

Proceeding Paper

Soil Optical and Hydraulic Properties of Burnt Forest Areas in Greece after the Implementation of Postfire Restoration Works—Preliminary Results [†]

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Abstract: The short-term changes in micrometeorological and hydraulic attributes of burnt forest soils were evaluated under the influence of three types of post-fire restoration works (wattles, log barriers, and log dams). Comparisons between the two zones (erosion EZ and deposition DZ) formed at the area between two consecutive restoration work units were performed. The reflectance presents minor differences in the two zones, being slightly higher in the EZ, whereas cooler surface temperature and higher soil moisture were recorded in the DZ. The DZ can effectively infiltrate precipitation water with rates of about 150% higher compared to the EZ.

Keywords: restoration; optical properties; hydraulic conductivity; Greece; forests; MoRe Forests



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1. Introduction

Forest fires in the Mediterranean and, particularly in Greece, are a major risk for forests with various environmental and socioeconomic impacts. On average, 1465 fire incidents are recorded in Greece per year, with an average size of 35.6 ha and with high spatial variability at the different regions both in fire frequencies and burned areas [1]. Considering that the first direct impacts of a forest fire are floods and soil erosion and that most fires in Greece occur during summer, soil protection measures have to be implemented immediately after the fire, and any works should be constructed before the beginning of the rainy season, since precipitation water is a critical attribute driving erosion, especially in the diverse topographical pattern of Greece.

Soil erosion is determined using the surface slope, the length, and the curve of the slope, as well as the soil type. Highly inclined areas and sloped surfaces with long lengths present a high erosion risk, whereas, in convex surfaces, erosion is higher compared to hollow ones. The water infiltration rate in the soil decreases after a fire because the burnt soil surface layer becomes hydrophobic, enhancing runoff [2,3] and, thus, water erosion. In general, forest fires change the hydraulic soil characteristics and affect the soil's ability to infiltrate and store water. De Bano et al. [2] reported decreased field capacity immediately after a fire, which, however, was restored to the pre-fire levels as vegetation coverage increased [2,3].

The restoration of a burned area is not an easy task and should be based on the specific site characteristics considering the impacts of forest fires on the soil properties. The restoration works can be grouped into two main categories:

- Urgent restoration works: log barriers, log dams, wattles, etc., are included in this group of active restoration works, which aim to prevent erosion, decrease surface runoff, increase deep infiltration, and protect surface soil.
- Long-term restoration works: plantations, seeding, soil enrichment, vegetation management, and passive restoration measures are included in this group of works, aiming to restore the ecosystem on a long-term basis.

Urgent restoration works are common in Mediterranean countries, including Greece. Log barriers and wattle piles are installed in sloppy areas on the hillslopes of the streams, whereas the log dams are constructed into the streambeds at varied lengths and heights depending on the stream water flow and the inclination of the surface, following specific methodological approaches. In all cases, the application of these works should be limited to high-risk areas to reduce costs [4]. In addition, natural materials from the burnt area should be used to reduce the environmental impact.

The function of these works is to decrease the slope length, smooth the curve angle of the burnt surface, and create obstacles to runoff water moving downwards. Thus, the velocity of the runoff water is reduced, the water remains longer on the soil surface, higher amounts are infiltrated deeper into the soil, and less water remains available to contribute to runoff. This process decreases not only runoff but also the allocation of seeds, nutrients, and soil particles since large quantities are concentrated in the attached to the construction upward zone where the bulk of the runoff sediment is deposited. It should also be mentioned that these works have a relatively small life duration when constructed using the burned wood since its decay provides additional nutrients for the long-term restoration of the burnt area. The positive contribution of the works also includes changes in the physio-chemical soil properties as well as in the optical (radiation absorbance and reflectance) and micrometeorological surface characteristics that result in the formation of multiple microenvironments (shaded or sunlit, warm or cool, moist or dry) that enhance the biodiversity of local flora or fauna and accelerate the total ecosystem restoration.

