

Aggregation of under canopy and bare soils in a Mediterranean environment affected by different fire intensities

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21 8 **Abstract**
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25 10 Soil macroaggregation in relation to soil organic matter (SOM) and calcium
26 11 carbonate (CaCO_3) content was studied, before and after experimental fires of different
27 12 intensities, in two environments (under canopy and on bare soil). In 1995, two
28 13 experimental fire treatments, based on the addition of different biomass amounts, were
29 14 applied on a set of nine plots at the Permanent Field Station of La Concordia (Valencia,
30 15 Spain). Three plots were burned with high intensity fire (T1), three with moderate
31 16 intensity (T2) and three plots were left unburned to be used as control treatment (T3).
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34 17 Soils under canopy were characterized by higher macroaggregate stability (SMS),
35 18 SOM content and mean weight diameter of aggregates (MWD) than bare soils, which
36 19 presented higher CaCO_3 contents.
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39 20 After the fires, tendencies to increase were observed in the SOM and SMS of all
40 21 burned soils, probably because of the incorporation of partially burned plant material.
41 22 The trends of SMS and SOM in T1 burned soils were towards to decrease with the
42 23 occurrence of the first erosive rainfalls. These trends continued until the end of the
43 24 study. MWD of under canopy soils on T1 and of soils on T2 showed a decreasing trend
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1 immediately after fire treatments. Not significant differences between sampling periods
2 were found for CaCO₃ content, with the exception of under canopy soils on T1 which
3 tended to increase, and showed higher values at the end of the studied period. The
4 differences observed initially between under canopy and bare soil disappeared after one
5 year of fire in T1, which suggests a major degradation of soils affected by this
6 treatment.

7 Significant changes of the studied properties were not observed in unburned soils
8 during one year of research. In these soils, organic matter showed significant
9 correlations with macroaggregate stability and mean weight diameter. However,
10 significant statistical relationships were not observed between the studied properties in
11 burned soils, showing that fire impact probably affected other soil characteristics related
12 to soil aggregation.

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14 **Keywords:** Macroaggregation, Soil Organic Matter, Calcium Carbonate, Mean Weight
15 Diameter, Experimental plots.

16 17 **1. Introduction**

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19 Aggregate stability is one of the key characteristics of soil resistance to post-fire
20 erosion. The most important binding agents involved in aggregation includes organic
21 matter, calcium carbonates, organo-metallic compounds, microbial mucilage, etc.
22 (Tisdall and Oades, 1982; Le Bissonnais, 1996; Boix-Fayos et al., 2001).

23 The heating of soil by fire tends to alter these agents and, therefore, the aggregate
24 stability (Giovannini et al., 1990; Kutiel and Inbar, 1993; Andreu et al., 1996; DeBano,

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5 1 2000). According to different authors (Giovannini, 1994; Pardini et al., 2004; Six et al.,
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7 2 2004), the heating of a soil up to 220°C do not modify soil characteristics significantly.
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9 3 The heating between 220°C and 460°C causes the combustion of some cementing agents
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11 4 and other organic substances in soil. Temperatures higher than 460°C during enough
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13 5 time provoke the total combustion of soil organic matter and decomposition of the
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15 6 carbonates. However, the macroaggregation can be increased through the aggregation of
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17 7 clay and silt components into sand-sized particles (Giovannini, 1994).
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21 8 The temperature thresholds reported in the literature derived almost exclusively
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23 9 from controlled laboratory experiments and prescribed fires (Giovannini and Lucchesi,
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25 10 1997; DeBano, 2000; Badia and Marti, 2003; Ubeda et al., 2005; Hubbert et al., 2006).
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27 11 Studies that measure soil temperatures reached during burning are scarce and generally
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29 12 inferring them from post-fire indicators, such as soil colour (Ketterings and Bigham,
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31 13 2000). Little is also known about the pre-fire characteristics of soil in these cases.
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34 14 To solve these problems, an approach to comprehensively study the impacts of
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36 15 two experimental fire treatments on different soil properties was developed at the
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38 16 Permanent Field Station of La Concordia in Valencia (Spain) (Rubio et al., 2003). This
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40 17 approach is in agreement with Giovannini (1994), who consider that one of the best
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42 18 ways to study the effect of fire on soil quality is through the performance of
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44 19 experimental fires.
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48 20 The objectives of this research were: (i) to asses the impact of experimental fires
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50 21 of different intensities on organic matter, calcium carbonate, and macroaggregate
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52 22 stability of a Mediterranean forest soil; and (ii) to study the possible changes and
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54 23 relations between these three parameters immediately after fires and throughout a year
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56 24 in two different soil environments, under the vegetation canopy and in bare soil.
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2. Materials and Methods

2.1. Study area

This work was carried out at the Permanent Field Station of La Concordia, in the municipality of Liria, 50 km NW of Valencia City, Spain (39°45' N and 0°43' W). The Field Station is located on a forested concave hillside with a SSE aspect, 22° of slope and an altitude around 575 m a.s.l. The terrain was ceded by the Forestry Services of the Valencian Government (Generalitat Valenciana).

Soils are classified as Rendzic Leptosol type according to the FAO-UNESCO (1988), developed on Jurassic limestones, which show variable depth, always less than 40 cm thick, high stoniness (45%) and sandy loam texture.

Mean annual precipitation of the area is 400 mm, with a maximum in autumn (51.7 mm in October) and a less rainy period in spring (34.1 mm in April). The dry period usually ranges from April or May to September, with a mean temperature of 25.8°C. The mean annual temperature is 17.2°C.

Vegetation cover is characterized by a Mediterranean shrubland that was developed after a wildfire occurred in 1978. The most abundant species before experimental fires were Rosmarinus officinalis, Ulex parviflorus, Quercus coccifera, Rhamnus lycioides, Stipa tenacissima, Globularia alypum, Cistus clusii and Thymus vulgaris.

