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Water Infiltration after Prescribed Fire and Soil Mulching with Fern in Mediterranean Forests

Bruno Gianmarco Carrà [1], Giuseppe Bombino [1], Pietro Denisi [1], Pedro Antonio Plaza-Àlvarez [2], Manuel Esteban Lucas-Borja [2] and Demetrio Antonio Zema [2,*]

[1] Department AGRARIA, Mediterranean University of Reggio Calabria, Loc. Feo di Vito, I-89122 Reggio Calabria, Italy; brunog.carra@unirc.it (B.G.C.); giuseppe.bombino@unirc.it (G.B.); pietro.denisi@unirc.it (P.D.)
[2] Escuela Técnica Superior Ingenieros Agrónomos y Montes, Campus Universitario, Universidad de Castilla-La Mancha, E-02071 Albacete, Spain; pedro.plaza@uclm.es (P.A.P.-À.); manuelesteban.lucas@uclm.es (M.E.L.-B.)
* Correspondence: dzema@unirc.it

Abstract: Prescribed fire is commonly used to reduce the wildfire risk in Mediterranean forests, but the soil's hydrological response after fire is contrasting in literature experiences. The mulch treatment can limit the increases in runoff and erosion in the short term after a fire. The use of fern is preferable to straw, due its large availability in forests. However, no experiences of post-fire treatment with fern mulch have been found in the literature and therefore the mulching effectiveness has not been evaluated. This study has measured water infiltration rate (IR) and water repellency (SWR) using a rainfall simulator in three Mediterranean forest stands (pine, oak and chestnut) of Calabria (Southern Italy) after a prescribed fire and mulching treatment with fern in comparison to unburned soil. Prescribed fire reduced water infiltration in all forests in the short term compared to the unburned conditions, and increased SWR in pine and oak forests. These reductions in IR in the time window of disturbance after fire increased the runoff generation capacity in all soils, but had a lower effect on peak flows. However, soil mulching with fern limited the runoff rates and peak flows compared to the burned soils, but this treatment was less effective in pine forest. One year after fire, IR increased in burned soils (treated or not) over time, and SWR disappeared. The effects of mulching have disappeared after some months from fire. The study confirms the usefulness of mulching in broadleaves forest in the short term, in order to control the hydrological effects of prescribed fire in Mediterranean forests. Both post-fire management techniques should be instead adopted with caution in conifer forests.

Keywords: water infiltration rate; rainfall simulator; time to peak; peak discharge; surface runoff; soil water repellency

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1. Introduction

Prescribed fire is the planned use of low-intensity fire to achieve very different goals given certain weather, fuel and topographic conditions [1,2]. This management tool has been adopted for long time in many countries under different climatic conditions (e.g., Mediterranean ecosystems) to mitigate the impact of large-scale wildfire in forested environments [3]. The main objective of prescribed fire is the creation of forest areas with low fuel, in order to reduce the intensity, severity and damage of large wildfires [4]. However, prescribed fire leads to other beneficial effects, since it facilitates the germination and growth of understory vegetation, increases landscape heterogeneity, and improves pastures for livestock [3,5,6].

Prescribed fires are usually of a low intensity and their effects depend on the type and amount of fuel load and soil moisture [2,7]. The forest areas, where fire is applied in each operation, are variable in size, and depend on the topographic and climatic conditions [8].

The effects of the prescribed fire are thought to have small impacts on the different components of the forest ecosystems, due to the low fire severity and patch nature [9,10]. The literature has shown that prescribed fires do not have generally detrimental impacts on soil properties, since the burning temperature and fire duration are low [11–13]. However, the research is not unanimous about the effects of prescribed fire on the hydrological response of forest soils. For instance, González-Pelayo et al. [14] and Vega et al. [15] report increases in runoff and erosion by one and two orders of magnitude, respectively, compared to unburned areas [16], while, by contrast, Coelho et al. [17], and de Dios Benavides-Solorio and MacDonald [18] reported minimal erosion after prescribed fire [19]. This depends on both the operation parameters of fire application (intensity, cover, duration, temperature) and the physical properties of the treated soils (texture, aggregate stability, water content) [2,9]. In general, fire removes vegetation and modifies the hydrologic properties of soil [9,20,21]. A soil left bare due to vegetation removal becomes more susceptible to raindrop impact and particle detachment [22]. Moreover, water infiltration rates, which are generally high in undisturbed forest soils [23], can decrease. Both these fire effects may increase surface runoff and erosion rates [24].

Particular attention has been paid to Mediterranean ecosystems, where the intrinsic climate and soil characteristics may enhance the hydrological hazards not only in burned forests, but also in unaffected valley areas [21,25]. Although the prescribed fires have lower impacts on soil hydrology compared to wildfire, changes in the hydrological response of burned areas may be important [9,20,21], with noticeable increases in runoff and erosion rates in the time “window of disturbance” immediately after fire. In the Mediterranean forests, the hydrological processes generating surface runoff are dominated by the infiltration–excess mechanism [26]. In this environment, the reduction in the water infiltration rate (IR) of soil can enhance flooding and hydrogeological instability after the frequent and intense rainstorms that are typical of the Mediterranean climate [25]. Moreover, IR can be further decreased by soil water repellency (SWR), which is common in Mediterranean forest soils [7,27], which is primarily determined by the accumulation of long-chain organic compounds in/around soil particles.

In spite of ample literature, the studies about the changes in SWR and IR after fires of different severity are not consistent and are sometimes contrasting [9]. For instance, increases in SWR were observed by [4] in pine forests burned by prescribed fires in SE Spain; these effects were found to be even higher compared to high-severity fires [28]. Other authors report slight or no changes in SWR in soils burned at low temperatures [23,29]. Therefore, no direct associations between fire severity and SWR can be found as resulting from several factors, such as the natural variability in the study sites (soil water content and texture, and vegetation type) [9]. These inconsistencies also affect soil infiltration rates [30], with reductions [23] or insignificant changes [7] in IR after prescribed fires. Ash released by fire plays an important role in driving the hydrological properties of burned soils, but also, in this case, the effects can be contrasting (e.g., increase in water retention and reduction in sediment transport [31], or clogging of soil pores and sealing of the soil surface [32,33]). Furthermore, IR and SWR can be different in soils with the same properties, but covered by trees of different species or age [34,35].

It is evident that the characteristics of the soil surface after fire are critical for its hydrological response at both hillslope and catchment scales [33]. In order to reduce soil’s susceptibility to runoff and erosion after fire, several treatments have been proposed and their effectiveness has been verified in many environmental contexts [22,36]. Mulching is one of the most common post-fire management techniques, particularly when vegetation residues are used [6,37]. The objective of mulching is primarily the prevention of raindrop impact and decrease in hydraulic connectivity, but a mulch cover increases the infiltration rates and soil quality, and soil protection with ground cover, if used properly and at the correct time [37]. However, mulching can also have negative impacts on burned soils, since infiltration rates can be reduced when soil is in unsaturated and dry conditions [26].

Straw is commonly applied as mulching material on burned soils, and, in this case, the mulch cover can be removed by wind in some areas and become too thick in others, which hamper vegetation regeneration [38]. In addition, seeds, agro-chemicals and parasites may be transported by straw, determining the development of non-native vegetation and diseases to plants [39]. Forest residues and herbaceous plants may properly replace straw as mulch cover, since they do not contain non-native seeds or chemical residues, and are more resistant to wind [22]. In Mediterranean forest floor, residues of fern (*Pteridium aquilinum* (L.) Kuhn)—a vascular plant that abundantly grows also in semi-arid climates (where the water competition among plants is high [40])—contains low lignin (and thus can be easily incorporated into the soil over time) and can be easily transported inside the forestland. Therefore, its use as a mulch material in fire-affected areas could be preferable to straw. However, to the best of the authors' knowledge, no experiences about using fern to protect burned soil from runoff and erosion impacts after fire are available in the literature. The effectiveness of soil mulching with forest residues, such as fern, are of utmost importance, to control runoff and erosion generation. Therefore, the beneficial effects of this species on the hydrological properties of burned soils should be explored.

This study evaluates the surface hydrology of three Mediterranean forest stands (pine, oak and chestnut) in Calabria (Southern Italy) after a prescribed fire and mulching treatment with fern in comparison to unburned soil. More specifically, IR, surface runoff and peak flow were measured immediately and one year after fire using a portable rainfall simulator, and SWR was determined using a Water Drop Penetration Test. We aimed to test if: (i) water infiltration is significantly reduced by fire in the short term, but the mulch cover with fern can limit this decrease, and (ii) SWR can affect forest soil immediately after fire, but its effect is temporary, since it disappears after some months.

