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Soil water dynamics in burned areas after a late summer rain. The role of fire intensity, microsite, sampling depth, and time of measurement

M.J. Molina & J.V. Llinares
Centro de Investigaciones sobre Desertificación –CIDE (CSIC-UV-GV), Camí de la Marjal s/n 46470Albal, Valencia-España
Email: maria.j.molina@uv.es

Abstract

In Mediterranean areas, where fire is a recurrent process, soil water availability may be a major cause for the spatial and temporal pattern of plant recovery after fires, since water is found to limit plant growth in semiarid environments.

In the Spanish region of Valencia we studied the water dynamics of a typical forest soil subjected to experimental fires of contrasted levels of fire intensity, and also that of a control (unburned) soil. This was done in the field by TDR examination of their water content variations at the 0-10 mm surface soil and at the 10-100 mm subsoil, in the plant spaces and the plant interspace patches, after the first intense rainfall following the 1995 June fires.

Water contents of the surface soil varied as a function of fire intensity, microsite and time after the rain. Water conditions of the subsoil in the plant spaces affected by fire, regardless intensity, resulted significantly higher than those of the surface soil, and remained above limiting water potentials during the twelve day period of study after the rain. The ecological and practical significance of our results is that in ecosystems like the case of study, and disregarding many other factors that may affect germination, seeds stored in the subsoil of the post-fire plant spaces have better water conditions to germinate and establish. This greater availability of water in the subsoil may also favour the recovery of resprouters.

1 Introduction

In Mediterranean areas, where fire is a recurrent process, heterogeneity in soil resources, intensity of fire and depth of soil at which major changes take place are regularly invoked as important for seed germination, seedling establishment and plant growth (Hook[6]; Izhaki[7]; Knapp[9]; Lamont[10]). These last are the result of interaction between diverse environmental factors. Among these, soil water availability may be a major cause for the spatial and temporal pattern of plant recovery after fires, since soil water is found to limit plant growth in semiarid environments (Nobel[12]).

An integral study about the impact of fire intensity on soil, erosion and vegetation dynamics in the Southern Europe, gave us the opportunity of performing experimental fires of varied intensities in La Concordia (Valencia). First results indicated that the post-fire physical properties of soil that may influence the soil water dynamics varied as a function of intensity, the type of microsite and the depth at which soil was sampled (Llinares[11]). On the basis that the soil water dynamics should reflect these changes, the present study was designed to complement the research by focusing on the implications that it could have on plant recovery.

2 Material and methods

In June 1995, experimental fires were performed in a mountainous area of 30-40% slope exposed to the Southwest and located in La Concordia (39° 45' N, 0° 43' W), 50 Km Northwest of Valencia city, at an altitude of between 550-575 m a.s.l. The area had previously been burnt in 1986 by a wildfire.

Mean annual precipitation in the area is 400-500 mm. Mean monthly temperatures range from 13.3 °C in January to 25.8 ° C in August.

The soil type is a shallow and rocky Rendzic Leptosol (FAO classification) Lithic Haploxeroll (USA classification) developed on limestone. Volumetric Rock fragment content in the soil profile is 50%. Soil depth varies between 30 and 40 cm. Colour is dark brown (10YR3/3). Texture is sandy loam (61 % sand, 28 % silt and 11% clay). Organic matter is around 11% in the A1 horizon. Carbonate content is 57% and pH around 7. These characteristics apply to the soil in the plant spaces. The soil in the plant interspaces has higher surface rock fragment content, less depth (<30 cm), a dark yellowish brown colour (10YR3.5/4), a loam texture (44% sand, 40 % silt and 16% clay), and less organic matter content (8%). Differences in soil characteristics are attributed, on the one hand, to the effect of shrubs as fertility islands (litterfall, decreased erosion etc.), and, on the other hand, to the erosion process acting on the plant interspaces.

Vegetation is dominated by *Ulex parviflorus* and *Rosmarinus officinalis* with a variety of species including *Thymus vulgaris*, *Globularia alypum*, *Cistus clusii* and *Cistus monspeliensis* generalised in all plots, and some individuals of *Rhamnus lycioides*, *Quercus coccifera* and *Stipa tenacissima* appearing only in some plots. Dry biomass of the vegetation in the area is 2 Kg m^{-2} on average.

At the midslope, nine 20x4 m plots were selected at random in order to have three replicates per treatment. Treatments were randomly assigned to the plots. The treatments were Intense fire, Moderate fire and Control (unburned). Total fuel load (standing vegetation plus added biomass cut from the surroundings to make firebreaks) averaged 4 Kg m^{-2} for the intense fire and 2 Kg m^{-2} for the Moderate fire.