The Permanent Field Station consists of a set of nine 80 m² erosion plots, 4 m wide by 20 m long, with similar pedological and vegetation cover characteristics. The selection of each plot location was made after intensive surveys on soil, vegetation,

1 slope angle, and surface morphology (rock outcrops and bare soil percentage) based on
2 58 transects transversal to the slope with a 2 m interval. Plots are closed, oriented
3 parallel to the slope and bounded by bricks.

4 Meteorological parameters were monitored by a logging system of sensors with
5 GSM data transmission, placed at half slope in the central part of the experimental
6 station. The rainfall parameters recorded were: total volume, rainfall intensity (I_{30}), and
7 duration of the rainfall event (D).

9 **2.2. Experimental fire design and performance**

10 In June 1995, two sets of three plots each were burned with high (T1) and
11 moderate (T2) intensity fires. The assignment of the fire treatment to each plot was
12 made at random, without blocking. To achieve these intensities, the addition of different
13 amounts of fuel load to the plots was necessary: 4 kg m⁻² for T1 and 2 kg m⁻² for T2.
14 Added biomass distribution also guaranteed the continuous progression of the fire front.
15 To maintain the same type of vegetation inside the plots, this biomass was taken from
16 the surrounding area. The remaining three plots were kept unburned to be used as the
17 control treatment (T3).

18 Temperatures on the soil surface were measured by means of thermocouples and
19 thermosensitive paints. With thermocouples, the residence time of temperatures on soil
20 was also measured. In this way, direct estimates were made of the duration of
21 temperatures higher than 100°C on the soil surface. This value was selected because
22 beyond this temperature the most relevant changes in the soil can occur (Whelan, 1995;
23 Gimeno-García et al., 2000). In each plot, six thermocouples type K Inconel 600-
24 insulated were installed at ground level along parallel lines running down the slope and

1 separated from one another by 3 m. Additionally, a set of 24 thermosensitive paints
2 (Omega Stick Crayons) ranging between 100°C and 677°C was applied on iron rods and
3 placed in each square meter of the plot to measure the maximum temperature reached.
4 Each iron rod was covered with another identical rod, not painted, to protect them from
5 ashes and flames. A total of 80 iron rods per plot were used.

6 The mean soil surface temperature reached was 439°C in T1 plots and 232°C in T2
7 plots, and temperatures higher than 100°C lasted 36 and 17 minutes for each treatment,
8 respectively, as noticed by Gimeno-García et al. (2004).

9 10 **2.3. Soil sampling and analysis**

11 Four samples per plot, two from soil under canopy and two from bare soil, were
12 taken from 0-5 cm depth (12 samples per treatment; a total of 36 samples per sampling
13 period). Samples were taken before fire, immediately after, one month, four months,
14 and one year after the fire. Samples were air-dried and screened to remove the fraction
15 higher than 2 mm diameter, and stored in plastic boxes until analysis.

16 Organic matter content was determined by the Walkley-Black method (Jackson,
17 1958). Total carbonates were measured using the Bernard calcimeter method (MAPA,
18 1986). The aggregate stability measured with a 0.25 mm diameter mesh is called
19 macroaggregate stability according to the Edward and Bremner (1967) classification
20 (microaggregates: <0.25 mm and macroaggregates: >0.25 mm). To assess this soil
21 macroaggregate stability, a wet-sieving procedure was used (Primo-Yufer and
22 Carrasco, 1973).

23 The soil was hand screened, with a sieves battery, to separate it in the following
24 aggregate size fractions: 2-1 mm, 1-0.5 mm, 0.5-0.25 mm, 0.25-0.1 mm, 0.1-0.05 mm

1 and <0.05 mm. The percentage by weight of aggregates at each fraction was used to
2 calculate the Mean Weight Diameter index (MWD) (Chaney and Swift, 1984).

3 Analysis of variance, Tukey's and t-Student's tests at $\alpha=0.05$ were performed to
4 detect differences in the studied soil characteristics. Standard statistical bivariate and
5 partial correlation analyses were applied, at 95 and 99% significance levels, between the
6 aggregate size distribution, the macroaggregate stability and the cementing agents
7 (SOM and CaCO_3).

8 9 **3. Results and Discussion**

10 11 **3.1. Soil Macroaggregate Stability (SMS)**

12 Results obtained showed that the statistically significant differences observed on
13 SMS were mainly related to the presence or absence of vegetation for all fire treatments
14 (Fig. 1). Before fires, soils under canopy presented higher SMS values (~35%) than bare
15 soils (~24%). The high stabilities measured in soils under canopy could be understood
16 as consequence of the incorporation of organic matter into the soil and its role as
17 cementing agent in a more protected environment (Tisdall and Oades, 1982; Schulten et
18 al., 1993; Amézketa, 1999).

19 Immediately after fires, SMS changes on both fire treatments were not statistically
20 significant respect to their pre-fire values (Table 1). Soils on T1 showed increasing
21 stabilities during the first post-fire month, but only statistically significant in those
22 under canopy (Fig. 1). Besides a possible incorporation of organic matter into bare soils,
23 the trend to increase measured in this environment could be, in part, related to a
24 hardening of soil aggregates, possibly due to changes on clay lattice layers or in iron

1 oxides crystallinity at temperatures higher than 220°C (Giovannini and Lucchesi, 1997;
2 Guerrero et al., 2001). Soils of both environments on T2 presented also increasing
3 trends during the first month after fire (Fig. 1).

4 The first rain events (Table 2) occurred two months after the fire could have
5 changed the SMS tendency on T1 soils. In under canopy soils on this treatment,
6 statistically significant differences were found between the SMS values of the first
7 month and one year sampling. Aggressiveness of rain events favoured erosion on these
8 soils, as was reported by Campo et al. (2006), and possibly homogenised the SMS
9 values obtained. In this treatment, four months after the fire, differences in SMS of
10 under canopy and bare soils were not found.

