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SOIL RESPIRATION, MICROBIAL BIOMASS AND RATIOS (METABOLIC QUOTIENT AND MBC/TOC) AS QUALITY SOIL INDICATORS IN BURNT AND UNBURNT ALEPPO PINE FOREST SOILS

Javier Hedo[1]* --- Manuel Esteban Lucas-Borja[2] --- Consuelo Wic[3] --- Manuela Andrés Abellán[4] --- Jorge de Las Heras[5]

[1, 5] *Department of Plant Production and Agricultural Technology, School of Advanced Agricultural Engineering, Castilla La Mancha University. Campus Universitario, Albacete, Spain*

[2, 3, 4] *Department of Agroforestry Technology and Science and Genetics, School of Advanced Agricultural Engineering, Castilla La Mancha University. Campus Universitario, Albacete, Spain*

ABSTRACT

Wildfires affecting forest ecosystems and post-fire silvicultural treatments may cause relevant changes in soil properties. Soil plays an important role in the fertility and stability of the forest ecosystem [1] as it highlights the microorganisms that accomplish reactions to release soil nutrients for vegetation development [2]. Wildfires and post-fire silvicultural treatments may cause relevant changes in forest and soil properties [3, 4]. Fire may alter physical-chemical soil properties (i.e., soil organic matter content and its structure, hydrophobicity, pH and nutrient cycles) [5], microbiological and biochemical soil properties (i.e., microbial biomass, microbial activity, soil enzymes activities) [5]. Long-term studies into soil quality, or which evaluate soil recovery capacity after forest fires or post-fire silvicultural treatments, are scarce. To evaluate soil quality, the use of a general character parameter like soil respiration is commonly used [6, 7]. This study aimed to investigate soil respiration, microbial biomass and ratios (metabolic and MBC / TOC) in burnt and unburnt soils of an Aleppo pine forest ecosystem affected by a wildfire event 17 years ago. It is noteworthy that we define recovery as a scenario which returns to the same activity levels before wildfire perturbation. Our results demonstrated that 17 years after the fire event occurrence, the quality of the burnt soils reached the undisturbed soil levels.

Keywords: Soil respiration, Post-fire, Long-term recuperation, Aleppo pine.

† Corresponding author

Contribution/ Originality

This study is one of very few studies which have investigated long-term recovery of the burnt Mediterranean soils, in dry and semiarid climates, and the paper's primary contribution is finding that forest management must be taking into account soil parameters to achieve good adaptive procedural guidelines.

1. INTRODUCTION

Mediterranean ecosystems are very fragile and sensitive to changes due to different anthropogenic and natural disturbances. One of the main problems of Mediterranean forests is wildfire disturbance. Fire should be considered more an ecological factor [8] but, in contrast to the role of fire, it is now a closely related factor to human action. Fire causes not only direct effects on soil, produced by its heat on the physical, chemical and biological properties, but also indirect effects such as loss of vegetation cover, appearance of ash and, above all, greater susceptibility to erosion. The study of soil quality assessment has been encouraged by the growing concern about the state of this resource since it is a basic component of much critical importance in the biosphere, and as a driver of important ecosystem balance functions. Not only is soil quality the basis on which life is based as it acts as a physical support for plant growth, but it is also a reservoir of water and essential nutrients, a regulator of water flow, and it mitigates the buffer system [9]. It is therefore an important factor in forest ecosystems, and more markedly so in a global change context where the fire regime is changing due to changes in land use and climate change. Among the various factors that determine soil quality, biological and biochemical properties are particularly relevant in Mediterranean climates, even in semiarid areas, because vegetation cover degradation exhibits direct behaviour, along with scarce organic matter in soils [10]. This study describes the long-term (17 years) effect caused by fires on the microbiological and biochemical soil quality, as determined by changes in organic matter and microbial activity in semiarid soil. Relationships between microbiological parameters have been widely used to evaluate the microbial ecophysiology [11]. The metabolic quotient (qCO_2) has been used by various authors and expresses the amount of CO_2-C produced per unit of biomass and time. Llorente and Turrión [12] used it as an indicator of environmental conditions adversity. The carbon ratio of microbial biomass with TOC (total organic carbon), hereinafter "MBC / TOC", is an indicator of the potential mineralisation of organic matter (Garcia and Hernandez, 2000). By studying basal respiration, microbial biomass and ratios (metabolic and MBC / TOC) can offer a rough idea of not only the community of microorganisms present in soil, but also the dynamics of these external factors.