2. Materials and Methods

2.1. Study Area

The experiments were carried out in three forest sites close to the municipality of Samo (Calabria, Southern Italy) (Figure 1). The first site ("Calamacia", UTM coordinates 590293 E; 4215327 N) was a reforested stand of pine (*Pinus pinaster* Aiton, age of 20 years old) at an elevation between 650 and 700 m above sea level. The second forest ("Rungia", 588635 E; 4216172 N) consisted of a natural stand of oak (*Quercus frainetto* Ten.) between 900 and 950 m. A third stand was a site ("Orgaro", 590389 E; 4215530 N) reforested in 1990 with chestnut (*Castanea sativa* Mill.) at 700–750 m. In all sites, shrub formations mainly consist of *Quercus ilex L., Rubus ulmifolius S., Leucanthemum vulgare Lam.* (pine forest), *Cyclamen hederifolium, Leucanthemum vulgare Lam*. (oak) and *Rubus ulmifolius S., Pteridium aquilinum L., Leucanthemum vulgare Lam.* (chestnut). None of these forest stands have been managed from their plantation.

The climate of the area is typically semi-arid ("Csa" class, "Hot-summer Mediterranean" climate, according to Koppen [41]). Winters are mild and rainy, while summers are warm and dry. The mean precipitation is 1102 mm per year, while the mean annual temperature is 17.4 °C with minimum and maximum values of −4.3 and 43.1 °C, respectively (weather station of Sant'Agata del Bianco, geographical coordinates 4217548 N, 595159 E, period 2000–2020).

2.2. Experimental Design

In each experimental site, two areas were delimited in forest hillslopes with the same gradient (19.8 ± 0.62%) (Appendix A, Figure A1).

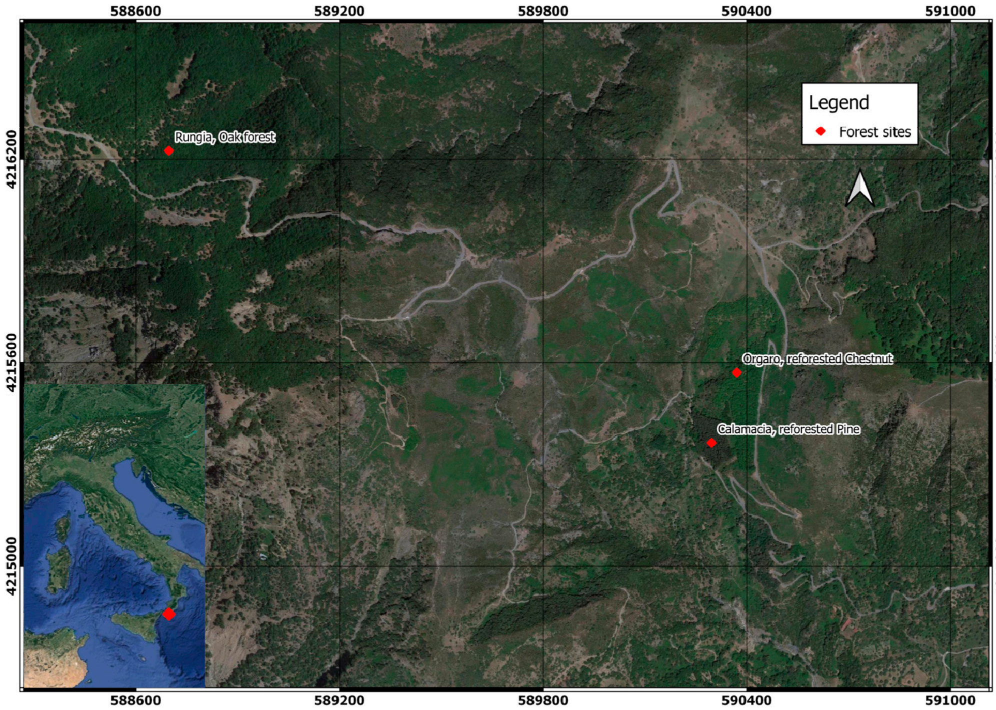

Figure 1. Location of the experimental site (Samo, Calabria, Southern Italy).

A first area (about 200 m^2) was burned in early June 2019, simulating a prescribed fire. The fire operations were carried out with the support of the Forest Regional Agency ("Calabria Verde") and the surveillance of the National Corp of Firefighters. During the fire, air temperature was on the average 26 (Calamacia, pine forest) to 43 (Rungia, oak) °C (Figure A2). The mean and maximum soil temperatures, measured by a thermocouple (at a distance of 0.50 from fire flame) connected to a datalogger at a soil depth of 2 cm, were 22.0 and 22.7 °C (pine), 21.0 and 26.9 °C (oak), and 24.7 and 28.8 (chestnut) °C. Fire operations lasted from 15 to 30 min, and the flame had a maximum temperature between 645 (chestnut) and 720 (oak) °C. The wind was practically absent and the air humidity was between 50 and 60%.

In this burned area, a small portion (about 3 m^2) was covered with small branches of fern, which were cut from an adjacent zone and spread on the ground at a dose of 500 g/m^2 of fresh weight (Figure A2) in the same day after the prescribed fire application. The mulch dose is equivalent to a dry matter of 200 g/m^2 of straw, usually applied in burned and mulched areas [26,42].

A second area was not burned and left undisturbed and was considered as a "control" for each experimental site.

The soils of the experimental sites were of a loamy sand texture (10.6 ± 2.57% of silt, 8.76 ± 0.61% of clay, and 80.7 ± 2.68% of sand), except for the unburned area of the pine forest in Calamacia, which was sandy loam (10.1 ± 1.01% of silt, 9.0 ± 0.01% of clay, and 81.0 ± 0.99% of sand).

Overall, the experimental design consisted of three forest stands (pine, oak and chestnut) × three soil conditions (unburned, burned and not treated, and burned and mulched).

2.3. Hydrological Measurements and Analysis

For each forest stand and soil condition, rainfall simulations were carried out in three points randomly chosen. An Eijelkamp® rain simulator was used [43,44], according to the method setup by Bombino et al. [45] (Figure A3) This simulator allows reproducing rainfall with a maximum height and intensity of 18 mm and 360 mm h^{-1} (drop diameter of 5.9 falling 40 cm from the ground) and the collection of runoff and sediments in a small bucket. Previously, the simulator was calibrated by generating a rainfall of 3.0 mm at an intensity of 37.8 mm h^{-1} over a surface area of 0.305 m × 0.305 m. The water volume in the sprinkler tank (about 0.3 litres) was dosed by varying the pressure head, as suggested in the operating manual. In more detail, the pressure head on the sprinklers has been properly tuned by moving the aeration tube upward or downward. Throughout the simulated rainfall (300 s), the surface runoff volume was collected in a small graduated bucket on a time scale of 30 s. The time to peak, peak flow and cumulated runoff volume were measured. More specifically, the time to peak was the time measured from the rainfall start to the peak flow occurrence.

Moreover, the infiltration curves were determined by subtracting the runoff from the rainfall at each 30-s time interval. The infiltration test stopped when three equal time measurements of instantaneous infiltration had been recorded. The final infiltration rate was assumed as the IR.

Finally, the SWR was measured immediately beside (about 0.25 m) to the measurement point of IR, using the Water Drop Penetration Test (WDPT) method [46,47] on a soil with a natural water content. According to this method, 15 drops of distilled water were released, using a pipette, on the soil surface. The time necessary for drops to completely penetrate into the soil was measured. SWR was classified according to the values of WDPT proposed by [48]: (i) non water-repellent or wettable soil (class 0, WDPT < 5 s); (ii) slightly water-repellent soil (class 1, 5 < WDPT < 60 s); (iii) strongly water-repellent soil (class 2, 60 < WDPT < 600 s); (iv) severely water-repellent soil (class 3, 600 < WDPT < 3600 s); and (v) extremely water-repellent soil (WDPT > 3600 s) (Figure A4).

SWR is strongly influenced by soil humidity [49,50]. For this reason, soil water content (SWC) was also measured simultaneously to SWR by a device (Vegetronix VG400, accuracy of 2%, measurement range 0–50%), placed on the soil surface and connected to a data logger (UX120 4-channel Analog Logger, Onset HOBO, Bourne, MA, USA).

Although there was no difference between burned and not treated soils, and also burned and mulched soils immediately after the fire (because the mulch material was not incorporated into the soil), the WDPT tests were carried out on both soil conditions since fire and mulch application.

2.4. Statistical Treatment

The statistical significance of the differences among soil conditions for each forest stand was determined by applying a 2-way ANOVA test to the hydrological variables measured (IR, SWR, time to peak, cumulated runoff and peak flow). The latter were considered as dependent variables, while the simulation date (1 or 365 days from fire) and the soil condition (unburned, burned, and burned and mulched) were the independent factors. The pairwise comparison by Tukey's test (at $p < 0.001$) was also used to evaluate the statistical significance of the differences in the hydrological variables of SWR among factors. In order to satisfy the assumptions of the statistical tests (equality of variance and normal distribution), the data were subjected to a normality test or were square root-transformed whenever necessary and separated for each forest species. The statistical analysis was carried out using the XLSTAT release 2019 software.