11 Despite the high sediment yields measured on the T2 plots (Campo et al., 2006),
12 increasing tendency registered in the SMS of soils under canopy on this treatment
13 continued until four months after the fire. It seems that rainfalls affected in a greater
14 way soils on T1 than on T2 reflecting the lower vulnerability to degradation of T2 soils.
15 The moderate fire intensity and the small variation in SOM content of soils under
16 canopy on T2 after fires (Fig. 2) could have preserved the stability of these soils
17 reducing the raindrop impact effect. Temperature reached during the moderate intensity
18 fire (232°C average) could have created an accumulation of hydrophobic substances in
19 soil, which could react stabilizing soil macroaggregates (Giovannini, 1994; Mataix-
20 Solera and Doerr, 2004).

21 Statistically significant differences in SMS were not found between under canopy
22 and bare soils on T1 four months after fire. On the other hand, on T2, despite the
23 decreasing tendency in the SMS of under canopy soils, statistically significant
24 differences between them and bare soils were detected during all the studied period.

1 One year after the beginning of the research, the unburned bare soils showed very
2 low macroaggregate stability. The aggressive 1995 autumn rains, typical of the
3 Mediterranean region, could have impacted the more stable macroaggregates of these
4 soils. The absence of vegetation cover could explain the difference of ~16% in the SMS
5 values found at the end of the study between both environments in the soils on this
6 treatment (Fig. 1).

8 **3.2. Soil Organic Matter (SOM)**

9 Trends observed for organic matter in the studied soils were similar to those
10 reported for macroaggregate stability. Differences in SOM contents were not
11 statistically significant between the fire treatments applied (Table 1), but they were
12 detected between environments (Fig. 2). Before fire, all soils under canopy presented
13 higher SOM contents (~12%) than bare soils (~9%). As mentioned above, these higher
14 contents in the soils of this environment seem to be the agent responsible for their
15 higher macroaggregate stability.

16 Changes in the SOM content of burned soils, immediately after the fires, were not
17 statistically significant (Table 1). Despite a slight decrease in the SOM of under canopy
18 soils on T1, soils in both environments on this treatment showed increased trends during
19 the first month (Fig. 2), suggesting a direct relation between SOM and SMS (Table 3).
20 This insignificant decrease could be related with combustion of SOM, according with
21 the results reported by Fernández et al. (1997), Mataix-Solera et al. (2002) and
22 González-Pérez et al. (2004) in Mediterranean and Atlantic soils burned with similar
23 treatment.

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5 1 Soils in both environments on the moderate intensity fire (T2) presented also
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7 2 increasing SOM trends during the first month. All these increasing tendencies could be
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9 3 due to incorporation of ashes and residual biomass partially burned into the soil
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11 4 (Gimeno-García et al., 2000). The organic matter content measured in these ashes was
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13 5 approximately 5% in T1 and 8.5% in T2 plots. Small changes produced by moderate
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15 6 temperatures, especially in the aromatic recalcitrant compounds (Pardini et al., 2004),
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17 7 could also help to explain this trend in T2 soils.
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21 8 Torrential rainfall events fell two months after the fire (Table 2) produced high
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23 9 sediment yields (Campo et al., 2006) and losses of SOM close to 20 g m⁻² (Gimeno-
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25 10 García et al., 2000). In the fourth month post-fire, soils of both environments on T1
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27 11 showed decreasing tendencies in their SOM content, which could be directly related
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29 12 with erosive processes.
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33 13 Increasing SOM trend, of soils under canopy on T2 soils was still observed four
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35 14 months after the fire, conversely to bare soils, in which it changed one month after. As
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37 15 mentioned before, the moderate intensity fire occurred in this treatment produced ashes
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39 16 with high organic matter content (8.5%), and its incorporation into the soil could
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41 17 explain this fact. High SOM content would help also to preserve the high SMS of this
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43 18 soil, even after raindrop impact.
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47 19 In the period between four months and one year after the fire, all burned soils
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49 20 showed decreasing trends in their SOM contents. Soil under canopy on T1 appeared to
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51 21 be the more degraded, losing approximately 40% of its initial SOM. In spite of this
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53 22 tendency to decrease, statistically significant differences were only found in the SOM
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55 23 content of bare soils on T1 between one month and one year after the fire. Organic
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1 matter of T2 soils did not show statistically significant differences during the whole
2 study period (Fig. 2).

3 SOM on control soils (T3) scarcely changed during the one year research period.
4 Bare soils on this treatment always presented the lowest contents (Fig. 2).

6 **3.3. Calcium Carbonate (CaCO₃)**

7 The studied soils showed high calcium carbonate contents (Fig. 3). Similarly to
8 the other characteristics already described, there were not statistically significant
9 differences in the CaCO₃ contents of soils between fire treatments (Table 1), but they
10 were observed between the studied environments.

11 However, the CaCO₃ content presented an opposite trend to SMS and SOM
12 because higher calcium carbonate contents were observed in bare soils (~50%) than in
13 soils under canopy (~46%). In both environments, the large soil stoniness (Jurassic
14 limestones) greatly contributed to preserve these high contents because of the
15 dissolution and re-precipitation of calcite, typical of superficial soils horizons developed
16 on carbonated rocks (Duchaufour, 1984; Dutil, 1987).

17 Immediately after the fires, the little variations measured in the CaCO₃ values of
18 burned soils were not statistically significant (Table 1). However, the difference in the
19 CaCO₃ contents found before the fire between under canopy and bare soils disappeared
20 in both fire treatments (Fig. 3). As stated by Christensen (1973), the high content on
21 alkaline metal carbonates found in ashes deposited on soil after fires could be a source
22 of CaCO₃, particularly on under canopy soils.

23 Significant changes in the CaCO₃ content of studied soils were not observed
24 during the first four months, even after the early autumn rains (Table 2).

