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EFFECTS OF SLASHBURNING ON SOME SOIL PHYSICAL PROPERTIES IN AN OLM-OAK COPPICE

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ABSTRACT

The aims of this paper is to report the effects of an induced forest fire on certain physical properties of an olm-oak coppice soil (a Typic Xerochrept with > 60% coarse fragments, a pH = 6.2, more than 20% clay and more than 20% organic matter in fine earth of surface horizon). The effects of experimental fire upon aggregate stability and water retention was studied in samples from A1 horizons in two different cases: i) Under laboratory conditions, where temperature (up to 300 °C) and heat can be controlled; ii) under real slashburning; the evolution of certain soil physical parameters was monitores for a year after fire. The use of controlled soil experiments on plots and simultaneous experiments in laboratory conditions permitted the differentiation of the effects of heating on the structure from those of the seasonal evolution during the year.

Key words: Aggregate stability, Soil heating, Water repellency, Water retention, Soil structure.

RESUMEN

El propósito de este trabajo es presentar los efectos de un incendio forestal provocado sobre algunas propiedades físicas de un suelo de robledal (un Typic Xerochrept con más del 60% de fragmentos gruesos, un pH de 6.2, más del 20 % de arcilla y más del 20 % de materia orgánica en la materia fina del horizonte superficial). El efecto del fuego experimental en la estabilidad de los agregados y en la retención hídrica ha sido estudiado en muestreos de los horizontes A1 en dos casos diferentes: i) Bajo condiciones de laboratorio, donde la temperatura (más de 300 °C) y el calor pueden ser controlados; ii) bajo quema real; la evolución de algunos parámetros físicos del suelo se ha seguido durante un año después del fuego. El uso de experiencias controladas en parcelas y experiencias simultáneas en condiciones de laboratorio ha permitido diferenciar los efectos del calor sobre la estructura de los de la evolución estacional a lo largo del año.

Palabras clave: Estabilidad de agregados, Quema del suelo, Repelencia hídrica, Retención hídrica, Estructura edáfica.

Influences of forest fires on the physical properties of soil have been reported in the literature (De Bano *et al.*, 1979; Giovannini *et al.*, 1987; Díaz-Fierros *et al.*, 1990) and they agree that in general water repellency and aggregate stability are the most important physical parameters of soil that can be modified by fire. These properties are closely related to other important properties, such as water movement. It is expected that forest fire increases soil erosion processes (De Bano, 1981).

It is hard to summarize the effects produced by fire, because characteristics of soil and soil-water conditions previous to fire control the kind of effects of forest fire on soil (Wells *et al.*, 1979).

The extension and depth of these effects depend also on the total cnergy released by the forest fire: fire intensity and fire residence time. Normally fire intensity can not be directly measure, and so fire temperature is often used. If soil fire is intense enough it will produce direct effects on soil physical properties but only in the top centimetres of mineral soil (Walker *et al.*, 1986). So there is no agreement about the basics aspects of the effects of forest fires on soil physical characteristics, and its magnitude.

It is very difficult to control fire intensity and fire residence time in situ due to of irregular fuel distribution and climatic conditions. Consequently, heating programs in laboratory simulation have been used to control inputs of heat and to measure the influence of temperature on soil properties (Giovannini *et al.*, 1988).

The aim of this paper is to study the effects of fire and temperature on soil structure and on soil-water relationships, in mediterranean forest soil. As field conditions can present a very large lateral variability an experimental study has been designed to ascertain the effecto of temperature on a forest soil under laboratory conditions.

In addition the evolution of the above mentioned effects was monitored for one year after a controlled fire under field conditions.

1. Materials and methods

An experiment with controlled fire in experimental plots was carried out in an olm-oak coppice in the Prades region (NW Spain). This field experiment was reported in Alcañiz *et al.*,1991).

The soil is a Typic Xerochrept, loamy-skeletal, micaceous, developed over schists, siliceous sandstones and microconglomerates. Morphological and physico-chemical characteristics are given in Table 1. This forest soil has a continuous layer of litter up to 7 cm thick, formed by the L horizon (1.5-2 cm thick), the F horizon (1.5 cm thick) and one H horizon (2.5-3 cm thick).