3. Results

Soil infiltration rates started from values around 37–38 mm/h (chestnut and pine) and 18–20 mm/h (oak for unburned and burned and mulched soils immediately after the prescribed fire) and decreased over time, when soil progressively was saturating. The time to steady conditions was short, from 180 (unburned soil in oak forest) to 390 s. This time was generally lower for measurements made one year after fire for pine and oak forests, without differences among the soil conditions. IR decreased faster in unburned soils immediately after fire, and throughout similar times one year after (Figure 2).

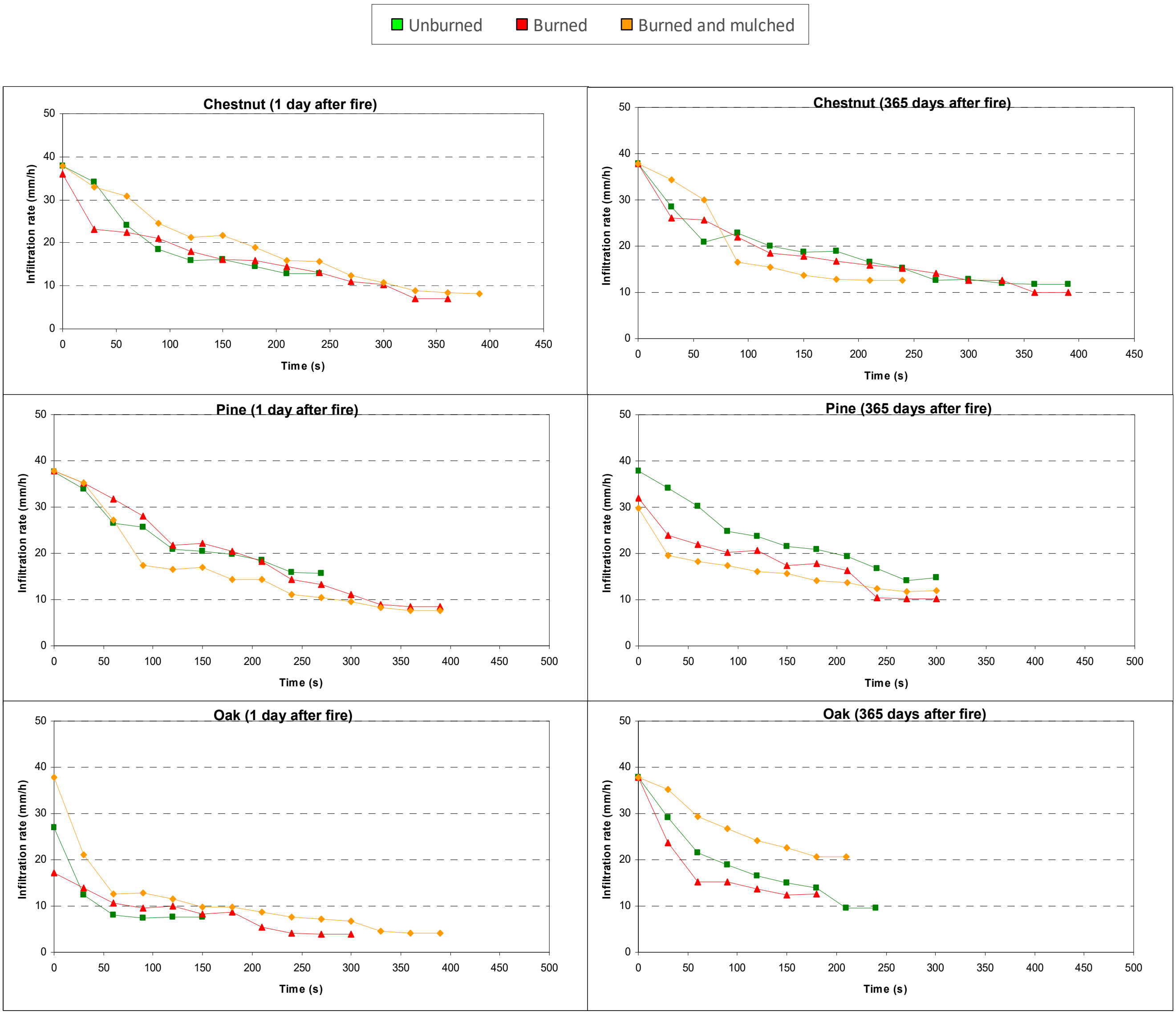

Figure 2. Infiltration curves measured using a portable rainfall simulator after prescribed fire and soil mulching with fern in the experimental site (Samo, Calabria, Southern Italy).

The analysis of water infiltration in unburned soils under steady conditions shows the highest IR in pine forest and the lowest in oak soil, while the soil covered by chestnut had intermediate values. This IR was on average stable over time, with very slight reductions in chestnut and pine forests, and a slight increase in oak soil one year after fire (Figure 3).

Although being of low severity, prescribed fire reduced the mean IR in soils of all forest species compared to the unburned conditions (Figure 3), and these differences were significant for chestnut and pine soils. The application of fern mulch helped in slightly increasing the mean IR in chestnut and oak soils, but not in pine (Figure 3). These variations were significant only for chestnut forest compared to burned soils, while the differences in IR between unburned as well as burned and mulched soils were significant only for pine soil.

One year after fire, the differences between the two survey dates were significant for oak and chestnut. The mean IR of burned soils increased compared to the measurements made immediately after fire. This effect was more noticeable in oak soils compared to chestnut and pine forests. The soils mulched with fern showed the highest IR among all soil conditions, except for pine soils. These values were always higher compared to the burned soils with a noticeable increase detected in oak soils (Figure 3).

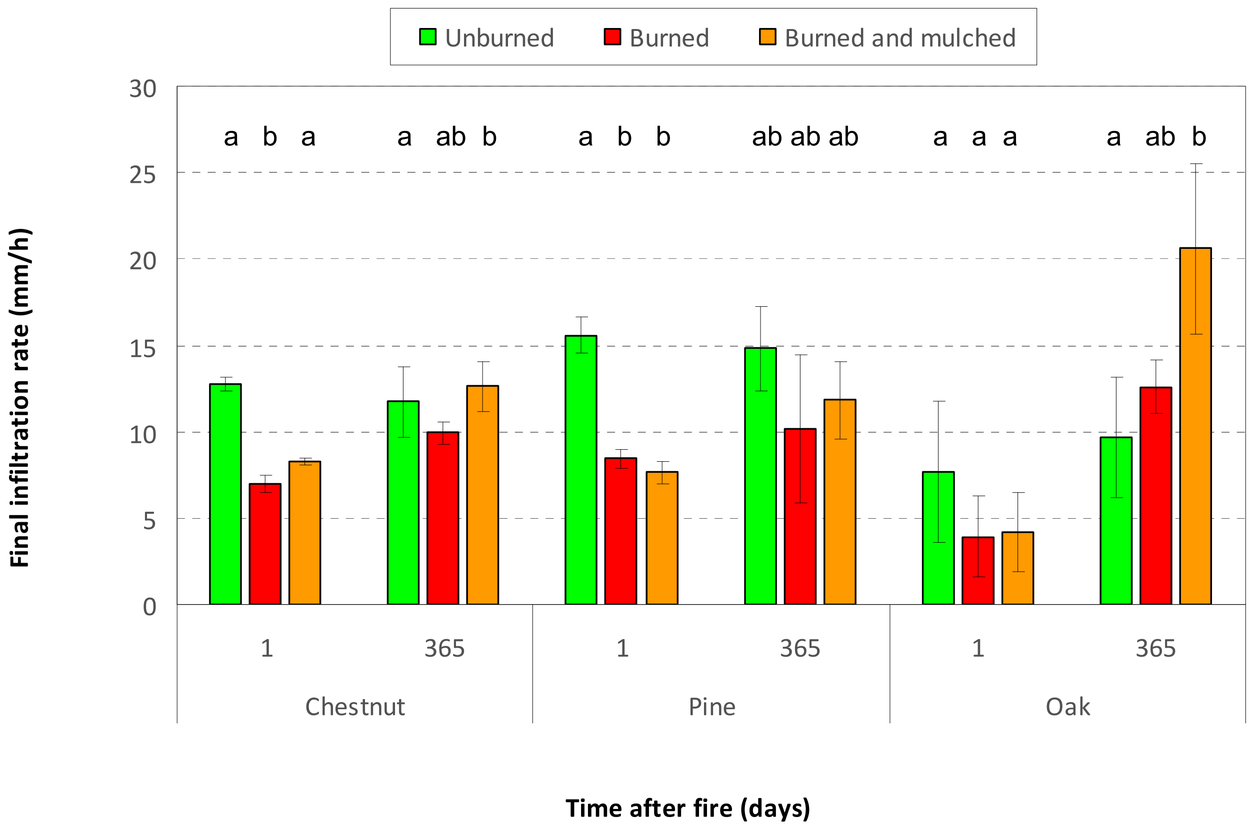

Figure 3. Water infiltration rate measured using a portable rainfall simulator after prescribed fire and soil mulching with fern in the experimental site (Samo, Calabria, Southern Italy). Note: different lowercase letters indicate significant differences in the interaction between soil conditions and time after fire, respectively, after Tukey's test ($p < 0.05$).