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5 1 Only the soils under canopy on T1 showed statistically significant differences one
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7 2 year after the fire. At this time, CaCO₃ values of under canopy and bare soils were
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9 3 similar on both fire treatments. Calcium carbonate coming from ashes and the parent
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11 4 material, together with that accumulated in surface by the ascent of salts due to
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13 5 evaporation processes could be responsible of the increase.
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16 6 During the one year of research, bare soils on T3 showed always statistically
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18 7 significant differences on CaCO₃ content with respect to the under canopy soils.
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20 8 Variations registered in calcium carbonate of these soils from one sampling season to
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22 9 another were not statistically significant.
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26 10 27 28 11 **3.4. Mean Weight Diameter (MWD)** 29

30 12 Fire effects on aggregation of the burned soils were also studied through the
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32 13 analysis of their aggregate size distribution before fire and one month after it. This was
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34 14 made using the Mean Weight Diameter (MWD). Thus, before fire MWD in under
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36 15 canopy soils (0.86 mm) was significantly different of MWD in bare soils (0.68 mm).
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39 16 The higher value measured in under canopy soils is clearly explained because of
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41 17 the major presence of aggregates higher than 0.5 mm found in these soils. Similar
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43 18 results were obtained by Cammeraat and Imeson (1998) in aggregation studies carried
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45 19 out in south eastern Spain and southern France. This fact suggests a good incorporation
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47 20 of organic matter into the soil coming from the vegetation cover, and its importance in
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49 21 the formation of large size aggregates.
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52 22 In bare soils, aggregates lower than 0.5 mm was the more common fraction,
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54 23 originating lower MWD values and provoking a major degradation of these soils.
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1 Changes in the MWD of burned soils immediately after the fires were not
2 statistically significant (Fig. 4). The tendency to decrease observed in under canopy
3 soils on T1 could be related with the reduction in the mass percentage of aggregates
4 >0.5 mm. Combustion of SOM produced by the high temperatures reached in this
5 treatment (439°C average) could break the linkage between soil aggregates decreasing
6 the mass percentage of those of higher size.

7 On the contrary, bare soils on T1 presented an increasing tendency in their MWD
8 after fire. So, the difference in MWD between both environments on this treatment
9 became not significant one month after it (Fig. 4).

10 In bare soils burned with high intensity fire, some kind of re-aggregation occurred,
11 increasing mass percentages on large size aggregates (>0.5 mm). According to
12 Giovannini et al. (1990) and Molina and Sanroque (1996), re-aggregation of fine
13 particles is possible at temperatures higher than 220°C. This is likely due to dehydration
14 of soil gels and transformations of the cementing Fe and Al oxides.

15 This hypothesis could also be confirmed with the results obtained by González-
16 Pelayo et al. (2006) who found, in another research developed also in the Permanent
17 Field Station of “La Concordia”, that soils burned with high intensity fire showed
18 values of soil water content at pF 2 significantly higher than those soils unburned or
19 burned with moderate intensity. These authors argued according with Ingelmo et al.
20 (2000) and Kay and VandenBygaart (2002), that water retained at pF 2 is gravitational
21 water adhered to soil particles by cohesion and capillary forces. Thus, the soil water
22 content increase at this pF was probably held in the pores between sand-sized particles
23 associated with the re-aggregation of clay-sized particles.

1 The moderate temperatures reached in the T2 treatment did not produce significant
2 changes in the MWD of soils. However, statistical significant differences between
3 environments were still observed in the soils on this treatment (Fig. 4).

4 Four months after the fire, aggregate size distribution of all burned soils showed
5 trends to decrease in the mass percentage of large aggregates. Differences in the MWD
6 of soils on T1 were statistically significant under canopy, and non significant for the
7 bare soils. As stated before, the presence of hardened aggregates with high
8 macroaggregate stability in these bare soils could explain this fact. MWD reduction of
9 25% measured in the soils under canopy on T1 confirms their degradation (Fig. 4).
10 Significant differences in MWD between environments on this treatment were not
11 found.

12 Mean weight diameter of bare soils on T2 four months after the fire was lower
13 than before it. The tendency to decrease in the MWD of under canopy soils was still
14 noticeable, but the difference in respect of previous periods was not statistically
15 significant.

16 Erosive rains that fell in early autumn (Table 2) could be the factor responsible of
17 the trends observed in the MWD of all burned soils. These events could have caused the
18 breakdown of less stable macroaggregates, increasing the presence of those of lower
19 size (Le Bissonnais, 1996; Barthes and Roose, 2002). Imeson et al. (1992), who studied
20 the aggregation processes on a Mediterranean forest soil, suggested that unless the
21 burned soil between plants can be relatively rapidly covered, soil aggregates could
22 degrade into poorly aggregated finer material.

23 At the end of the research, the aggregate size distribution of soils under canopy on
24 T1 was similar to the distribution measured four months after the fire. The MWD of this

1 soil was still lower than at the beginning of the study (Fig. 4). In bare soils on T1,
2 MWD continued decreasing, but, statistical differences were not found between periods.
3 Both environments on this treatment presented similar MWD values one year after the
4 fire. Under canopy soils on T1 and T2 showed lower MWD than before the fire.

5 Significant changes were not measured in the MWD of the unburned soils during
6 the whole studied period, suggesting that variations in the structure of these soils under
7 natural conditions could be considered minimal.

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9 **3.5. Relationships between the aggregate characteristics and its cementing agents**

10 Correlation analyses between the aggregating agents (SOM and CaCO₃) and the
11 size distribution and stability of macroaggregates (MWD and SMS) were made for each
12 treatment (Table 3). Relationships between them in unburned soils were compared with
13 those of burned soils to study the possible changes produced by the fires in the
14 aggregation of the soils studied.

15 Significant correlation coefficients at $p < 0.01$ between SMS and MWD were
16 obtained in burned as well as in unburned soils (Table 3). This result was expected
17 because, generally, the higher the stability of a soil the higher the mean diameter of its
18 aggregates.

19 In unburned soils, increases in organic matter content were much related to the
20 rise in macroaggregate stability. The significant correlations of SOM with SMS and
21 MWD confirm the importance of organic matter in the formation and stabilization of
22 large size aggregates in these soils.

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5 1 After the fires impact, the SOM role as binding agent of soil macroaggregates is
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7 2 less clear. Only in the soils burned with high fire intensity, organic matter was
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9 3 positively correlated with macroaggregate stability.