The aim of the present work is to assess the impact of different types of restoration works on the post-fire environment on a short-term basis (during the first year after the wildfire) under Mediterranean conditions. Micrometeorological and soil hydraulic attributes are investigated in three different Greek forest areas burned by wildfires in the year 2021. The differences between the zones (erosion zone and deposition zone) formed in the area between two consecutive restoration work units were investigated. The results can be useful in hydrological modeling in burned forest areas and enhance our knowledge of optical characteristics and energy partitioning in disturbed fire ecosystems.

2. Materials and Methods

In the present study, three types of urgent restoration works (log barriers, log dams, wattles) were investigated in three sites located in three Greek Prefectures (Tatoi in Attica, Mavrolimni in Corinth–Peloponnese and Ancient Olympia in Ilia–Western Greece). Tatoi is characterized by semi-arid climate [5,6] and was burned on 3 August 2021 by a wildfire that destroyed about 8000 ha of land, according to the Hellenic National Observatory of Forest Fires (NOFFi, <http://epadap.web.auth.gr> accessed on 18 April 2023). In Mavrolimni, which has a semi-arid climate [5,6], 6407 ha were burned by wildfires on 19 May 2021. Finally, in Ancient Olympia (Ilia–Western Greece), the climate is humid [5,6], and the wildfire that occurred on 4 August 2021 burned 18,135 ha. In all sites, the restoration works were constructed in a relatively short time after the wildfires, and the measurements were taken the first summer (July 2022) after the work's construction.

In each site, at least three experimental plots per type of restoration work were installed (25 plots in total). In each plot, topographic (geographical coordinates, altitude, aspect, slope, and length between consecutive restoration units) and micrometeorological (soil

surface temperature, incoming and reflected global solar radiation, and soil moisture at 10 cm depth) measurements were recorded at noon (13:00 to 15:00 h), during one-day campaigns, under clear sky conditions. Field experiments were performed to estimate the unsaturated hydraulic conductivities, and soil samples were collected to determine their physicochemical properties. The plots were installed in the area between two consecutive restoration work units. In the plot, two different zones were formed: the erosion zone (EZ) at the upper part of the plot, where the soil was eroded by precipitation, and the deposition zone (DZ) at the lower part of the plot, where the bulk soil sediment was concentrated. The differences in the micrometeorological, hydrological, soil, and vegetation properties between the two zones were assessed with respect to the restoration work type.

The incoming and reflected solar radiation was measured by an LP 471 RAD probe (Delta OHM), and an MI-210 infrared radiometer (Apogee Electronics) was used to measure surface temperature. The soil moisture per volume was recorded by a delta-t SM150 sensor. To estimate the unsaturated hydraulic conductivity, a minidisk infiltrometer (Meter Group) was used according to Zhang's [7] methodology [8].

3. Results and Discussion

The optical properties of the natural surfaces, specifically of forests, are highly affected by vegetation coverage. They are of critical importance in forest ecosystems since they drive the energy and mass transfer between the ecosystem and the atmosphere and also determine the energy partitioning in the ecosystem [9]. The disturbance due to a wildfire alters the optical behavior of the forest and thus the energy partitioning and effectiveness of using energy. The installation of restoration works on burned surfaces alters their roughness and color and, thus, changes their optical behavior.

In the present study, the reflectance (albedo) of the soil was estimated above the erosion zone (EZ) and the deposition zone (DZ) in the area between consecutive restoration work units. EZ presented slightly higher albedo compared to the DZ (Figure 1a), suggesting that less solar energy is absorbed by the soil in the DZ, regardless of the type of restoration work. Considering the absence of vegetation, the absorbed radiation is used for heating the soil and not effectively for photosynthesis or plant-related processes [10].