SWC did not show significant variations among all soil conditions in the two measurement dates when the SWR measurements were carried out. In more detail, mean SWC was always in the range 15–20% for all forests and soil conditions at both measurement dates, except for oak soils immediately after fire, when SWC was on average between 16 and 22%, although this difference was not significant (Figure 4).

The similarity in SWC among the three soil conditions for each survey makes possible the comparisons of SWR values in the forest soils [51]. Immediately after fire, the unburned soils showed only a slight repellency (chestnut and pine) or no SWR (oak). Prescribed fire determined a slight repellency in chestnut soils, while a strong repellency was found in both pine and oak, with or without mulch cover (Figure 5). The difference between the mulched and untreated soils was due to the natural variability of the soil properties. Only the burned soil of oak forest had a significantly different SWR compared to the unburned forest, while SWR of burned and mulched soils were always significantly different compared to unburned sites. Fire increased WDPTs of all soils, and the difference over time was significant for all forest species. These variations did not alter SWR of chestnut forest (still in class 1), but made the pine and oak soils strongly repellent (SWR of class 3). For the soils treated with fern mulch, WDPT values increased in chestnut and pine, respectively, and decreased in oak. The SWR class was the same as the burned soils for all forests.

One year after fire all soils became non-repellent (SWR of class 1), as shown by the WDPT values that were equal to one (Figure 5).

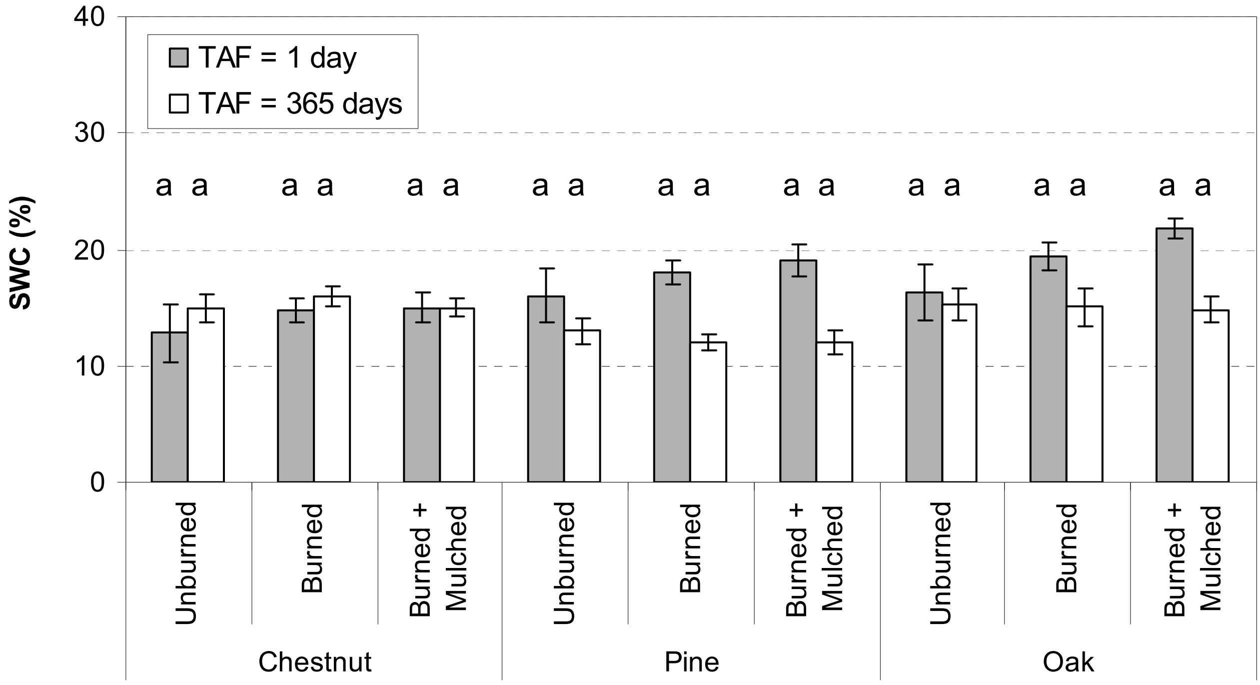

Figure 4. Soil water content (SWC) measured after prescribed fire and soil mulching with fern in the experimental site (Samo, Calabria, Southern Italy). Notes: bars report mean ± std. dev. (n = 3); TAF = time after fire. Different lowercase letters indicate significant differences in the interaction between soil conditions and time after fire, respectively, after Tukey's test ($p < 0.05$).

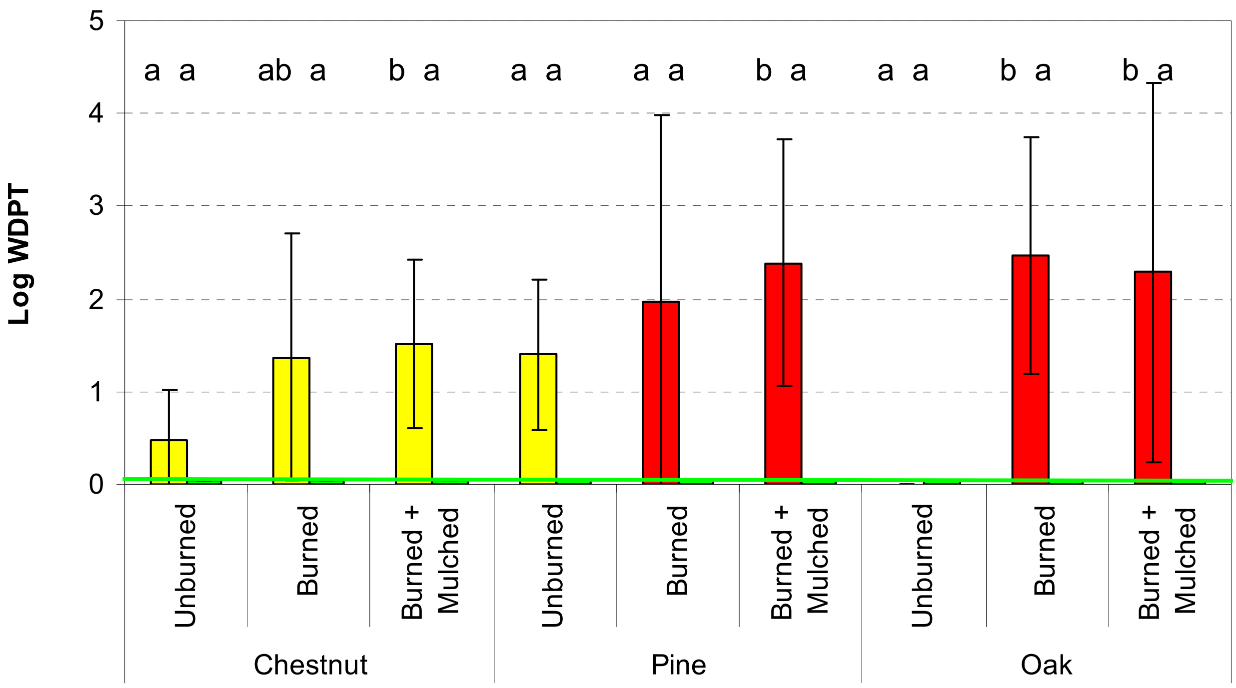

Figure 5. Soil water repellency (as WDPT) measured after prescribed fire and soil mulching with fern in the experimental site (Samo, Calabria, Southern Italy). Notes: Bars report mean ± std. dev. (n = 3); left and right bars of chart are the values measured one day and one year after the prescribed fire, respectively. Green, yellow and red colours refer to SWR class 0, 1 and 2, respectively. The green line identifies the non-repellency condition of soi. Different lowercase letters indicate significant differences in the interaction between soil conditions and time after fire, respectively, after Tukey's test ($p < 0.05$).

The variations of the monitored hydraulic properties determined changes in the hydrological response of the three forest soils among the different conditions. More specifically, the runoff generated in the unburned soils by the simulated rainfall did not show significant variations at the two dates of the experiment. Fire negatively affected the runoff generation capacity in chestnut and mainly in oak soils (but only in this case significantly), while this increase was negligible for pine. Soil mulching with fern was effective, although not significantly, in reducing the runoff response in chestnut soils, and less in oak forests, while the runoff measured in pine soils was basically the same as the other soil conditions. One year after fire, the hydrological response of oak soils was statistically similar among the three conditions, while the burned soils of pine and chestnut showed a higher runoff generation capacity (Table 1).