The main objective of this work was to evaluate the quality of soil, comparing burnt soils with unburnt soils, 17 years after the fire, which acts as a slide of the status of these soils and their potential recovery. The main hypothesis is that after 17 years, the burnt soils of a stand of Aleppo pine present in dry or semiarid Mediterranean climates are able to recover naturally. The fires which occurred in Yeste (Albacete) and Calasparra (Murcia) in the summer of 1994 are the ideal setting for the main purpose of this work.

2. MATERIAL AND METHODS

2.1. Study Area

In the summer of 1994, two large fires affected 14,000 and 30,000 hectares in Calasparra and Yeste in the provinces of Murcia and Albacete, respectively, in the southeast area of the Iberian Peninsula. These fires affected mature *Pinus halepensis* Mill. and its accompanying vegetation (Table 1). The potential vegetation at the first site corresponds to the *Rhamno lycioidis-Quercetum cocciferae* series, while Yeste corresponds to the *Bupleuro Querceto rotundifoliae S. Rigidi* series [13]. The two study sites are on the mesomediterranean floor, which is semiarid at Calasparra and dry at Yeste. The average temperature and rainfall for the study area are, respectively, 282 mm Calasparra and 16.3°C, and 503 mm and 13.5°C for Yeste (AEMET). A characterisation of the soils is seen in Table 1. Both sites presented high post-fire natural regeneration, with a density of about 7,000 trees / ha in Yeste and of 45,000 trees / ha in Calasparra.

2.2. Experimental Design

In December 2011, three plots (150 m^2, 10m x 15m) in the burnt area of Yeste and three in the burnt area of Calasparra were selected. Some others were selected in the unburnt areas surrounding the perimeter of each fire. In all five subplots, the plots were established randomly as 4 m^2 (2m x 2m), in which six composite samples and distributed random subsamples were taken to make the samples as representative as possible. After removing litter, samples were sieved through a 2-mm sieve and were homogenised in the laboratory. Samples were kept at 4°C until all the laboratory tests were performed [14].

2.3. Physical and Chemical Variables

The collected samples weighed 500 g and were used to carry out the analysis of some physical, chemical and microbiological properties. Electric conductivity and pH were measured in an aqueous 1.5 solution (w / v) using a pH meter (Horiba model Navi). Total organic carbon (TOC) was determined by the method of Yeomans and Bremner [15], while organic matter was calculated from the TOC value multiplied by 1.728 [16]. Total carbonate was measured by evaluating excess HCl with NaOH [4]. Available phosphorus was determined using the method described by Olsen and Sommers [17]. Total nitrogen was measured by the method of Kjeldahl, but modified by Bremner [18]. The texture analysis was analysed following the method of Guitián and Carballas [19].

2.4. Biochemical and Microbiological Variables

For the quantification of the microbial biomass, the biomass carbon was determined by the method of Vance, et al. [20] adapted by García, et al. [21]. Basal respiration was obtained by the method of static incubation at 28ºC as described by Anderson [22]. The metabolic quotient (qCO_2), the equivalent to the respiration per unit biomass, was also found, as was the ratio obtained from biomass carbon and TOC.

2.5. Statistical Analysis

The means and analysis of variance (double classification) were obtained by the Statsgraphics Centurion program.

3. RESULTS

Soil texture and electrical conductivity showed no differences between sites (Yeste and Calasparra), or between fire and no fire. Phosphorus, total nitrogen, organic matter and carbonates were higher in Calasparra than in Yeste, while pH and the C/N ratio presented a different behaviour, and were lower in Calasparra than in Yeste. The fire factor was significant only for organic matter and carbonates, and was higher in the burnt areas.