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11 4 A negative relationship between CaCO_3 and SOM was found in all studied soils
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13 5 (Table 3). Correlation analyses between CaCO_3 and SMS showed significant negative
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15 6 coefficients in T3 and T1 soils. As this negative correlation could be due to the
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17 7 interaction of the negative relationship between SOM and CaCO_3 , partial correlation
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19 8 analyses between SMS and MWD with CaCO_3 controlling the effect of SOM were
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21 9 done.

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25 10 The partial correlation analyses confirmed that the negative relationships found
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27 11 between SMS and CaCO_3 , and between MWD and CaCO_3 were highly related to the
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29 12 SOM interaction. In the table 3 can be observed that the significant correlation
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31 13 disappeared when the partial correlation analysis is done (Pearson correlation
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33 14 coefficients in parentheses). It seems that calcium carbonate effect in the binding of
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35 15 macroaggregates in the studied soils, burned and unburned, is minimal.

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39 16 In agreement with the results, organic matter content appears to drive the
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41 17 aggregation of the unburned soils of this work. According to Boix-Fayos et al. (2001),
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43 18 the stability of macroaggregates in soils of the Southeast of Spain is dependent of the
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45 19 organic matter when its content is greater than 5 or 6%. Below this threshold, the
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47 20 aggregate stability is more dependent of the calcium carbonate content.

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50 21 In this study, the binding agents responsible of the macroaggregate stabilization of
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52 22 burned soils were not clearly identified. However, soils on T1 and T2 showed similar
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54 23 trends in the evolution of their SMS and SOM contents, which were different to their
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56 24 CaCO_3 content tendency. Thus, in burned soils with high organic matter content, this
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1 agent appears to be more important in the binding of soil macroaggregates than calcium
2 carbonate.

3 4 **4. Conclusions**

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6 In general, before the fire, soils under canopy presented higher SOM contents,
7 MWD (aggregates >0.5 mm) and stability than bare soils. Aggregates <0.5 mm were the
8 dominant fraction in bare soils, which showed lower MWD, SOM and stabilities but
9 higher calcium carbonate contents.

10 Scarce changes in the studied properties were observed immediately after the fires,
11 and they were not statistically significant. During the first month after them, organic
12 matter tended to increase in all studied soils, which can be attributed to the
13 incorporation of partially burned material with high organic matter content.

14 Under canopy, soils affected by high intensity fire showed the highest SMS one
15 month after, whereas only scarce changes on SMS and MWD were observed in bare
16 soils. In the moderate intensity treatment, both environments showed similar trends, but
17 statistical significant variations in SMS and SOM were not found. First high intensity
18 rainfalls after fire could have caused the change in the SMS and SOM tendencies of all
19 studied soils, related probably with the break down of high size aggregates as showed
20 the MWD decreasing trends.

21 The decreasing trends on MWD, SOM and SMS and the increase in CaCO₃ of the
22 soils affected by the high intensity treatment provoked that, one year after the fire
23 experiment, the statistical significant differences existing in all the studied properties

1 between environments on this treatment disappeared, which can be interpreted as soil
2 degradation since the values in under canopy soils were always higher than in bare soils.

3 According with the results obtained, in the Mediterranean forest soils, the presence
4 of vegetation contributes to increase the soil organic matter content that, usually,
5 favours the increase in macroaggregate stability and aggregates size. Even after the
6 impact of fires of different intensities, SOM seems to be the main binding agent of soil
7 macroaggregates, and the role of CaCO₃ on that could be not relevant.

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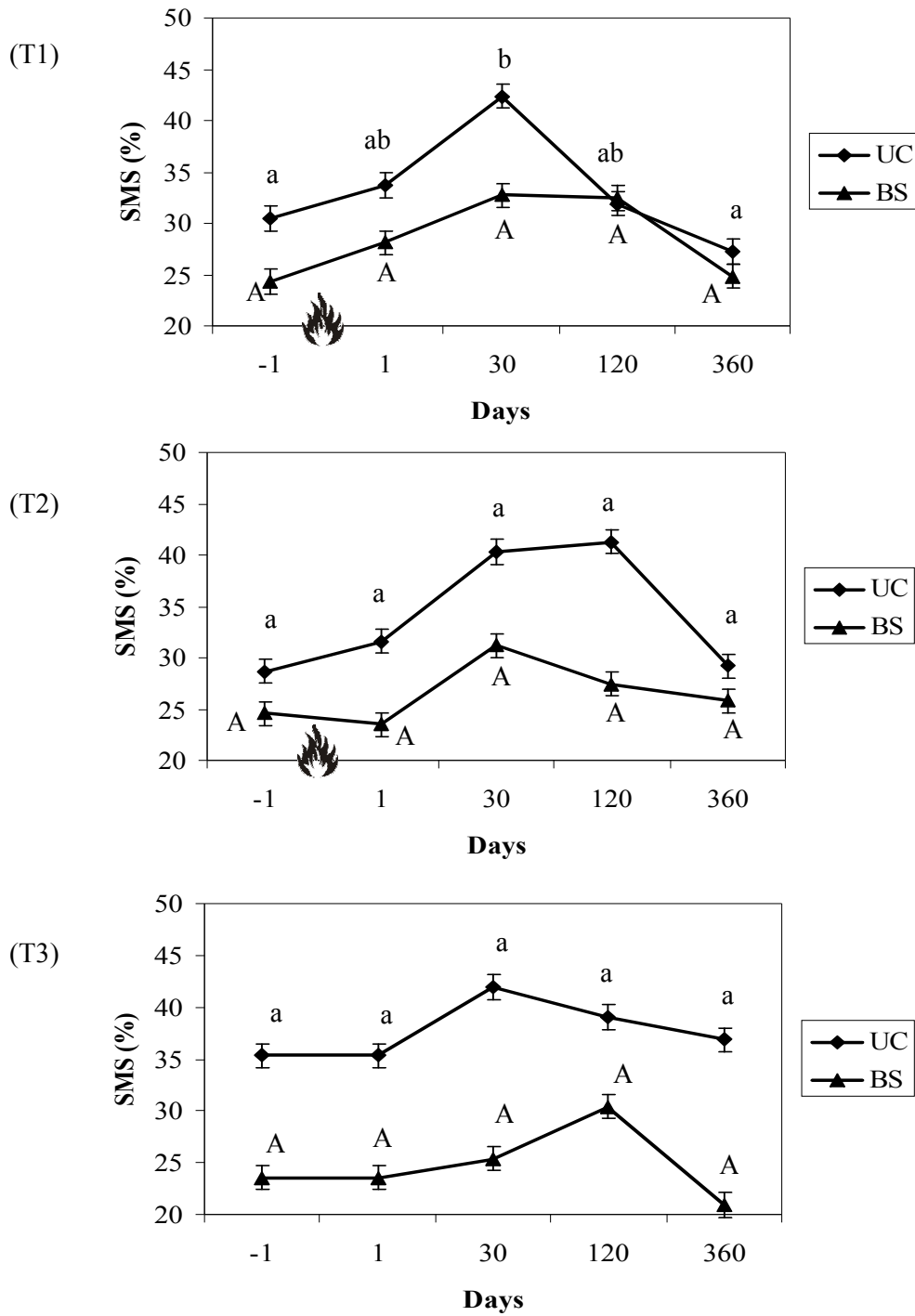