A complementary experiment to assess temperature effects was carried out under laboratory conditions using soil material coming from the A1 horizons of the same plots.

Table 1a. Analytical data of a representative soil of Prades Mountain region

Depth cm	Hor.	Coarse sand %	Fine sand %	Silt %	Clay %	Coarse frag. %
0-2.5	O	23.07	18.55	23.75	26.25	59.70
2.5-30	A	19.45	33.65	10.50	18.25	73.40
30-55	Bw	38.95	25.90	22.25	10.90	91.90

Tabla 1b. Analytical data of a representative soil of Prades Mountain region

Depth cm	Organic C %	pH water (1/2.5)	pH KCl (1/2.5)	EC25(1/5) dS/m	ECC cmol $_c$ /kg
0-2.5	14.33	6.2	5.6	0.46	23.0
2.5-30	1.01	4.8	3.9	0.41	15.2
30-55	0.72	4.9	4.0	0.27	9.1

2. Sampling

Three kinds of samples were taken. The first sample was taken for control measurements of the top-soil physical properties. This specific sample was taken on the control and on the burned plot in November 1989 and was prepared mixing 4 individual samples from 0 to 2 cm depth of mineral topsoil. The sample was air-dried and a part was sieved through 2 mm.

A second sampling was taken in May 1990 to obtain an homogenous sample for the heating simulation program in laboratory conditions. The sample was taken from 0 to 2 cm deep in the mineral soil. An air-dried sample was sieved through 2 mm and divided in five equal subsamples, which were used in simulation program.

Other composite samples were taken in both control and experimental plots, to assess top-soil monitoring changes in soil properties during the first year. For each sampling time one composite sample of mineral top-soil (0 to 5 cm depth) in both control and experimental plots were taken. Each sample was obtained from 6 sampling sites chosen at random. The sample was made by mixing a part of each subsample previously sieved through 2 mm.

The first year after the fire three sampling periods were chosen: November 1988 (8 days after fire), May 1989 (203 days after fire) and November 1989 (371 days after fire). Another composite sample had been taken in August 1988 (68 days before the fire). This sample was used to measure physical properties before the fire experiment.

3. Laboratory simulation program

Four of the five subsamples collected in May 1990 were introduced for 30 minutes in an oven at 50°C, 100°C, 200°C and 300°C respectively. The fifth subsample was taken as a control. Samples were weighed before and after being placed in the oven.

4. Analytical methods

All samples were tested for aggregate size distribution, soil instability test, drop test, waterdrop penetration time, field capacity and permanent wilting point.

The aggregate size distribution was measured carefully sieving the sample following Kemper & Roseneau (1986) with a Fritsch automatic sieving device for 5 minutes at an intensity of 6. As the sample had not previously been sieved, stones were removed before weighing. Sieves used were 20, 4, 2, 1, 0.5, 0.25 and 0.125 mm. Results are expressed as dry meanweight diameter (DMWD). This test was done with samples coming from both the control and the experimental plot. Measurements were carried out in two replicate samples from plots and in four replicates for laboratory simulation.

Water instability test (Is) for aggregate stability determination was carried out following Henin *et al.*, 1969. Aggregate stability was measured by water sieving. For slaking, dry aggregates (<2 mm) were immersed quickly in water (Rw). Two pretreatments of samples in alcohol (Re) and in benzene (Rb) emphasized the importance of cohesion forces and organic matter in aggregate stability. Results are expressed as percentage of resistant aggregates. Three replicates were made for each sample.

Water drop impact test (WDI) water drops fall on an aggregate and the stability at the moment of impact is measured (Grieve, 1979, lightly modified: aggregates were not pre-wetted). For each sample twenty dry aggregates of between 4 and 5 mm were selected. 150 drops (0.1 g with from 1 m height and 1 drop/sec) were allowed to fall on each aggregate. Results are expressed as percentage of unbroken aggregates.