Significant differences were found only with respiration and biomass carbon for the microbiological parameters and according to site (Yeste or Calasparra) after considering the fire factor. Conversely, no significant differences with any factor (and fire site) were observed for the metabolic quotient (qCO_2) or the MBC-TOC ratio.

4. DISCUSSION

Biomass carbon and basal respiration have been widely used by several authors to determine soil quality [23, 24]. The results showed that measured soil properties do not differ between burnt and non-burnt areas, but differ from the semiarid Mediterranean and the dry Mediterranean climates. The predominant vegetation in both study areas is Aleppo pine. We can state that the differences observed between Calasparra and Yeste were not caused by vegetation. Soil texture was similar in both study areas. The higher temperatures and lower rainfall in Calasparra, in comparison to the lower temperatures and greater precipitation in Yeste, explain the differences in both basal respiration and biomass carbon. Sardans and Peñuelas [25] argued that high temperatures adversely affect soil microbial biomass, and other authors have also shown that soil moisture is related to rainfall and evapotranspiration. Hence temperature significantly affects the microbiological variables of forest soils [26]. Fires exert profound effects on soil quality and its dependent vegetation recovery [27]. In this study, the basal respiration and biomass carbon results revealed no significant differences between burnt and non-burnt sites. This can be explained by the high resilience of Aleppo pine xeric communities because 17 years after the fire occurred, vegetation was able to revegetate the area naturally [28]. Similar trends have been observed in other studies, which have indicated recovery indicators of microbial biomass [29]. Mataix-Solera, et al. [5] found low basal respiration values where poor vegetation recovery occurred, which led to poor organic matter recovery in soil.

The MBC / TOC ratio is highly dependent on weather conditions [30]. In our study however, we observed no significant differences for any of the study factors. Bastida, et al. [31] found that the values in soils not affected by disturbances were higher than in the soils affected by disturbances, which is due to high organic matter accumulation content in areas where disturbances did not occur. The missing differences in our study may be due to a recovery in burnt areas after 17 years for the fire soil factor. The soils from semiarid areas and those from dry areas obtained comparable values.

A similar behaviour showed that the metabolic quotient (qCO_2) obtained comparable values for all cases. García, et al. [10] found that qCO_2 increased when a floor of a semi-arid environment was subjected to stress. In our case, that of recovery and a return to pre-disturbance values, no differences were observed after fire disturbance.

5. CONCLUSIONS

Vegetation is an effective protector of soil microbial activity. Specifically, Aleppo pine is a resilient tree species to fire events, which exerts soil recovery through effective post-fire plant recovery. Indeed 17 years after the fire event occurrence, the quality of the burnt soils reached the undisturbed soil levels.

Further studies in which various analyses are performed, such as enzyme activities, and which also consider several factors, such as seasonality, silvicultural management and climate change, would be beneficial for the recovery of post-fire arid and dry Mediterranean soils.

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Table-1. Characteristics of each experimental site*.

Site	Fire	Tree age	Main vegetation	Soil type	Texture
Calasparra	Burnt	17	Pinus halepensis Mill.; Macrochloa tenaccisima (L.) Kunth; Rosmarinus officinalis	Aridisol	Loam
	Unburnt	70-80	Pinus halepensis Mill.; Macrochloa tenaccisima (L.) Kunth; Rosmarinus officinalis	Aridisol	Loam
Yeste	Burnt	17	Pinus halepensis Mill.; Rosmarinus officinalis L., Brachypodium retusum	Inceptisol	Loam
	Unburnt	70-80	Pinus halepensis Mill.; Rosmarinus officinalis L., Brachypodium retusum	Inceptisol	Clay loam

*Ph: Aleppo pine; T: soil temperature (mean ± standard error) during the sampling period; H: soil moisture (mean ± standard error) during the sampling period.

Table-2. Soil physicochemical parameters for each site and experimental condition.