Temperature levels and duration of heat were measured by means of 6 thermocouples installed in each plot before burning. Mean peak temperatures at the soil surface were 539 °C for the Intense treatment and 341 °C for the Moderate treatment. Residence time of temperatures greater than 100°C ranged from 17 to 82 min in the soil subjected to the Intense treatment and from 5 to 12 min in the soil subjected to the Moderate treatment.

We selected two of the three plots per treatment to study the water dynamics of the soil. This was determined by measuring over time, the water content variations after the first intense storm following the experimental burning. Measurements were taken at the soil surface (0-10 mm topsoil) and at 10-100 mm subsoil. The water content of soil was measured simultaneously to the soil temperature, from 11 to 14 a.m., the 1st, 2nd, 6th and 12th day after the rain occurred on 23 August 1996. The 26.2 l m^{-2} rainfall had a mean intensity of 16.4 mm h^{-1} and caused runoff and sediment production in the plots.

The TDR (time domain reflectometry) technique was used for soil water content measurements (see Topp[18,19]). A TDR cable tester Tektronix 1502 C was used. Fig. 1 shows the main characteristics of the TDR probes used. They were installed horizontally in the 0-10 mm surface soil, and vertically in the 10-100 mm subsoil. Roth's equation (Roth[15]) was used to convert TDR measurements into volumetric soil water contents. In the Control (unburned) treatment, 8 sampling points refer to the soil in the plant spaces (there was litter covering the soil surface), and also 8 points refer to the soil in the plant interspaces (bare soil with rock fragments covering the surface). For the Intense and the Moderate fire treatments, the same number of sampling points refer to the soil with ashes in the plant spaces or to the soil with ashes in the plant interspaces.

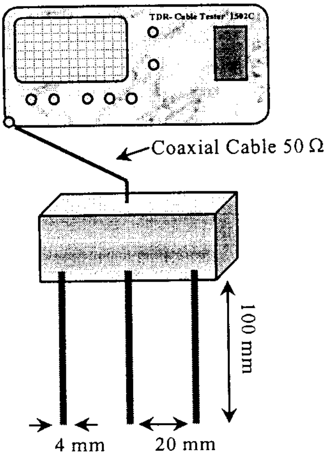

Figure 1: Characteristics of the TDR probe.

Grand mean values and 95% confidence intervals obtained for the water contents of the 0-10 mm soil and the 10-100 mm subsoil were used to analyse the effect of the depth of sampling. MANOVA analyses were conducted on the data to explore, for each depth, the effects of the treatment, the microsite, and the date of measurement on the measured soil water contents. Also their interactions were analysed, although, for the sake of simplicity, only the main effects and the three-factor interactions will be discussed. To give a biological interpretation to the resulting interactions, we compared mean values of water content with the mean water content of the soil near wilting point (between 300 and 500 kPa) determined in the laboratory for the soil of study (0.035 ± 0.015 cm^3 cm^{-3}, n=6). Assuming that 0.05 cm^3 cm^{-3} is the upper limit of soil water content at wilting point, we tried to ascertain what soil environment had the most favourable water conditions from the point of view of post-fire colonisation. Interpretation of results was given in terms of the number of days that the water content of soil in each environment was above 0.05 cm^3 cm^{-3}. We based on some studies conducted under our climatic conditions (Verdú[20]) which reveal that seeds of plants such as *Pistacia lentiscus,* need more than 10 days of water potentials in soil above -300 kPa to germinate and establish.

3 Results

Tab. 1 shows the analysis of variance for the water content of the 0-10 mm soil as influenced by the treatment, the microsite and the time of measurement. In this table you can observe that the three factors have significant effects on the soil water content. Some two-factor interactions and also the three factor interactions are significant.

Source of variation	SS	d.f.	MS	F-ratio	Sig. Level
MAIN EFFECTS					
A:Treatment	.0561	2	.0281	13.616	.0000
B:Micro	.0109	1	.0109	5.317	.0223
C:Time	.6419	3	.2139	103.779	.0000
INTERACTIONS					
AB	.0022	2	.0011	.538	.5849
AC	.1191	6	.0198	9.633	.0000
BC	.0003	3	.0001	.056	.9827
ABC	.0265	6	.0044	2.150	.0503
Residual	.3463	168	.0020		
Total (Corrected)	1.203	191			

Table 1: Analysis of variance for the water content of the suface soil.