Water repellency was measured by counting the time that a water drop took to be adsorbed into the soil (WDPT). Fifty replicates were made. Water repellency is classified by De Bano (1981) as: lower than 6 seconds, wettable; between 6 and 60 sec., slightly water repellent; between 60 and 600 sec., moderately water repellent; and over 600 sec., extremely water repellent.

Field capacity (FC) and wilting point (WP) were measured following the usual procedure (Kemper & Roseneau, 1986). Results are expressed as percent of soil water content at -0.03 and -1.5 MPa water potential. Two replicates were made. The energy with which water was retained was related to pore diameter, so FC and PWP can be related to the porosity characteristics. According to Kay (1990) water is retained with a potential of less than -1.5 MPa in micropores (diameter minor than 0.2 microns) and it is retained in mesopores (diameter minor than 30 microns) with a potential of less than -33 kPa.

5. Results and discussion

Effects of soil heating are reported in the tables and figures. The effect can be noted in the way in which heat and/or combustion influence the soil structure and modify the parameters Rw, Re, DMWD, WDI as well as the differences Re-Rw and Re-Rb. Parameters Rb and WDPT are also affected, but as they are more related to hydrophobicity they will be discussed later.

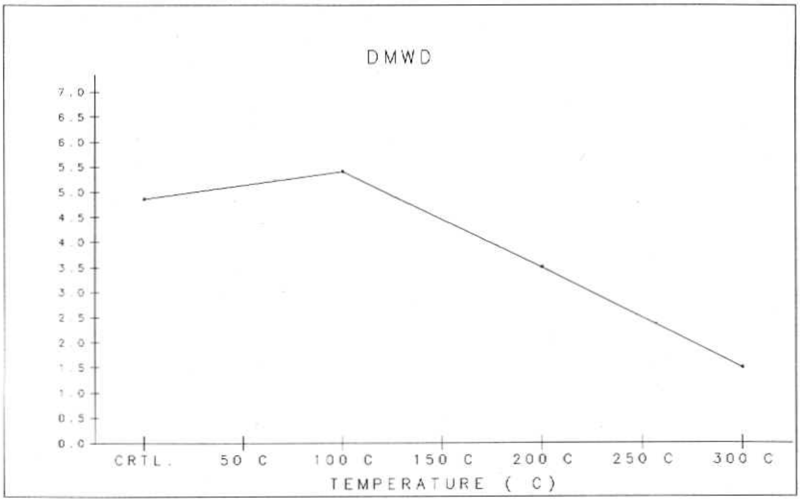

Figure 1. Effect of heating on DMWD of soil samples submited to a simulation program

Results from simulated soil heating in laboratory conditions indicate that aggregate sizes significantly decrease when temperature increases (Fig. 1). DMWD decreases to one third of its initial value when the sample is exposed to 300 °C (the value decrease is already significant after 200 °C). Nevertheless, this decrease in DMWD is not enough to differentiate, in the field work, between the samples of the control plot from those heated one year after the fire. Only with a larger number of surface samples (Table 2) can some non-significant difference be found.

Table 2. Results of top-soil analyses. Analytical results of 0-2 cm samples of control and burned plots. Samples were collected in Nov. 89 (one year after of fire experiment).

Plot	DMWD	WDI %	Is	Rw %	Re %	Rb %	WDPT sec.
Depth 0-5 cm							
Control	2.25	91.7	<1	63.6	65.4	71.9*a	23.37*a
Burned	2.26	93.5	<1	64.3	61.7	65.0*b	9.20*b
Depth 0-2 cm							
Control	3.51	67.8*a	<1	72.0	71.8	74.5	0.80*a
Burned	2.46	91.5*b	<1	70.0	70.5	69.8	5.20*b

*: are significative differences only between plots

Increase in temperature creates a higher fragility in larger aggregates under dry conditions, causing their breakdown into smaller fragments, which are more likely to be eroded. This fact is corroborated by the erosion data from Guerlach channels obtained by Soler (1991): meanweight diameters of aggregates is somewhat larger in the control plot (1.71) than in the burnt plot (1.11). The total amount of the sediment during the whole period is 308.48 g and 7017.92 g respectively.