Fig. 1. Mean Soil Macroaggregate Stability (SMS) for under canopy soil (UC) and bare soil (BS) by treatment: (T1) high fire intensity, (T2) moderate fire intensity and (T3) unburned. Standard errors in bars show significant differences between environments. Different letters indicate significant differences between each studied period (lower case letters are used for under canopy soil data and upper case letters for bare soil data). Time in days is measured respect to the day of the experimental fire

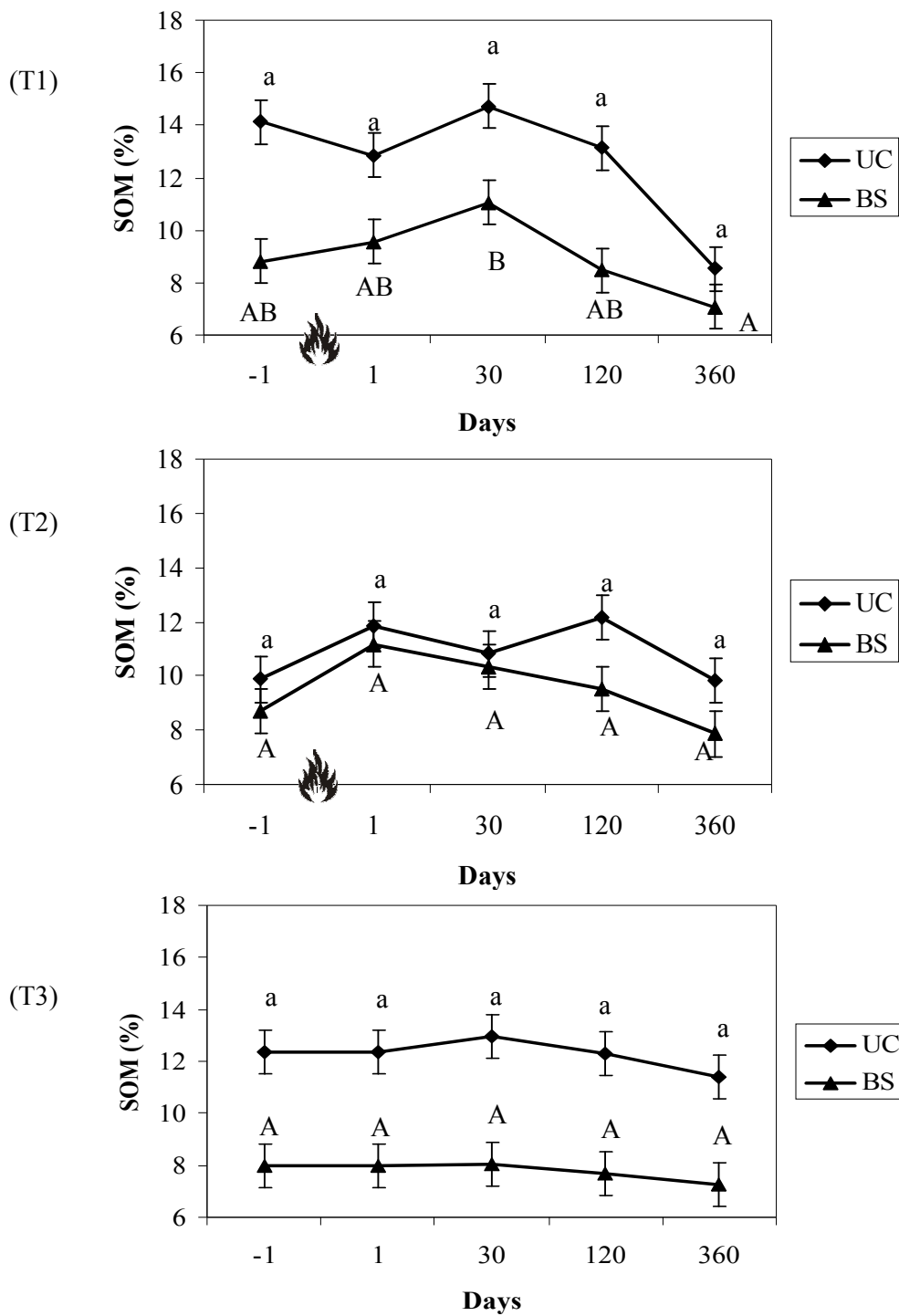


Fig. 2. Mean Soil Organic Matter (SOM) for under canopy soil (UC) and bare soil (BS) by treatment: (T1) high fire intensity, (T2) moderate fire intensity and (T3) unburned. Standard errors in bars show significant differences between environments. Different letters indicate significant differences between each studied period (lower case letters are used for under canopy soil data and upper case letters for bare soil data). Time in days is measured respect to the day of the experimental fire