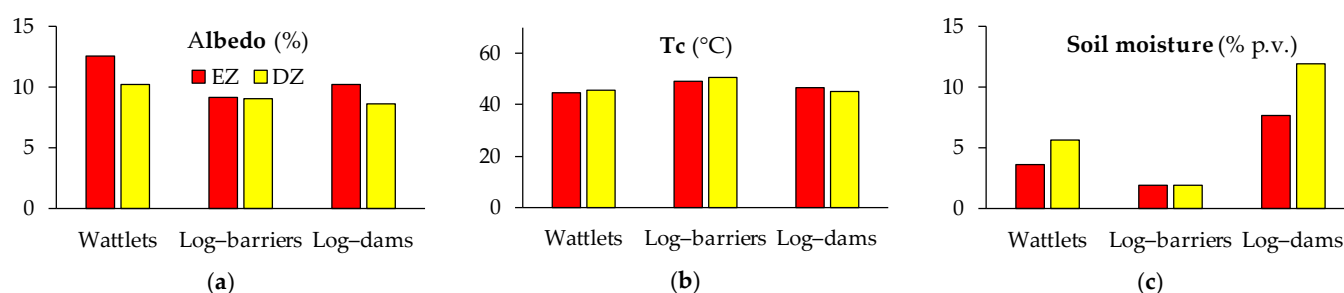


Figure 1. (a) radiation reflectance (albedo), (b) soil surface temperature T_c , and (c) soil moisture at the erosion (EZ) and soil deposition (DZ) zones of different types of restoration works.

On average, $9.2 \pm 3.1\%$ of the incoming solar radiation is reflected in DZ, and the remaining part is absorbed by the soil, whereas the respective percentage for the EZ is slightly higher ($10.4 \pm 2.4\%$). This pattern can be partly associated with the slightly higher water content of the soil in the DZ (soil moisture $6.4 \pm 7.6\%$ p.v., Figure 1c) compared to the EZ ($4.4 \pm 5.7\%$ p.v.), which enhances the absorbance due to the water's ability to store energy. The higher amounts of absorbed radiation in the DZ are consistent with the higher surface temperatures compared to the EZ (Figure 1b). This high heat storage in the DZ could be useful for the natural regeneration of vegetation compared to EZ, especially in spring and autumn. However, the extremely high T_c ($46.5 \pm 11.3^\circ\text{C}$ for EZ and $47.5 \pm 11.8^\circ\text{C}$ for DZ) indicates that in the post-fire environment, especially in summer, vegetation is under thermal stress, and the young seedlings is not likely to survive, considering also the limited water availability during this season. At this stage (the first year after the fire) and under

such stressful micrometeorological conditions, only deep-rooted and drought-tolerant plants and seedlings are expected to survive. This is further supported by our findings from vegetation assessment conducted in the plots, which indicated that the regenerated shrubs with deep root systems that survived the fire dominate the burned landscape, whereas herbaceous species or young seedlings are rare or absent.

At the different types of works, albedo differences between EZ and DZ were minor. Albedo for the wattle piles and log dams were slightly higher at the EZ (by +0.024 and +0.016, respectively) compared to DZ, whereas negligible differences were found for the log barriers. Wattles and log barriers presented warmer T_c at the DZ (by -1.06 and -1.5 °C), whereas log dams DZ were cooler (by $+1.2$ °C) compared to EZ. The high height of log dams probably led to a relatively cooler microenvironment in DZ, which also has higher soil moisture differences (by 4.3%).

The positive impact of urgent restoration is more sound when assessing the ability of the burnt soils to infiltrate water (Figure 2). The soil deposited in the DZ presents much higher unsaturated hydraulic conductivity, K values, that exceed by 144% on average the K in the EZ, with respect to the differences between different soil types, regions, and types of restoration works. The average K indicates that EZ soil infiltrates water at a rate of 18.7 ± 16.3 mm h⁻¹, whereas the respective value for DZ is 45.8 ± 35.9 mm h⁻¹. Such high infiltration rates in the DZ minimize the risk of surface runoff that can lead to soil erosion. It should be mentioned, however, that the above-mentioned K values for the DZ present high variability ranging from 22.9 ± 20.1 mm h⁻¹ in the log barriers of Tatoi (Attica), which have sandy loam soils to 75.8 ± 77.8 mm h⁻¹ in the log dams of Ilia (Western Greece) with the sandy loam soils. The K values for the EZ have smaller variability and range from 6.7 ± 6.1 mm h⁻¹ at the sandy loam soils of the wattles in Ilia to 26.7 ± 23.6 mm h⁻¹ to the log barriers of Corinth (Peloponnese), which have clay loam, loam, and sandy loam soils. It is evident, though, that in all cases, the DZ can infiltrate higher water amounts compared to the EZ, and this suggests that the application of urgent restoration works surely protects the ecosystem from further degradation, limiting the risk of water erosion. The new vegetation is expected to favor infiltration since the hydraulic conductivity is positively affected by the forest canopy cover [11]. As plants grow deeper roots, the soil matrix will develop stable pathways for the movement of water that will increase the soil's hydraulic conductivity [12–14], which is also related to the preferential flow of the soil water around the roots [15]. Thus, it is extremely important to accelerate vegetation growth in burned ecosystems via restoration and also provide the appropriate time for the full ecosystem recovery.