Small (±11.5%, pine and oak soils) or negligible (+5.2%, chestnut soil) variations in peak flow were measured in all forest soils immediately after the prescribed fire. The mulch application reduced the peak flow in chestnut (by 50%) and oak (by 26.5%) soils down to values that were even lower (by 18%, oak, and 47.4%, chestnut) than in unburned soils. In contrast, in the pine forest treated with mulching, the peak of the hydrograph increased by 13.6% compared to the unburned soil. One year after fire, the increase in peak flow between burned and unburned soils became high only in the pine soil (+85.8%), while these variations were lower in the other forest soils (+10.3%, chestnut, and +27.9%, oak). The mulch application did not noticeably alter the peak flow measured in the unburned soils of chestnut (+6.9%) and oak (−3.3%) forests, which instead increased very much in pine soils (+92.9%) (Table 1).

The time to peak (between 90 and 120 s in unburned soils) generally decreased (to 60 s) in burned soils at both the dates of rainfall simulations, with one exception (150 s, pine forest immediately after fire). Compared to unburned soils, mulch application increased (chestnut and oak soils, 150 s) or did not vary (pine forest) the time to peak immediately after fire. One year after, this time was the same as in the unburned soils (chestnut and oak forest), while it decreased to 90 s in pine soils (Table 1).

Table 1. Runoff volume, peak flow and time to peak measured after prescribed fire and soil mulching with fern in the experimental site (Samo, Calabria, Southern Italy). Mean ± std. dev. (n = 3).

Species	Time after Fire (Days)	Soil Condition		
		Unburned	**Burned**	**Burned and Mulched**
		Runoff (mm)		
Chestnut	1	0.44 ± 0.07 a	0.60 ± 0.11 a	0.29 ± 0.17 a
	365	0.40 ± 0.24 a	0.56 ± 0.05 a	0.49 ± 0.12 a
Pine	1	0.33 ± 1.00 a	0.35 ± 0.03 a	0.36 ± 0.01 a
	365	0.41 ± 0.26 a	0.64 ± 0.57 a	0.65 ± 0.19 a
Oak	1	0.54 ± 0.40 ab	1.21 ± 0.00 c	1.06 ± 0.30 a
	365	0.63 ± 0.06 ab	0.65 ± 0.02 bc	0.61 ± 0.05 bc
		Peak flow (mm h^{-1})		
Chestnut	1	11.46 ± 0.85 a	12.06 ± 0.01 a	6.03 ± 5.12 b
	365	11.66 ± 5.70 a	12.86 ± 2.41 a	12.46 ± 3.04 a
Pine	1	9.55 ± 0.28 a	8.44 ± 1.84 a	10.85 ± 10.23 a
	365	8.44 ± 1.65 a	15.68 ± 19.61 b	16.28 ± 1.21 b
Oak	1	24.52 ± 5.57 a	27.34 ± 5.12 a	20.10 ± 3.48 a
	365	13.67 ± 4.18 b	17.49 ± 0.70 b	13.22 ± 3.04 b
		Time to peak (s)		
Chestnut	1	120 ± 60 a	60 ± 30 a	150 ± 30 b
	365	90 ± 7.67 a	60 ± 30 a	90 ± 0 a
Pine	1	120 ± 30 a	150 ± 30 b	120 ± 60 a
	365	120 ± 30 a	60 ± 60 c	90 ± 0 a
Oak	1	90 ± 0 a	90 ± 0 a	115 ± 30 a
	365	120 ± 15 b	60 ± 15 c	120 ± 30 c

Note: different lowercase letters indicate significant differences in the interaction between soil conditions and time after fire, respectively, after Tukey's test ($p < 0.05$).

4. Discussion

The Mediterranean climate is characterized by flash rainfall events with a very low duration and, therefore, a high intensity [25]. Moreover, the dominant runoff generation mechanism is "infiltration-excess" [21]. When a high-intensity rainfall exceeds the water infiltration rate of soil, runoff can be generated also in the early stage of a rainstorm, and this makes significant our experimental rainfall simulation. Moreover, the measurement of the IR carried out in this study relates to the unsaturated fire-affected soil, and this parameter may be initially more important than saturated hydraulic conductivity at the time scale of convective rainfall, which is typically short and only lasts 20–60 min, but is common in many post-wildfire response domains [26,52]. Therefore, the rainfall simulations carried out in the experimental site helped in identifying the changes in IR and SWR after the prescribed fire, which are somewhat contrasting in the literature [9]. The IR of burned soils decreased more rapidly compared to the other soil conditions (mainly one year after fire), and this may be a detrimental effect for soil. The reduction in IR in the short term may be due to two synergistic effects. First, the presence of the ash layer left by fire may have clogged soil pores and induced sealing of the soil surface, [32,33], while it was not able to increase water adsorption before infiltration [31,53], due to its small thickness. Other studies about prescribed fire have shown that ash contributed to reduce infiltration, creating a thin layer (few mm) of low porosity and permeability [53]. Second, fire has induced water repellency in the soils of all forest species, with particular intensity in pine and oak forests (where repellency was strong). This result is basically in line with some previous studies, which showed that increases in SWR are common after low-intensity fires [4]. However, the literature results are not consistent about the occurrence and extent of SWR after prescribed fires [2], since water repellence may increase [54], not change [23] or decrease [55].

Reductions in water infiltration rates have been shown by some authors after prescribed fires [23,30], but these effects are limited to a few months after burning and generally are not significant [7,56]. In contrast, significant decreases in steady-state infiltration rates were found by other studies in areas burned with prescribed fires, and these reductions were attributed to the synergistic effects of increased water repellency and sealing, and reduced vegetation cover [11].

In the oak wood of our experimental site, the noticeable SWR did not lead to as much significant decrease in IR, and this may be surprising, since an increase in repellence is generally associated with lower water infiltration [30]. IR and SWR (measured by WDPT) are physical parameters that quantify two different processes (infiltration and hydrophobicity). The variability of these processes may be opposite (increases in hydrophobicity can be associated to decreases in water infiltration), but, in some cases, may be the same [34], and this depends on a number of physical and chemical properties of soil (mainly organic matter, texture, plant species). As a matter of fact, Cawson et al. [9] stated that the increase in SWR is not the only reason of infiltration reduction after low-intensity fire. The low content of clay in the experimental soils could have been a reason for the limited effect of SWR affecting the burned soils, since soils with prevailing fine fractions generally exhibit the highest effects of repellency [51]. Moreover, it cannot be excluded that prescribed fire only had a punctual effect on soil repellency, without affecting the entire soil surface exposed to rainfall. This is in close accordance with Neary and Leonard [8], who stated that water repellency occurs in very localized zones after prescribed fires, and that these spots usually do not play significant effects over larger areas. It is also possible that the initially low infiltration rate of oak soils may have gradually increased as water repellence was broken down, as reported by [9,23], and also when water repellence is moderately strong. Following some of these studies, these increases are generally of a low extent, and this makes the effects of SWR on soil hydraulic properties negligible [23,29]. A possible explanation for IR decrease measured in the pine forest may be the partial sealing of soil due to wax, aromatic oil and resin of trees (released after fire). Instead, water repellence did not affect soils with species (oak and chestnut) that do not release these compounds [11,57].

The irregular distribution of litter and herbaceous covers in the chestnut forest let the prescribed fire have a patchy nature, which smoothed its effects on the short-term changes in soil hydraulic properties. This is in accordance with Cawson et al. [9], who state that low-fire severity and burn patchiness are the main reasons for the small impacts that follow prescribed burning. The decoupling of SWR and IR in soils covered by different tree species was noticed also by Zema et al. [34] in similar forest ecosystems covered by pines, junipers and oaks. However, all these effects require further investigations, since it is quite difficult to disentangle the actions of soil coating due to resin release and water repellence due to the OM content [11,58].

The reductions in IR measured immediately after fire in the soils of all forest species were of 45–50% compared to the unburned conditions, and worsened the soil's hydrological response. As a matter of fact, while the runoff generation capacity of the unburned soil was stable, fire increased the runoff generation capacity up to 120% in oak forest (presumably due to the complete litter burning in this broadleaves species, which retain rainfall and shadows soil from erosion). At a plot scale, Vega et al. [15] Morales et al. [59] and Vieira et al. [60] also measured significantly higher runoff volumes compared to unburned soils for one year after a prescribed fire.

Conversely, the application of the prescribed fire had a lower effect on peak flows (maximum increase of 11%). In other words, the prescribed fire did not affect the peak values of the runoff hydrograph measured throughout the rainfall simulations, and this means that fire is not able to enhance the flood risk due to increased peak flows. This complies with the statements by Robichaud et al. [23], who report constant runoff hydrographs in rainfall simulations after low intensity burns. In contrast, Keesstra et al. [33] noticed in runoff hydrographs after rainfall simulations a sudden increase in the runoff rate and then a quick decrease until a constant value of runoff. However, since in our study the time to peak of burned soils sometime decreased compared to unburned soils. An increase of the time of concentration in flood events may be possible, and this requires attention.