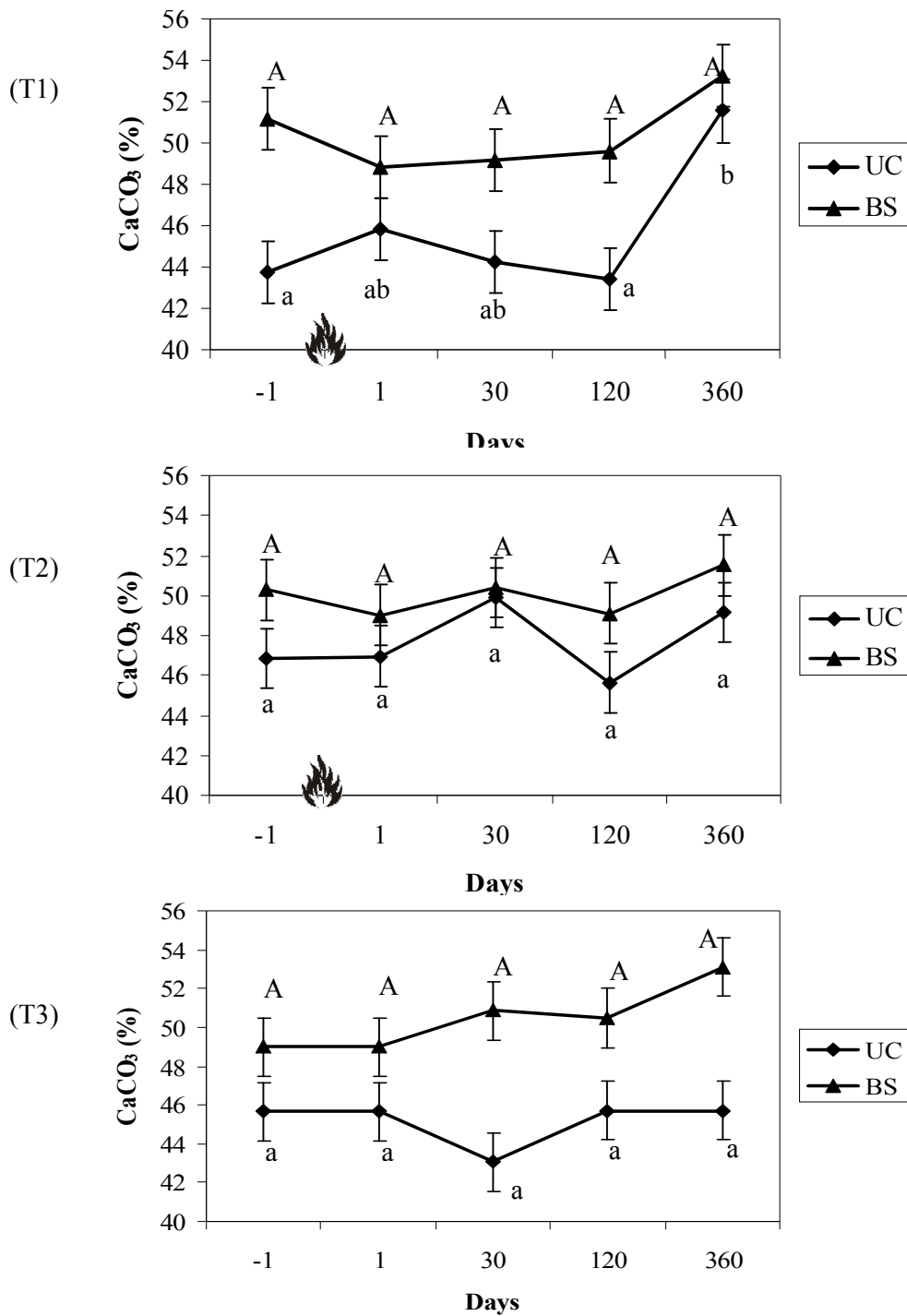


Fig. 3. Mean Calcium Carbonate Content (CaCO₃) for under canopy soil (UC) and bare soil (BS) by treatment: (T1) high fire intensity, (T2) moderate fire intensity and (T3) unburned. Standard errors in bars show significant differences between environments. Different letters indicate significant differences between each studied period (lower case letters are used for under canopy soil data and upper case letters for bare soil data). Time in days is measured respect to the day of the experimental fire