The general aggregate instability index (Is) is in all instances below 1 (Table 3), indicating good stability overall (Henin et *al.*, 1969) both before and after thermic treatments. These results agree with the drop test results: 90% of aggregates between 4 and 5 mm in diameter are resistant to the impact of 150 water drops (index WDI). Only after the higher temperature treatment is a significant reduction obtained (Figure 2). Like the parameter DWMD, the WDI is not of great importance when observing the samples after a year. The samples from the control plot at 0-2 cm present similar values as the samples treated at 300 °C, while samples from the burnt plot have values close to 90% (Table 2).

The percentage of stable aggregates after a fast immersion in water, using samples previously treated with different polar liquids, provides information about the characteristics of the cementing agents as shown in this particular case, where the effects of the temperature are studied. The high Rw values in the control samples indicate that the cementing agents are neither soluble in water (salts or soluble organic components) nor dispersible under large amounts of water (Rengasamy *et al.*, 1984).

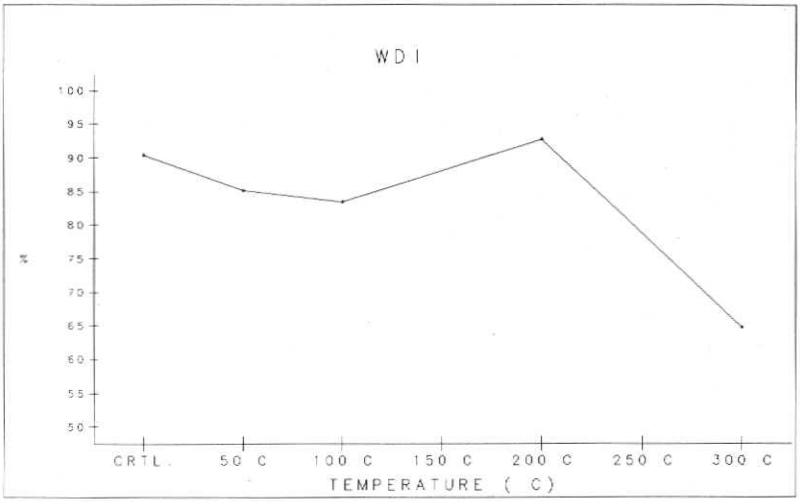

Figure 2. Effect of heating on water drop impact test (WDI) of soil samples submited to heating simulation under laboratory conditions.

Alcohol pretreatment, which obliterates the slaking effect, allows the evaluation of the cohesive forces after wetting. Values near zero in the Re-Rw difference indicate that aggregates have a high resistance to slaking (Henin *et al.*,. 1969). Results obtained both from laboratory simulations and in field conditions (Figure 3 and Table 4) indicate that there is no notable variation in the cohesive forces resulting from temperature treatment during the year following the fire: Rw and Re remain stable during the period measured.

Table 3. Results of laboratory simulation experience. Is instability index (Henin et al., 1967) and stable aggregate differences between alcohol (Re), water (Rw) an benzene (Rb) treatements, (AWC) available water capacity.

Temperature	Is	(Re-Rw)	(Re-Rb)	AWC
Control	<1	4.5	2.8	21.04
50°C	<1	2.7	2.0	20.88
100°C	<1	0.1	-4.5	18.55
200°C	<1	0.3	-19.8	19.98
300°C	<1	5.2	-14.0	24.92

According to the aggregation model of Emerson, organic matter and mineral colloids act as cementing agents of mineral grains. Positive correlations have been found between the percentage of stable aggregates and organic matter content (Tisdal & Oades, 1980), with non-humified organic matter (Combeau & Quantin, 1964) and in the presence of longchain aliphatic compounds (Dinel *et al.*, 1991). According to the latter authors, the Re-Rb difference can also be used to distinguish between the structure stabilizing agents. In our samples, this difference is not remarkable, except for the shift from positive to negative which takes place after 100 °C.