Soil treatment with fern mulch, whose immediate effects on soil were only mechanical, limited the reduction in water infiltration due to fire in oak and chestnut forests (IR lower by 46% and 35% compared to unburned soils). Consequently, the runoff measured in these soils decreased compared to the fire-affected areas (by 10% to 50%), and was higher by 96% (oak) or even lower by 35% (chestnut) compared to the unburned areas. Moreover, peak flows were noticeably lower than in both unburned and burned conditions (−20% to −50%, respectively). The lower hydrological response in the mulched areas may be also due to the soil roughness, which was increased by the vegetal residues distributed over ground. Soil mulching also reduced the time to peak in the short term. In contrast, no effects of mulching on IR, runoff, peak flow and time to peak were detected in pine soils. This may be due to the ineffectiveness of mulching treatment in reducing SWR, which is the main reason of IR decrease in pine soils. Conversely, Bento-Goncalves et al. [39] think that pine needles fell after prescribed fire are able to adequately protect soil as a mulch cover, thus reducing the overland flow.

The increase in the IR of burned soils (treated or not) over time is expected [2,9]. This increase may be primarily due to the disappearance of ash, sealing and repellency—with a vanished effect on water infiltrability—and secondarily to the incorporation of litter residues into soils in burned areas, which sums up to the vegetal residues of fern in mulched soils. SWR after prescribed fires is usually of a short duration, since the hydrophobic compounds are slightly water soluble and dissolve generally one or two years after a fire [23]. In some Mediterranean pine forests, the effects of SWR even disappeared just after one month from fire [4]. Soil enrichment in organic matter is beneficial for the hydraulic properties of soils. Although no measurements in OM were made in this study (which focuses on the hydraulic response of soils rather than on the physical and chemical properties), the high amounts of litter material in oak forest visually noticed on the survey area compared to the other species may support this explanation. As a matter of fact, the IR increase was more noticeable in oak soils compared to chestnut and pine forests, and the same effect was observed in mulched soils, which showed the highest IR. It is worth highlighting that oak soils treated with fern mulch not only showed the highest IR among all the investigated soil conditions, but their infiltrability was higher by 110% compared to the unburned soils. In any case, IR of mulched soils was by 15% (for pine soils) to 60% (oak forest) higher than in burned areas, and this proves the effectiveness of mulching in improving the hydrological properties of soils after burning. Despite the increases measured in IR in mulched areas, one year after the prescribed fire the runoff generation capacity of the treated soils was not significantly different compared to the other soil conditions in chestnut or oak forests. As a matter of fact, variations in runoff between −3% and +20%, and in peak flow between −3% and −7% were detected, and the same was noticed for the times to peak, which means that the soil's hydrological response was not influenced by mulching. In pine forest, mulching determined increases in runoff and peak flow by 2% and 4%, respectively, which means that the hydrological response of burned and treated soils (runoff generation, peak of hydrograph and time to concentration) even worsened compared to burned but not treated forests. Although fern has a limited leaf cover (at least in comparison to broadleaf species), the residues can retain water, which afterwards can evaporate, thus limiting surface runoff. However, water drops may flow over the stems and leaves of the residues with a quicker path compared to the overland flow, and therefore a runoff velocity that is higher. To avoid this undesired process, a patchy distribution of fern residues over ground can be suggested, which creates a hydraulic disconnectivity in these quick water flow paths. Unfortunately, the small size of the simulator area does not allow evaluating the impacts of mulching in decreasing hydraulic connectivity, which is a beneficial effect in reducing the travel times of water and sediment flows at the catchment scale [61]. An increased hydraulic connectivity after wildfire may have serious off-site effects, such as increased risk of flooding and pollution of water bodies. The vegetal residues of the mulch cover over ground increases soil roughness and represents obstacles against the water and sediment flows, disrupting the continuity of runoff and sediment pathways.

5. Conclusions

This study has evaluated the changes in the soil infiltration of pine, chestnut and oak forests due to prescribed fire and post-fire treatment with fern mulch in field experiments using a rainfall simulator. The fire application reduced water infiltration immediately after fire compared to the unburned conditions, and this reduction has been ascribed to the released ash and SWR. This latter effect was more noticeable in pine forest and less intense in oak soil. These reductions in IR in the window of disturbance after fire increased the runoff generation capacity (conversely stable in unburned soils) in all soils, but had a lower effect on peak flows. Due to the lower reduction in infiltration in oak and chestnut forests due to fern application after fire, soil mulching limited runoff rates and peak flows compared to the burned soils. In contrast, the treatment was less effective in the pine forest.

One year after fire, IR increased in burned soils (treated or not) over time, since ash cover, sealing and SWR disappeared and the residues of litter and mulch were incorporated in the soil. Mulched soils in oak forest showed the higher IR increase compared to chestnut and pine forests. However, this increase was not able to determine significant reductions in runoff and peak flow in treated soils compared to burned and unburned conditions. Therefore, the effects of mulching have disappeared after some months from fire.

Overall, this investigation has confirmed both the working hypothesis that prescribed fire may worsen the soil's hydrological response to burning, but mulching is particularly effective in reducing runoff volumes and peak flow immediately after fire in broadleaves species (but not in conifers). Its hydrological effects decrease over time until they are not significant or even negligible some months after the fire, and, in conifers, even detrimental. This study has been carried out on a local scale and under simulated rainfall, and has not evaluated the erosion response of burned soils (treated or not). Further research is needed with field scale extension to plots or hillslopes (perhaps incorporating the time variability of natural rainfall and comparing soil loss in the different conditions). This extension is welcome in order to consider the patchy nature of prescribed fire and the effects of mulching on hydraulic connectivity, and to give indications about the most suitable distribution of mulch material over soil (e.g., homogenous cover or patchy distribution).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

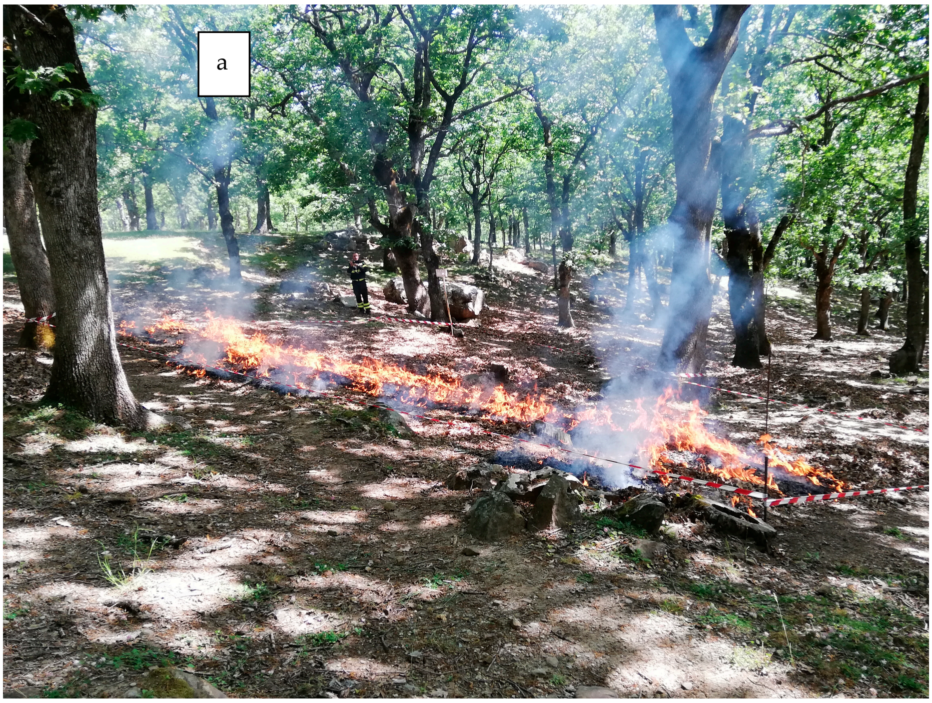

Figure A1. *Cont*.

Figure A1. Prescribed fire operations (**a**) and mulching application (**b**) in the experimental site (Samo, Calabria, Southern Italy).

Figure A2. *Cont*.

Figure A2. Experimental areas unburned or subjected to prescribed fire and mulching with fern (Samo, Calabria, Southern Italy). (**a**) oak; (**b**) chestnut; (**c**) pine.

Figure A3. Measurements of soil hydraulic conductivity (using a portable rainfall simulator) and fern mulch application into the rainfall simulator at the experimental site (Samo, Calabria, Southern Italy).

Figure A4. Measurements of soil water repellency (by the WDPT method) in the experimental site (Samo, Calabria, Southern Italy).