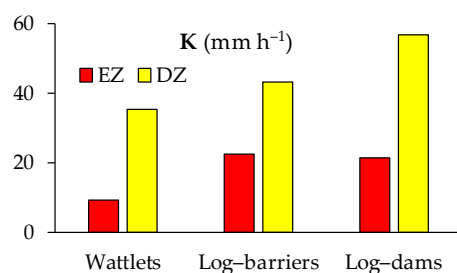


Figure 2. Unsaturated hydraulic conductivity K at the erosion (EZ) and soil deposition (DZ) zones of different types of restoration works.

4. Conclusions

The impact of wildfires on forest soil properties is critical for the post-fire regeneration and restoration of forest ecosystems. Especially in the Mediterranean region, the optical and hydraulic properties of the burned forest soils are highly affected by precipitation rates during the first rainy period after a wildfire and also by the weather and micrometeorological conditions (temperatures, soil moisture availability, and radiation fluxes) at the summer following the fire event, when the soil is uncovered from vegetation and thus vulnerable

to erosion and further degradation. In this study, the impact of the restoration works on forest soil's radiation reflectance (albedo), surface temperature (T_c), and unsaturated hydraulic conductivity (K), measured at different types of interventions (log barriers, log dams, wattles) was assessed. The differences in these parameters in the area between two consecutive construction works were investigated by conducting measurements in the eroded zone (EZ) and in the zone (DZ) where the bulk of the runoff sediment was deposited. The measurements were taken during single-day campaigns in the first summer (July 2022) following the wildfires and after the construction of the works in three Greek Prefectures (Attica, Peloponnese, and Western Greece).

Results indicate that the erosion zones of the wattle piles and log dams present slightly higher reflectance compared to the bulk soil deposition zones, whereas the differences at the log barriers were negligible. Small surface temperature differences between the zones were identified, with slightly warmer conditions prevailing at the deposition zones of the wattles and the log barriers and slightly cooler at the log dams compared to the respective erosion zones. The cooler conditions at the erosion zone of the log dams are associated with higher soil moisture. It should be stated, however that in all cases, soil moisture was extremely low and soil surface temperatures extremely high in both zones, suggesting that the persisting warm conditions, in conjunction with the small soil water availability, will negatively impact the survival of vegetation especially for young seedlings or herbaceous species. Under such environments, only deep-rooted species with roots that survived the fire can only regenerate, or new seedlings that managed to develop a deep root system in spring.

The unsaturated hydraulic conductivity of soil is significantly higher at the deposition zone, indicating its enhanced ability to infiltrate water with almost 150% higher rates compared to the erosion zone. However, the specific percentage varies with respect to the type of construction work, the soil type, and the region.

The results presented in this work are preliminary and refer to the characteristics of a recently burned forest (the first summer after a wildfire) under the impact of the application of urgent restoration works. Further research is required in different regions, soil types, and for longer periods in order to produce solid conclusions and assessments on the permanent restoration of burned areas and on the effectiveness of such types of restoration works. Future work by the authors will include the changes of micrometeorological, hydraulic, soil, and vegetation attributes of the burnt forests for longer periods after a fire to investigate the changing environment in the ecosystem until its stabilization.

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