Site	Fire	pH	Electrical conductivity (µS cm-1)	Organic matter (%)	Total carbonates (%)	P (mg kg-1)	Total N (%)	C/N
Calasparra	Burnt	8.7 Aa	20.7 Aa	5.8 Aa	2.4 Aa	12.0 Aa	0.1 Aa	68.1 Aa
	Unburnt	8.4 Aa	23.5 Aa	5.3 Ab	1.9 Ab	17.0 Aa	0.2 Aa	43.9 Aa
Yeste	Burnt	8.1 Ba	21.0 Aa	8.7 Ba	2.9 Ba	21.1 Ba	1.0 Ba	15.4 Ba
	Unburnt	8.4 Ba	21.9 Aa	6.4 Bb	2.9 Bb	20.6 Ba	0.8 Ba	33.0 Ba

For each parameter, the values represent the mean (standard error). The data followed by the same small letter are not significantly different according to the LSD test ($P<0.05$) for each experimental condition. For each experimental site, the data followed by the same capital letter are not significantly different according to the LSD test ($P<0.05$).

Table-3. Results of the two-factor ANOVA (site and fire) for microbiological properties and microbiological ratios.

	Respiration		Biomass carbon		qCO_2		MBC / TOC	
	F-ratio	P-value	F-ratio	P-value	F-ratio	P-value	F-ratio	P-value
Factors								
S	13.85	0.0008	4.04	0.0499	1.22	0.2781	0	0.9512
I	2.38	0.1327	0.17	0.6796	0.08	0.7817	3.09	0.0884
S x I	0	0.9867	0.04	0.8367	0.11	0.7439	0.02	0.8763

S: Site; I: Fire; S x I: interaction between S and I.

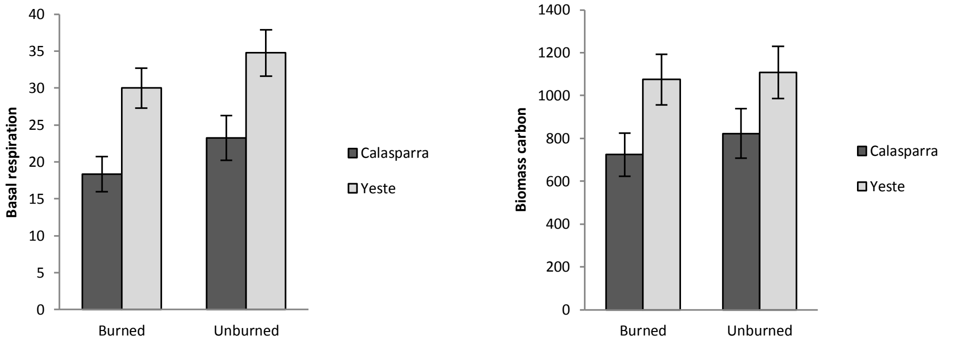

Figure-1. Soil respiration (mg CO_2 kg−1 soil) and microbial biomass carbon (mg kg−1) in relation to experimental site. Error bars are the LSD intervals at $P < 0.05$.

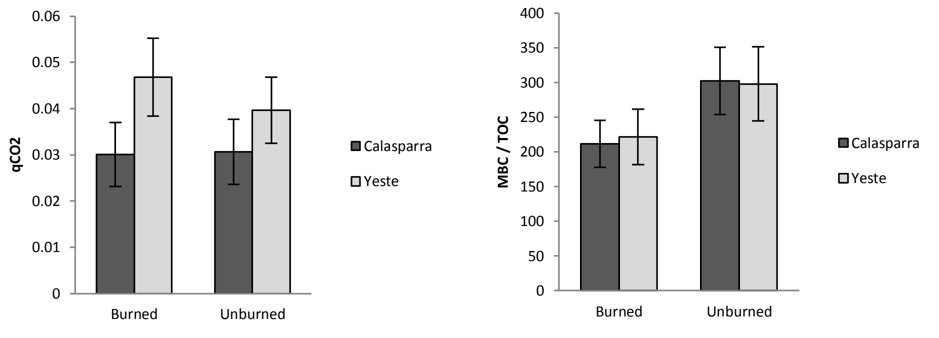

Figure-2. qCO_2 ratio and biomass carbon / total organic carbon. Error bars are the LSD intervals at $P < 0.05$.