References

1. Fernandes, P.; Davies, G.; Ascoli, D.; Fernández Filgueira, C.; Moreira, F.; Rigolot, E.; Stoof, C.; Vega, J.; Molina Terrén, D. Fire ecology—Cape fynbos biome. *Front. Ecol. Environ.* **2013**, *11*, e4–e14. [CrossRef]
2. Alcañiz, M.; Outeiro, L.; Francos, M.; Úbeda, X. Effects of Prescribed Fires on Soil Properties: A Review. *Sci. Total Environ.* **2018**, *613*, 944–957. [CrossRef] [PubMed]
3. Neary, D.G.; Klopatek, C.C.; DeBano, L.F.; Ffolliott, P.F. Fire Effects on Belowground Sustainability: A Review and Synthesis. *For. Ecol. Manag.* **1999**, *122*, 51–71. [CrossRef]
4. Plaza-Álvarez, P.A.; Lucas-Borja, M.E.; Sagra, J.; Moya, D.; Alfaro-Sánchez, R.; González-Romero, J.; De las Heras, J. Changes in Soil Water Repellency after Prescribed Burnings in Three Different Mediterranean Forest Ecosystems. *Sci. Total Environ.* **2018**, *644*, 247–255. [CrossRef] [PubMed]
5. Úbeda, X.; Badía, D.; Pereira, P. Prescribed fires (editorial). *Sci. Total Environ.* **2018**, *637–638*, 385–388. [CrossRef] [PubMed]
6. Lucas-Borja, M.E.; Plaza-Álvarez, P.A.; Gonzalez-Romero, J.; Sagra, J.; Alfaro-Sánchez, R.; Zema, D.A.; Moya, D.; de Las Heras, J. Short-Term Effects of Prescribed Burning in Mediterranean Pine Plantations on Surface Runoff, Soil Erosion and Water Quality of Runoff. *Sci. Total Environ.* **2019**, *674*, 615–622. [CrossRef]
7. Plaza-Álvarez, P.A.; Lucas-Borja, M.E.; Sagra, J.; Zema, D.A.; González-Romero, J.; Moya, D.; De las Heras, J. Changes in Soil Hydraulic Conductivity after Prescribed Fires in Mediterranean Pine Forests. *J. Environ. Manag.* **2019**, *232*, 1021–1027. [CrossRef] [PubMed]
8. Neary, D.G.; Leonard, J.M. Restoring fire to forests: Contrasting the effects on soils of prescribed fire and wildfire. In *Soils and Landscape Restoration*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 333–355.
9. Cawson, J.G.; Sheridan, G.J.; Smith, H.G.; Lane, P.N.J. Surface Runoff and Erosion after Prescribed Burning and the Effect of Different Fire Regimes in Forests and Shrublands: A Review. *Int. J. Wildland Fire* **2012**, *21*, 857–872. [CrossRef]
10. Francos, M.; Úbeda, X. Prescribed Fire Management. *Curr. Opin. Environ. Sci. Health* **2021**, *21*, 100250. [CrossRef]
11. Cawson, J.G.; Nyman, P.; Smith, H.G.; Lane, P.N.; Sheridan, G.J. How Soil Temperatures during Prescribed Burning Affect Soil Water Repellency, Infiltration and Erosion. *Geoderma* **2016**, *278*, 12–22. [CrossRef]
12. González-Pelayo, O.; Gimeno-García, E.; Ferreira, C.S.S.; Ferreira, A.J.D.; Keizer, J.J.; Andreu, V.; Rubio, J.L. Water Repellency of Air-Dried and Sieved Samples from Limestone Soils in Central Portugal Collected before and after Prescribed Fire. *Plant Soil* **2015**, *394*, 199–214. [CrossRef]
13. Pereira, P.; Francos, M.; Brevik, E.C.; Ubeda, X.; Bogunovic, I. Post-Fire Soil Management. *Curr. Opin. Environ. Sci. Health* **2018**, *5*, 26–32. [CrossRef]
14. González-Pelayo, O.; Andreu, V.; Gimeno-García, E.; Campo, J.; Rubio, J.L. Rainfall Influence on Plot-Scale Runoff and Soil Loss from Repeated Burning in a Mediterranean-Shrub Ecosystem, Valencia, Spain. *Geomorphology* **2010**, *118*, 444–452. [CrossRef]
15. Vega, J.A.; Fernández, C.; Fonturbel, T. Throughfall, Runoff and Soil Erosion after Prescribed Burning in Gorse Shrubland in -Galicia (NW Spain). *Land Degrad. Dev.* **2005**, *16*, 37–51. [CrossRef]
16. Cawson, J.G.; Sheridan, G.J.; Smith, H.G.; Lane, P.N.J. Effects of Fire Severity and Burn Patchiness on Hillslope-Scale Surface Runoff, Erosion and Hydrologic Connectivity in a Prescribed Burn. *For. Ecol. Manag.* **2013**, *310*, 219–233. [CrossRef]
17. Coelho, C.d.A.; Ferreira, A.J.D.; Boulet, A.-K.; Keizer, J.J. Overland Flow Generation Processes, Erosion Yields and Solute Loss Following Different Intensity Fires. *Q. J. Eng. Geol. Hydrogeol.* **2004**, *37*, 233–240. [CrossRef]
18. de Dios Benavides-Solorio, J.; MacDonald, L.H. Measurement and Prediction of Post-Fire Erosion at the Hillslope Scale, Colorado Front Range. *Int. J. Wildland Fire* **2005**, *14*, 457–474. [CrossRef]
19. Morris, R.H.; Bradstock, R.A.; Dragovich, D.; Henderson, M.K.; Penman, T.D.; Ostendorf, B.; Morris, R.H.; Bradstock, R.A.; Dragovich, D.; Henderson, M.K.; et al. Environmental Assessment of Erosion Following Prescribed Burning in the Mount Lofty Ranges, Australia. *Int. J. Wildland Fire* **2013**, *23*, 104–116. [CrossRef]
20. Certini, G. Effects of Fire on Properties of Forest Soils: A Review. *Oecologia* **2005**, *143*, 1–10. [CrossRef]
21. Shakesby, R.A. Post-Wildfire Soil Erosion in the Mediterranean: Review and Future Research Directions. *Earth-Sci. Rev.* **2011**, *105*, 71–100. [CrossRef]
22. Zema, D.A. Post-Fire Management Impacts on Soil Hydrology. *Curr. Opin. Environ. Sci. Health* **2021**, 100252. [CrossRef]
23. Robichaud, P.R. Fire Effects on Infiltration Rates after Prescribed Fire in Northern Rocky Mountain Forests, USA. *J. Hydrol.* **2000**, *231*, 220–229. [CrossRef]
24. Shakesby, R.A.; Bento, C.P.; Ferreira, C.S.; Ferreira, A.J.; Stoof, C.R.; Urbanek, E.; Walsh, R.P. Impacts of Prescribed Fire on Soil Loss and Soil Quality: An Assessment Based on an Experimentally-Burned Catchment in Central Portugal. *Catena* **2015**, *128*, 278–293. [CrossRef]
25. Fortugno, D.; Boix-Fayos, C.; Bombino, G.; Denisi, P.; Quinonero Rubio, J.M.; Tamburino, V.; Zema, D.A. Adjustments in Channel Morphology Due to Land-use Changes and Check Dam Installation in Mountain Torrents of Calabria (Southern Italy). *Earth Surf. Process. Landf.* **2017**, *42*, 2469–2483. [CrossRef]
26. Lucas-Borja, M.E.; Zema, D.A.; Carrà, B.G.; Cerdà, A.; Plaza-Alvarez, P.A.; Cózar, J.S.; Gonzalez-Romero, J.; Moya, D.; de las Heras, J. Short-Term Changes in Infiltration between Straw Mulched and Non-Mulched Soils after Wildfire in Mediterranean Forest Ecosystems. *Ecol. Eng.* **2018**, *122*, 27–31. [CrossRef]
27. Cerdà, A.; Doerr, S.H. Soil Wettability, Runoff and Erodibility of Major Dry-Mediterranean Land Use Types on Calcareous Soils. *Hydrol. Process. An. Int. J.* **2007**, *21*, 2325–2336. [CrossRef]