Table 2 shows the analysis of variance for the 10-100 mm subsoil. In this table you can observe the significant effects of the factors treatment and time, and a nearly significant effect of the microsite factor. The treatment-microsite was the only significant two-factor interaction, whereas the three-factor interaction was not significant.

Source of variation	SS	d.f.	MS	F-ratio	Sig. Level
MAIN EFFECTS					
A:Treatment	.0794	2	.0397	6.514	.0019
B:Micro	.0178	1	.0178	2.921	.0893
C:Time	1.0590	3	.3530	57.902	.0000
INTERACTIONS					
AB	.0408	2	.0204	3.351	.0374
AC	.0712	6	.0119	1.946	.0762
BC	.0015	3	.0005	.085	.9684
ABC	.0081	6	.0013	.222	.9694
Residual	1.0242	168	.0061		
Total (Corrected)	2.3022	191			

Table 2: Analysis of variance for the water content of the subsoil.

3.1 The effect of depth of sampling

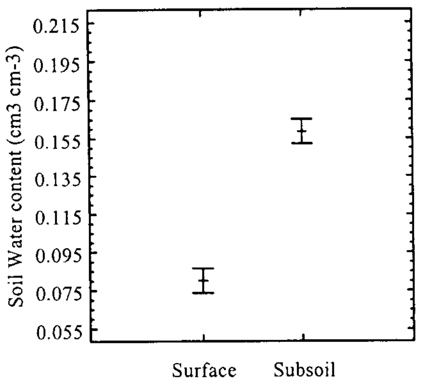

Figure 2: 95 % LSD intervals for the depth factor means.

Fig. 2 illustrates the influence that this factor has on the soil water content. The graph indicates that the mean water content for the 10-100 mm soil (0.16 cm^3 cm^{-3}) is significantly higher than that for the 0-10 mm soil (0.08 cm^3 cm^{-3}).

3.2 The effect of treatment

3.2.1 Surface soil

Fig. 3a indicates that the mean water content of the surface soil in the period of study increases significantly in the order Intense fire > Moderate fire = Control.

3.2.2 Subsoil

Fig. 3b indicates that the mean water content of the 10-100 mm subsoil in the period of study, increases in the order Intense fire = Moderate fire > Control. In contrast with the surface soil, water contents for the subsoil in the Intense and the Moderate fire are similar, although both of them are considerably higher than that of the unburned soil.

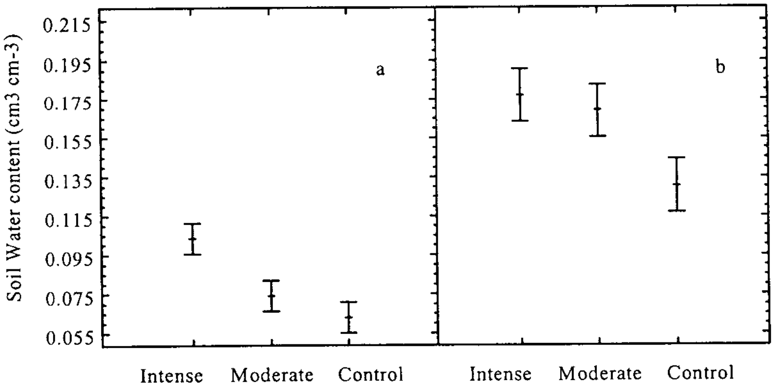

Figure 3: 95 % LSD intervals for the treatment factor means. (a): Surface. (b): Subsoil.

3.3 The effect of microsite

3.3.1 Surface soil

As shown in Fig. 4a, the mean water content of surface soil in the plant interspaces is higher than that of the plant spaces.

3.3.2 Subsoil

Although statistically not significant (P= 0.08; Tab. 2), the water content of the subsoil in the plant interspaces tends to have the opposite effect than that for the surface soil. Fig. 4b shows that the water content in the plant spaces tends to be higher than that of the plant interspaces.

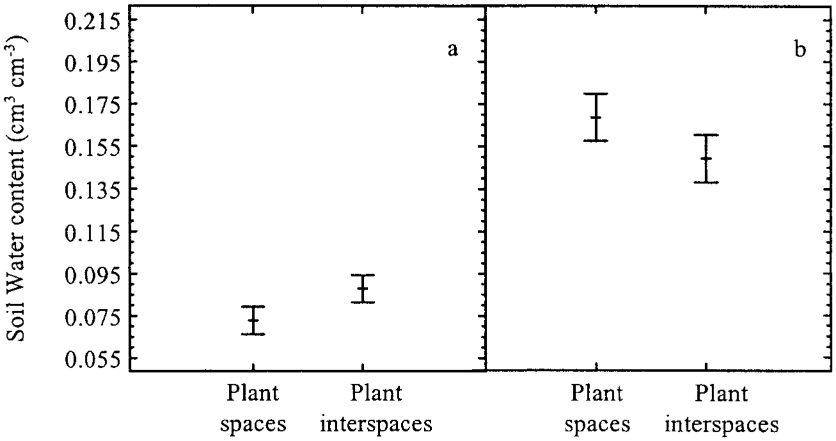

Figure 4: 95 % LSD intervals for the microsite factor means. (a): Surface. (b): Subsoil.