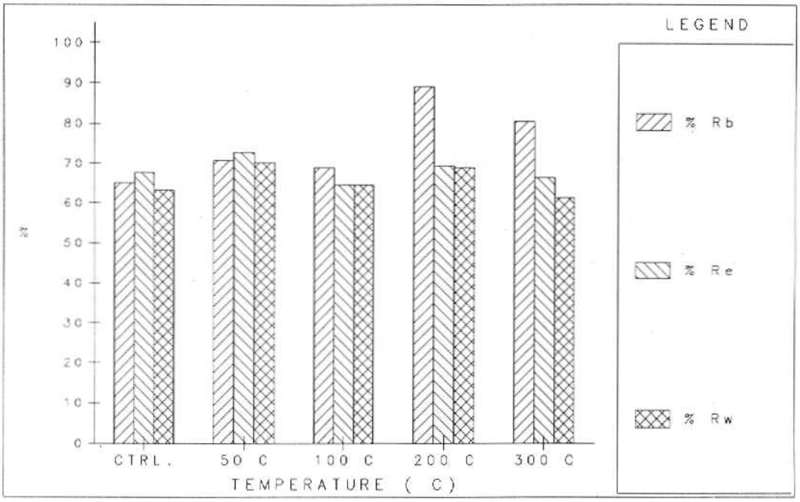

Figure 3. Effect of heating temperature on the stability of aggregate after benzene (Rb), alcohol (Re) an water (Rw) treatements

Other authors have found that organic matter contributes to the production of more hydrophobic aggregates, which are consequently more resistant to dispersion (Monnier, 1965). Affinity of these hydrophobic compounds to benzene has been shown by Giovannini & Lucchesi (1983). De Bano (1981) suggested that these compounds are frequently aliphatic hydrocarbons.

Savage *et al.*, (1969) and Ma'shun *et al.* (1988) report that these substances can coat mineral grains. During benzene pretreatment the presence of this kind of compound contributes to the coating of the aggregates with a hydrofuge layer which protects them even more.

In the WDPT test the control sample is moderately repellent to water because the WDPT index is longer than 6 sec. (Krames & De Bano, 1965), which is the threshold value for hydrophobicity. The natural hydrophobicity in forest soils has already been shown by Scholl (1971) and Giovannini *et al.*, (1982).

Table 4. Results of field experience in control and burned plots. Effect of fire treatement on stable aggregates (Is, Rw, and Re) during the period one year after fire.

Date	Is	Rw	Re	Date	Is	Rw	Re
AUG-88				**MAY-89**			
Control	<1	64.8	67.6	Control	<1	64.9	64.0
				Burned	<1	60.0	64.6
NOV-88				**NOV-89**			
Control	<1	62.5	61.5	Control	<1	63.6	65.4
Burned	<1	66.4	64.9	Burned	<1	64.3	61.7

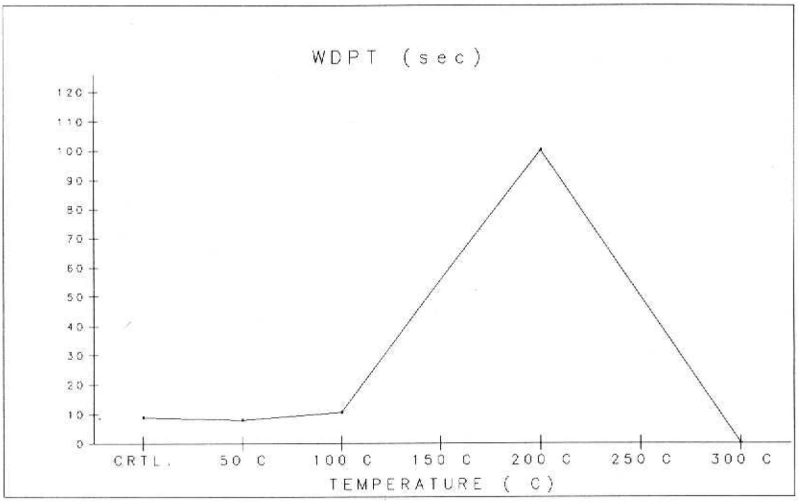

Figure 4. Water drop penetration test (WDPT) showing the temperature effect on soil samples