28. Huffman, E.L.; MacDonald, L.H.; Stednick, J.D. Strength and Persistence of Fire-induced Soil Hydrophobicity under Ponderosa and Lodgepole Pine, Colorado Front Range. *Hydrol. Process.* **2001**, *15*, 2877–2892. [CrossRef]
29. Doerr, S.H.; Shakesby, R.A.; Blake, W.H.; Chafer, C.J.; Humphreys, G.S.; Wallbrink, P.J. Effects of Differing Wildfire Severities on Soil Wettability and Implications for Hydrological Response. *J. Hydrol.* **2006**, *319*, 295–311. [CrossRef]
30. Wittenberg, L.; Malkinson, D. Spatio-Temporal Perspectives of Forest Fires Regimes in a Maturing Mediterranean Mixed Pine Landscape. *Eur. J. For. Res.* **2009**, *128*, 297–304. [CrossRef]
31. Cerdà, A.; Doerr, S.H. The Effect of Ash and Needle Cover on Surface Runoff and Erosion in the Immediate Post-Fire Period. *Catena* **2008**, *74*, 256–263. [CrossRef]
32. Onda, Y.; Dietrich, W.E.; Booker, F. Evolution of Overland Flow after a Severe Forest Fire, Point Reyes, California. *Catena* **2008**, *72*, 13–20. [CrossRef]
33. Keesstra, S.D.; Maroulis, J.; Argaman, E.; Voogt, A.; Wittenberg, L. Effects of Controlled Fire on Hydrology and Erosion under Simulated Rainfall. *Cuad. De Investig. Geográfica* **2014**, *40*, 269–294. [CrossRef]
34. Zema, D.A.; Plaza-Alvarez, P.A.; Xu, X.; Carra, B.G.; Lucas-Borja, M.E. Influence of Forest Stand Age on Soil Water Repellency and Hydraulic Conductivity in the Mediterranean Environment. *Sci. Total Environ.* **2021**, *753*, 142006. [CrossRef] [PubMed]
35. Zema, D.A.; Stan, J.T.V.; Plaza-Alvarez, P.A.; Xu, X.; Carra, B.G.; Lucas-Borja, M.E. Effects of Stand Composition and Soil Properties on Water Repellency and Hydraulic Conductivity in Mediterranean Forests. *Ecohydrology* **2021**, *14*, e2276. [CrossRef]
36. Lucas-Borja, M.E. Efficiency of Post-Fire Hillslope Management Strategies: Gaps of Knowledge. *Curr. Opin. Environ. Sci. Health* **2021**, 100247. [CrossRef]
37. Prosdocimi, M.; Tarolli, P.; Cerdà, A. Mulching Practices for Reducing Soil Water Erosion: A Review. *Earth-Sci. Rev.* **2016**, *161*, 191–203. [CrossRef]
38. Robichaud, P.R.; Lewis, S.A.; Brown, R.E.; Bone, E.D.; Brooks, E.S. Evaluating Post-wildfire Logging-slash Cover Treatment to Reduce Hillslope Erosion after Salvage Logging Using Ground Measurements and Remote Sensing. *Hydrol. Process.* **2020**, *34*, 4431–4445. [CrossRef]
39. Bento-Gonçalves, A.; Vieira, A.; Úbeda, X.; Martin, D. Fire and Soils: Key Concepts and Recent Advances. *Geoderma* **2012**, *191*, 3–13. [CrossRef]
40. Bombino, G.; Zema, D.A.; Denisi, P.; Lucas-Borja, M.E.; Labate, A.; Zimbone, S.M. Assessment of Riparian Vegetation Characteristics in Mediterranean Headwaters Regulated by Check Dams Using Multivariate Statistical Techniques. *Sci. Total Environ.* **2019**, *657*, 597–607. [CrossRef]
41. Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World Map of the Köppen-Geiger Climate Classification Updated. *Meteorol. Z.* **2006**, 259–263. [CrossRef]
42. Vega, J.A.; Fernández, C.; Fonturbel, T.; Gonzalez-Prieto, S.; Jiménez, E. Testing the Effects of Straw Mulching and Herb Seeding on Soil Erosion after Fire in a Gorse Shrubland. *Geoderma* **2014**, *223*, 79–87. [CrossRef]
43. Iserloh, T.; Ries, J.B.; Arnáez, J.; Boix-Fayos, C.; Butzen, V.; Cerdà, A.; Echeverría, M.T.; Fernández-Gálvez, J.; Fister, W.; Geißler, C. European Small Portable Rainfall Simulators: A Comparison of Rainfall Characteristics. *Catena* **2013**, *110*, 100–112. [CrossRef]
44. Hlavčová, K.; Danáčová, M.; Kohnová, S.; Szolgay, J.; Valent, P.; Výleta, R. Estimating the Effectiveness of Crop Management on Reducing Flood Risk and Sediment Transport on Hilly Agricultural Land–A Myjava Case Study, Slovakia. *Catena* **2019**, *172*, 678–690. [CrossRef]
45. Bombino, G.; Denisi, P.; Gómez, J.A.; Zema, D.A. Water Infiltration and Surface Runoff in Steep Clayey Soils of Olive Groves under Different Management Practices. *Water* **2019**, *11*, 240. [CrossRef]
46. Woudt, B.D. van't Particle Coatings Affecting the Wettability of Soils. *J. Geophys. Res.* **1959**, *64*, 263–267. [CrossRef]
47. Letey, J. Measurement of Contact Angle, Water Drop Penetration Time and Critical Surface Tension. In *Water-Repellent Soils*; DeBano, L.F., Letey, J., Eds.; University of California: Oakland, CA, USA, 1969; pp. 43–47.
48. Bisdom, E.B.A.; Dekker, L.W.; Schoute, J.F.T. Water Repellency of Sieve Fractions from Sandy Soils and Relationships with Organic Material and Soil Structure. *Geoderma* **1993**, *56*, 105–118. [CrossRef]
49. Dekker, L.W.; Ritsema, C.J. How Water Moves in a Water Repellent Sandy Soil: 1. Potential and Actual Water Repellency. *Water Resour. Res.* **1994**, *30*, 2507–2517. [CrossRef]
50. Alagna, V.; Iovino, M.; Bagarello, V.C. 5. Impact of Reforestations with Exotic and Native Species on Water Repellency of Forest Soils. In Proceedings of the 11th International AIIA Conference, Bari, Italy, 5–8 July 2017.
51. De Jonge, L.W.; Jacobsen, O.H.; Moldrup, P. Soil Water Repellency: Effects of Water Content, Temperature, and Particle Size. *Soil Sci. Soc. Am. J.* **1999**, *63*, 437–442. [CrossRef]
52. Moody, J.A.; Shakesby, R.A.; Robichaud, P.R.; Cannon, S.H.; Martin, D.A. Current Research Issues Related to Post-Wildfire Runoff and Erosion Processes. *Earth-Sci. Rev.* **2013**, *122*, 10–37. [CrossRef]
53. Balfour, V.; Woods, S.W. Does Wildfire Ash Block Soil Pores? A Micromorphological Analysis of Burned Soils. In Proceedings of the AGU Fall Meeting, San Francisco, CA, USA, 10–14 December 2007; p. H43F-1695.
54. Granged, A.J.; Jordán, A.; Zavala, L.M.; Muñoz-Rojas, M.; Mataix-Solera, J. Short-Term Effects of Experimental Fire for a Soil under Eucalyptus Forest (SE Australia). *Geoderma* **2011**, *167*, 125–134. [CrossRef]
55. Pierson, F.B.; Robichaud, P.R.; Moffet, C.A.; Spaeth, K.E.; Williams, C.J.; Hardegree, S.P.; Clark, P.E. Soil Water Repellency and Infiltration in Coarse-Textured Soils of Burned and Unburned Sagebrush Ecosystems. *Catena* **2008**, *74*, 98–108. [CrossRef]

56. Fernández, C.; Vega, J.A.; Fonturbel, T.; Jiménez, E.; Pérez, J.R. Immediate Effects of Prescribed Burning, Chopping and Clearing on Runoff, Infiltration and Erosion in a Shrubland Area in Galicia (NW Spain). *Land Degrad. Dev.* **2008**, *19*, 502–515. [CrossRef]
57. Doerr, S.H.; Shakesby, R.A.; Walsh, R. Soil Water Repellency: Its Causes, Characteristics and Hydro-Geomorphological Significance. *Earth-Sci. Rev.* **2000**, *51*, 33–65. [CrossRef]
58. Doerr, S.H.; Ferreira, A.J.D.; Walsh, R.P.D.; Shakesby, R.A.; Leighton-Boyce, G.; Coelho, C.O.A. Soil Water Repellency as a Potential Parameter in Rainfall-runoff Modelling: Experimental Evidence at Point to Catchment Scales from Portugal. *Hydrol. Process.* **2003**, *17*, 363–377. [CrossRef]
59. Morales, H.A.; Návar, J.; Domínguez, P.A. The Effect of Prescribed Burning on Surface Runoff in a Pine Forest Stand of Chihuahua, Mexico. *For. Ecol. Manag.* **2000**, *137*, 199–207. [CrossRef]
60. Vieira, D.C.S.; Fernández, C.; Vega, J.A.; Keizer, J.J. Does Soil Burn Severity Affect the Post-Fire Runoff and Interrill Erosion Response? A Review Based on Meta-Analysis of Field Rainfall Simulation Data. *J. Hydrol.* **2015**, *523*, 452–464. [CrossRef]
61. Hooke, J. Coarse Sediment Connectivity in River Channel Systems: A Conceptual Framework and Methodology. *Geomorphology* **2003**, *56*, 79–94. [CrossRef]