3.4 The effect of time of measurement

3.4.1 Surface soil

Fig. 5a shows that the water content of the surface soil decreases as the number

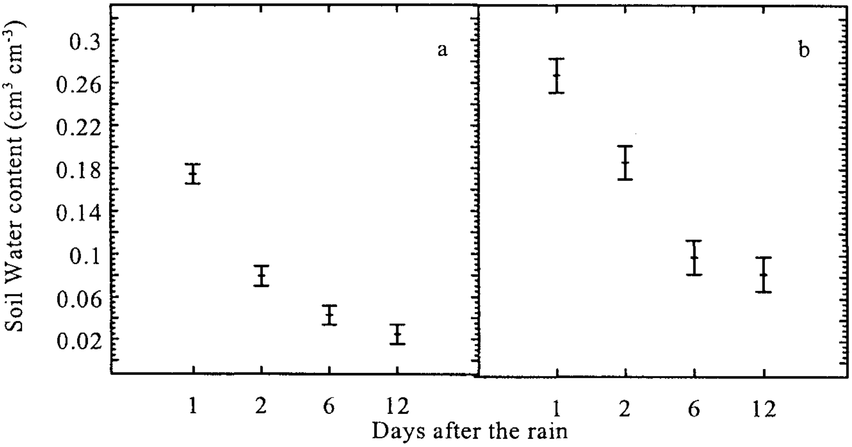

Figure 5: 95 % LSD intervals for the time factor means. (a): Surface.
(b): Subsoil

of days after the rain increases. This decay is very fast at the beginning of the study period, and seems to be slower as water contents of soil become lower.

3.4.2 Subsoil

Fig. 5b shows that the effect of time for the subsoil water content, is similar to that for the surface soil, although from the first to the second day after the rain, the decay is slower than that experienced by the surface soil.