The thermic treatment (Figure 4) produces important variations: hydrophobicity increases at 200 °C as does the number of stable aggregates in benzene. At 300 °C, it is followed by a statistically significant reduction in both Rb and (Re-Rb). When the temperature is raised to 200 °C, Rb, Re and Rw values are those of very stable aggregates, indicating a hydrophobicity increase without modification of the long chain aliphatic compounds, which are responsible for aggregation. Two facts can be observed looking at the results of experimental plots: heating soils of burned plot maintain throughout the control period a slightly lower WDPT (around 10 sec.), while in the control plot, values are higher (between 20 and 40 sec.) and with a certain seasonal variability (Figure 5). The same happens with Rb values (Figure 6), where burned plots reach slightly lower values, although they remain steady throughout the measurement period. Forest fire has produced a reduction (or loss) in seasonal variability of Rb values, as observed elsewhere by Ellsworth *et al.* (1991).

Water retention data show that laboratory heated samples have lower values at FC (Table 5); however at the WP the reduction is the greatest (up to 40% of loss at 300 °C). Nevertheless, this reduction in absolute value originates an increase in available water, calculated as the difference between FC-WP. Reduction in the percentage of water at WP must be attributed to microporosity reduction due both to partial organic matter destruction and to the collapse of the clay platelets.

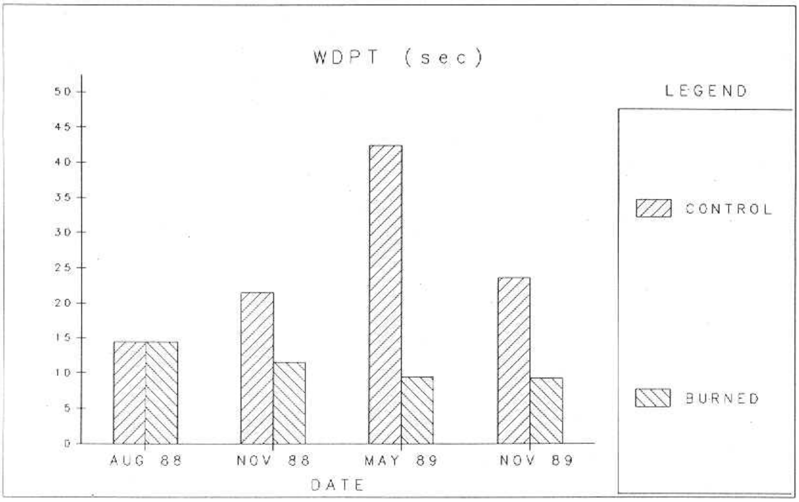

Figure 5. Evolution of WDPT on plot samples during the first year after the fire

Table. 5. Data from FC and WP of samples heated under laboratory conditions

Temperatures	Field Capac %	Wilting P %	A. Water Cap. %
Control	42.03	20.99	21.04
50°C	41.36	20.48	20.88
100°C	41.46	22.91	18.55
200°C	38.61	18.63**a	19.89
300°C	37.69	12.77**b	24.92

Values from experimental plots do not show conclusive results: although WP values are initially reduced in the burnt plot, they rapidly recover during the measurement period till they reach (and even exceed) the control plot values (Figure 7).

More effects are clear from FC values: after an initial reduction, the burned plot shows a continuous, progressive recovery.