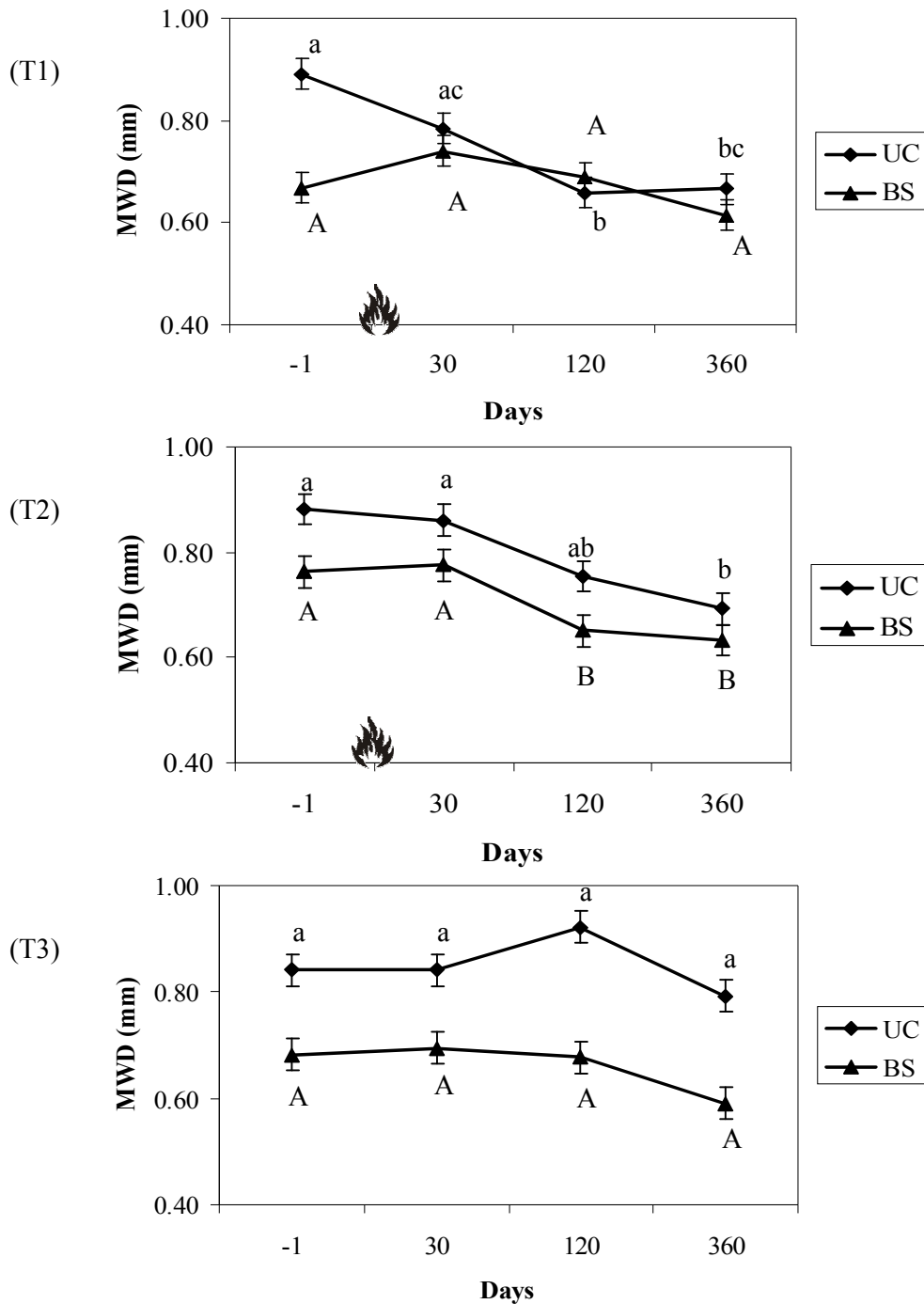


Fig. 4. Mean Weight Diameter (MWD) for under canopy soil (UC) and bare soil (BS) by treatment: (T1) high fire intensity, (T2) moderate fire intensity and (T3) unburned. Standard errors in bars show significant differences between environments. Different letters indicate significant differences between each studied period (lower case letters are used for under canopy soil data and upper case letters for bare soil data). Time in days is measured respect to the day of the experimental fire

Table 1. Mean values of soil macroaggregate stability (SMS), soil organic matter (SOM), and calcium carbonate (CaCO₃) in high (T1) and moderate (T2) fire intensity treatments, and in unburned soils (T3). n=12 samples per treatment

	Time ¹ (days)	T1	T2	T3
SMS (%)	-1	27.38 ^a	26.62 ^a	29.43 ^a
	1	30.91 ^a	27.53 ^a	29.43 ^a
	30	37.55 ^a	35.76 ^a	33.66 ^a
	120	31.95 ^a	34.36 ^a	33.88 ^a
	360	26.01 ^a	27.84 ^a	28.90 ^a
SOM (%)	-1	11.47 ^a	9.29 ^a	10.15 ^a
	1	11.22 ^a	11.52 ^a	10.15 ^a
	30	12.90 ^a	10.57 ^a	10.51 ^a
	120	10.81 ^a	10.84 ^a	10.00 ^a
	360	7.80 ^a	8.85 ^a	9.32 ^a
CaCO ₃ (%)	-1	47.47 ^a	48.56 ^a	47.33 ^a
	1	47.34 ^a	47.98 ^a	47.33 ^a
	30	46.71 ^a	50.15 ^a	46.96 ^a
	120	46.51 ^a	47.37 ^a	48.10 ^a
	360	52.39 ^a	50.34 ^a	49.41 ^a
MWD (mm)	-1	0.78 ^a	0.82 ^a	0.76 ^a
	30	0.76 ^a	0.82 ^a	0.77 ^a
	120	0.67 ^a	0.70 ^b	0.80 ^a
	360	0.64 ^a	0.66 ^b	0.69 ^a

¹ Time in days is measured from the day of the experimental fire

^{a, b} Values with the same superscript letter indicate no statistically significant differences between fire treatments detected by Tukey's test ($p < 0.05$), in each studied period

Table 2. Erosive rain events occurred after the 1995 fire at the Permanent Field Station of La Concordia

Date	Days after fires	Rain (mm)	Duration (minutes)	I_{30} (mm h ⁻¹)
23 August	64	26.26	90	20.80
31 August	72	9.36	285	14.56
18 September	90	7.54	135	10.92
18 September	90	18.72	95	35.36
4 October	106	22.62	280	22.40
11 November	144	4.42	240	1.60
25 November	158	2.60	30	5.20
29 November	162	3.38	75	4.16

Table 3. Pearson's correlation coefficients obtained between soil organic matter (SOM), calcium carbonate (CaCO₃), soil macroaggregate stability (SMS), mean weight diameter (MWD), in high (T1) and moderate (T2) fire intensity treatments and in unburned soils (T3). n=12 samples per treatment in each sampling period. Partial correlation coefficients obtained between CaCO₃, SMS and MWD with SOM as control variable are shown in parentheses

		SOM	CaCO ₃	SMS	MWD
T1	SOM	1			
	CaCO ₃	-0.62**	1		
	SMS	0.50*	-0.51* (-0.30)	1	
	MWD	0.24	-0.39 (-0.33)	0.67**	1
T2	SOM	1			
	CaCO ₃	-0.60**	1		
	SMS	0.21	-0.26 (-0.16)	1	
	MWD	0.37	-0.03 (0.23)	0.71**	1
T3	SOM	1			
	CaCO ₃	-0.76**	1		
	SMS	0.75**	-0.69** (-0.27)	1	
	MWD	0.60**	-0.59** (-0.32)	0.71**	1

** Significant correlation at p<0.01

* Significant correlation at p<0.05