3.5 Treatment-microsite-time of measurement interactions

3.5.1 Surface soil

Fig. 6a shows means and confidence intervals for the water contents of surface

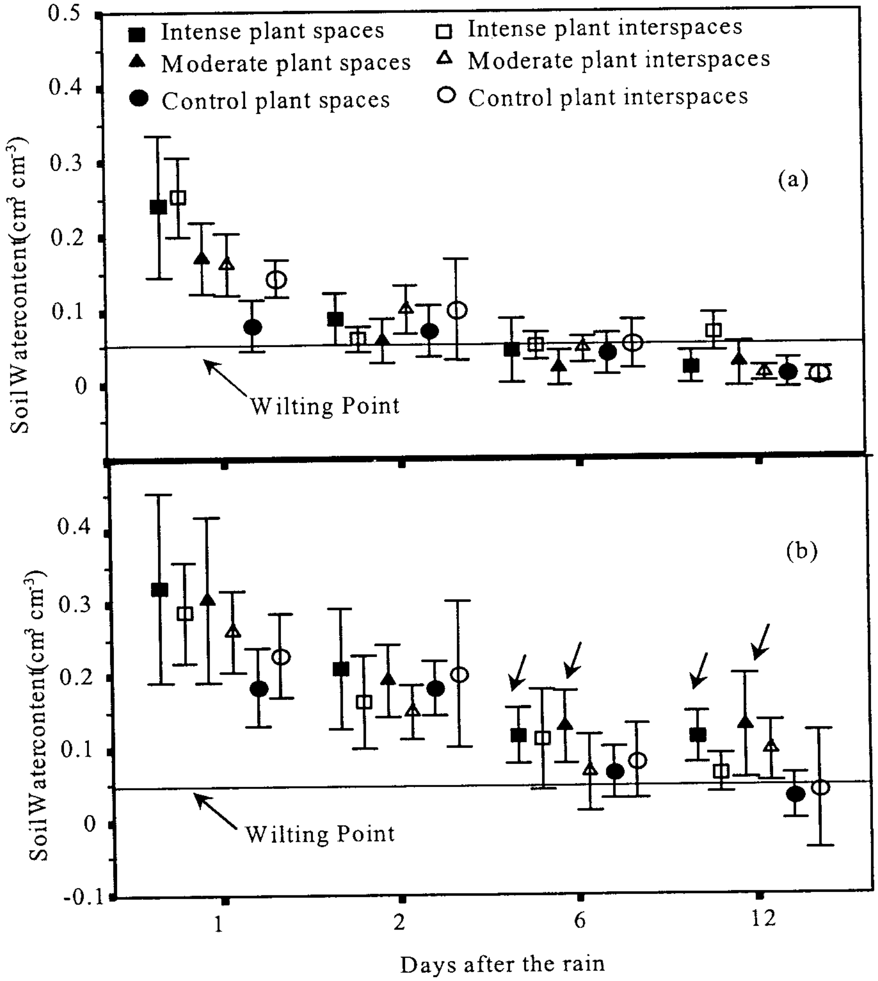

Figure 6: Means and 95 % LSD intervals for the water content of soil grouped by treatment, microsite and time. (a): Surface. (b): Subsoil.

soil grouped according to treatment, microsite and date of sampling. None of the surface soil environments are able to maintain water levels above 0.05 cm^3 cm^{-3} during more than two days after the rain. Under these conditions seeds germination may be limited.

3.5.2 Subsoil

Fig. 6b shows, for the subsoil, means and confidence intervals of water contents grouped according to the three factors. Only the water contents of the subsoil in the plant spaces in the two fire treatments (see the arrows in Fig.6b), remain above 0.05 cm^3 cm^{-3} even the twelfth day after the rain.

4 Discussion and conclusions

Fire, distribution of soil properties according to the pre-fire patchiness, depth of soil sampling and time after the rain influence the pattern of soil water content.

For the surface soil, this pattern depends on fire intensity. This result agrees with early studies in chaparral burning (Sampson[16]) and recent studies in young Pinus pinaster forests in Northern Portugal (Rego[14]).

Under the conditions of our study, the effect of fire intensity on the water content is to increase it in the order Intense > Moderate = Control. This result may be due to the fact that, in absence of vegetation, the evapotranspiration in burned areas is lower than that of the vegetated ones (Tiedeman[17]). The differences between Intense and Moderate fire may arise from differences in the physical properties related to water movement in soil. We have evidences (Llinares[11]) that main effects of fire intensity are confined to the soil surface, at which the Intense fire decreases the soil porosity, whereas the Moderate fire increases it. This agrees with several studies in the Southern USA (DeBano[2]). If so, water permeability decreases in the less porous soil, and water contents may be greater at the surface of intensely burned soil because it saturates before that the moderately burned soil.

Throughout the studied period, the subsoil water conditions are more favourable than those of the surface soil. This is an expected result since evaporation losses due to the black ashes covering the surface of burned soil (Raison[13]) are confined to relatively shallow depths.Capillary breaking at the topsoil-subsoil interface may be a cause of it too. The water content of the subsoil in the two fire treatments, regardless the intensity, is higher than that of the unburned soil. This result agrees with those observed by various authors (Haase[5]; De Ronde[3]). We deduce that intensity only affects the water content of the surface soil but not that of the depth soil. The lower water content of the unburned subsoil is interpreted as the result of the higher infiltration of water and its accumulation in the root zone.

The microsite factor also has an effect on the pattern of soil water content. The fact that the surface soil in the plant interspaces is wetter than that in the plant spaces may indicate that surface rock fragments (observed to cover the plant interspaces almost totally) can increase the retention of soil moisture (Agassi[1]) and also protect the soil against desiccation (Jury[8]; Nobel[12]).

The subsoil in the plant interspaces of the two fire treatments is drier than that in the plant spaces. We presume that the water content of the surface soil in the plant interspaces increases at the expense of the water retained in the subsoil due to the condensation of water under the rock fragments when it is moving towards the surface by evaporation (Jury[8]; Nobel[12]).

The subsoil water conditions in the plant spaces affected by fire are more favourable than the rest of soil environments. For similar plant communities, in recently burnt sites, it has been demonstrated that the density of seeds of the dominant species not affected by fire was higher in the 20-50 mm soil layer than in the 0-20 mm layer (Ferrandis[4]). Disregarding the influence of many other factors that may affect colonisation (soil temperature, pH etc.), the ecological and practical significance of our results is that the buried seeds stored in the subsoil of the plant spaces affected by fire have better soil water conditions to germinate and establish. This greater availability of water in the subsoil of the plant spaces affected by fire also may favour the recovery of resprouters.

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