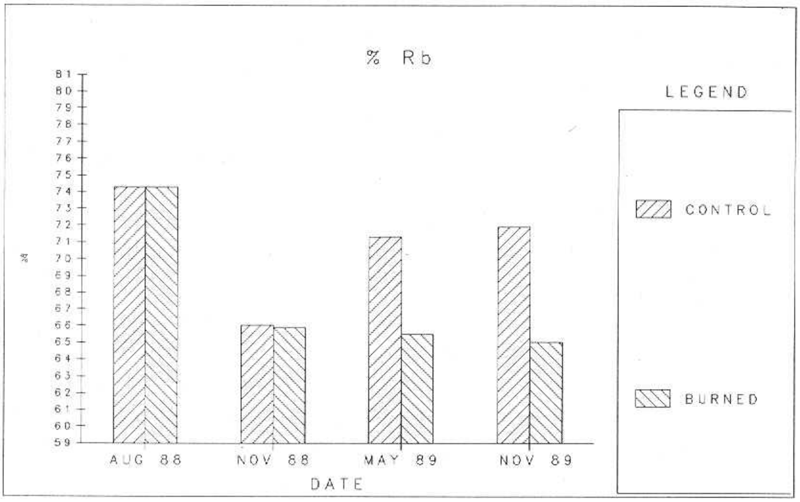

Figure 6. Evolution of the percentage of stable aggregates using a benzene pretreatement (Rb) during the first year after the fire.

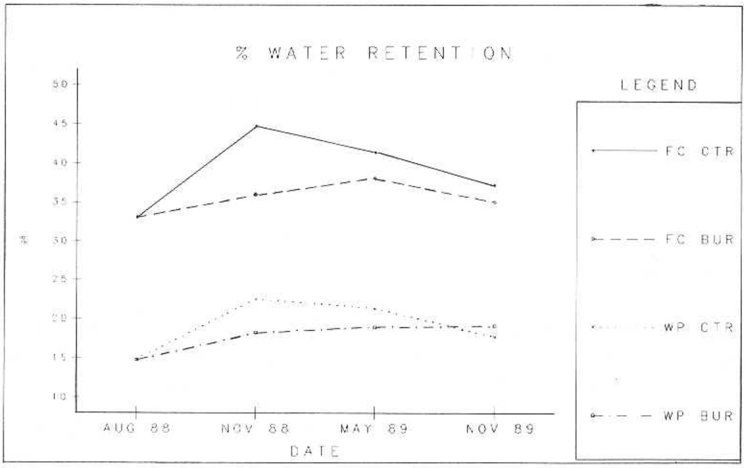

Fig. 7. Evolution of water content at field capacity (FC) and wilding point (WP) during the first year after the experimental fire.

Nevertheless results from the control plot indicate the considerable variations during the measurement period; this fact masks the fire effects somewhat. In the case of composite samples, it is not possible to differentiate between the influences of lateral variations and those due to seasonality.

6. Conclusions

Controlling forest fire effects on the physical properties of the soil is not easy because fire intensity and residence time are very difficult to measure accurately in natural conditions; even more so at a local scale.

Controlled soil experiments on plots and simultaneous experiments under laboratory conditions have enabled us to differentiate between heating effects on the structure and its seasonal evolution over one year.

The most important soil properties measured that are affected by heating in laboratory conditions are: DMWD, WDPT, WDI, Rb and WP.

The simultaneous use of a control plot has been very useful for monitoring periodical variations of structure properties. Some of these variations are more important than the fire effect as such (WDPT, water retention at FC and WP, for example).

Laboratory simulation shows that dry meanweight diameter is reduced by heating when the temperature reaches 200 °C. In these conditions aggregates are more fragile and break down more easily, and are thus more likely to be eroded.

The general instability index (Is) is not appropriate for revealing differences caused by heating in samples as stable as those in our experiements, but specific treatments (Rb,Rw and Re) can be used to detect changes in the cementing effect of organic matter in promoting soil structure.

The heating of soil samples in simulated conditions has shown hydrophobicity increases above 200 °C, but without notable changes of composition in the organic cementing material. Aggregates prove to be very stable after the heating treatment. The hydrophobic behavior of the samples is affected by temperature; it is maximum at 200 °C but disappears at 300 °C.

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