interception as simulated by a dynamic global vegetation model: implications for global water resources. Ecohydrology 7, 102–114. http://dx.doi.org/10.1002/eco.1325.

Nardoto, G.B., Bustamante, M.M.D.C., 2003. Effects of fire on soil nitrogen dynamics and microbial biomass in savannas of Central Brazil. P.A.B. 38, 955–962. http://dx.doi.org/10.1590/S0100-204X2003000800008.

Naveh, Z., 1994. The role of fire and its management in the conservation of Mediterranean ecosystems and land-scapes. In: Moreno, J.M., Oechel, W.C. (Eds.), The Role of Fire in Mediterranean-type Ecosystems. Springer-Verlag pp. 163–185.

Pathak, P.C., Pandey, A.N., Singh, J.S., 1985. Apportionment of rainfall in central himalayan forests (India). J. Hydrol. 76, 319–332. http://dx.doi.org/10.1016/0378-1127(92)90037-A.

Pausas, J.G., 2004. Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean basin). Clim. Change 63, 337–350. http://dx.doi.org/10.1023/B:CLIM.0000018508.94901.9c.

Penna, D., Stenni, B., Sanda, M., Wrede, S., Bogaard, T.A., Gobbi, A., Borga, M., Fischer, B.M.C., Bonazza, M., Chárová, Z., 2010. On the reproducibility and repeatability of laser absorption spectroscopy measurements for δ^2H and δ^{18}O isotopic analysis. Hydrol. Earth Syst. Sci. 14, 1551–1566. http://dx.doi.org/10.5194/hess-14-1-2010.

Prosser, I.P., Williams, L., 1998. The effect of wildfire on runoff and erosion in native Eucalyptus forest. Hydrol. Process. 12, 251–265. http://dx.doi.org/10.1002/(SICI)1099-1085(199802)12:2 < 251::AID-HYP574 > 3.0.CO;2-4.

Pruitt, W.O., Angus, D.E., 1960. Large weighing lysimeters for measuring evapotraspiration. Trans. ASAE 3, 13–18.

Putuhena, W.M., Cordery, I., 1996. Estimation of interception capacity of the forest floor. J. Hydrol. 180, 283–299. http://dx.doi.org/10.13031/2013.41105.

Reckerth, A., Stichler, W., Schmidt, A., Stumpp, C., 2017. Long-term data set analysis of stable isotopic composition in German rivers. J. Hydrol. http://dx.doi.org/10.1016/j.jhydrol.2017.07.022.

Rothfuss, Y., Merz, S., Hermes, N., Weuthen, A., Pohlmeier, A., Vereecken, H., Brüggemann, N., 2015. Long-term and high-frequency non-destructive monitoring of water stable isotope profiles in an evaporating soil column. Hydrol. Earth Syst. Sci. 19, 4067–4080. http://dx.doi.org/10.5194/hess-19-549 4067-2015.

Rothfuss, Y., Javaux, M., 2017. Reviews and syntheses: isotopic approaches to quantify root water uptake: a review and comparison of methods. Biogeosciences 14, 2199–2224. http://dx.doi.org/10.5194/bg-14-2199-2017.

Savenije, H.H.G., 2004. The importance of interception and why we should delete the term evapotranspiration from our vocabulary. Hydrol. Process. 18, 1507–1511. http://dx.doi.org/10.1002/hyp.5563.

Schaap, M.G., Bouten, W., 1997. Forest floor evaporation in a dense Douglas fir stand. J. Hydrol. 193, 97–113. http://dx.doi.org/10.1016/S0022-1694(96)03201-5.

Shakesby, R.A., Doerr, S.H., 2006. Wildfire as a hydrological and geomorphological agent. Earth-Sci. Rev. 74, 269–307. http://dx.doi.org/10.1016/j.earscirev.2005.10.006.

Shen, J.P., Chen, C.R., Lewis, T., 2016. Long term repeated fire disturbance alters soil bacterial diversity but not the abundance in an Australian wet sclerophyll forest. Sci. Rep. 6, 3–12. http://dx.doi.org/10.1038/srep19639.

Sprenger, M., Leistert, H., Gimbel, K., Weiler, M., 2016. Illuminating hydrological processes at the soil-vegetation-atmosphere interface with water stable isotopes. Rev. Geophys. 54, 674–704. http://dx.doi.org/10.1002/2015RG000515.

Stumpp, C., Maloszewski, P., Stichler, W., Maciejewski, S., 2007. Quantification of the heterogeneity of the unsaturated zone based on environmental deuterium observed in lysimeter experiments. Hydrol. Sci. J. 52, 748–762. http://dx.doi.org/10.1623/hysj.52.4.748.

Sutanto, S.J., Wenninger, J., Coenders-Gerrits, A.M.J., Uhlenbrook, S., 2012. Partitioning of evaporation into transpiration, soil evaporation and interception: a comparison between isotope measurements and a HYDRUS-1D model. Hydrol. Earth Syst. Sci. 16, 2605–2616. http://dx.doi.org/10.5194/hess-16-2605-2012.

Trabaud, L., 1982. Effects of past and present fire on the vegetation of the French Mediterranean region. In: Conrad, C.E., Oechel, W.C. (Eds.), Proceedings of the symposium on the dynamics and management of Mediterranean-type ecosystems. June. pp. 22–26.

Trabaud, L., Grandjanny, M., 2002. Post-fire reconstitution of the flowering phenology in Mediterrranean shrubland plants. In: Trabaud, L., Prodon, R. (Eds.), Fire and Biological Processes. Backhuys Publishers pp. 99–113.

Turco, M., von Hardenberg, J., AghaKouchak, A., Llasat, M.C., Provenzale, A., Trigo, R.M., 2017. On the key role of droughts in the dynamics of summer fires in Mediterranean Europe. Sci. Rep. 7. http://dx.doi.org/10.1038/s41598-017-00116-9.

Vadilonga, T., Úbeda, X., Germann, P.F., Lorca, M., 2008. Effects of prescribed burnings on soil hydrological parameters. Hydrol. Process. 22, 4249–4256. http://dx.doi.org/10.1002/hyp.7032.

van Eck, C., Nunes, J., Vieira, D., Keesstra, S., Keizer, J., 2016. Physically-based modelling of the post-fire runoff response of a forest catchment in central Portugal: using field vs. remote sensing based estimates of vegetation recovery. Land Degrad. Dev. http://dx.doi.org/10.1002/ldr.2507.

Vega, J.A., Fernández, C., Fonturbel, T., 2005. Throughfall, runoff and soil erosion after prescribed burning in gorse shrubland in Galicia (NW Spain). Land Degrad. Dev. 16, 37–51. http://dx.doi.org/10.1002/ldr.643.

Wang, P., Yamanaka, T., Li, X.Y., Wei, Z., 2015. Partitioning evapotranspiration in a temperate grassland ecosystem: numerical modeling with isotopic tracers. Agric. For. Meteorol. 208, 16–31. http://dx.doi.org/10.1016/j.agrformet.2015.04.006.

White, A.S., 1983. The effects of thirteen years of annual prescribed burning on a *Quercus ellipsoidalis* community in Minnesota. Ecology 64, 1081–1085. http://dx.doi.org/10.2307/1937817.