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Loss of organic matter in Atlantic forest soils due to wildfires. Calculation of the ignition temperature ☆

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Abstract

The effect of burning on the organic matter of three forest soils, which had been affected by wildfires within one month prior to sampling, was studied using a differential scanning calorimeter (DSC). The soils were cambisols under *Pinus* spp. located in Galicia (NW Spain).

Thermograms of the soils were carried out between 50 and 600°C. The combustion enthalpies of the soils were determined from the thermograms. By comparing the combustion enthalpy data of the burnt soils and that of the corresponding unburnt soils, the loss of organic matter due to the burning was calculated. The ignition temperature for each soil was also estimated from the thermograms.

Keywords: DSC thermograms; Soil; Soil combustion enthalpy; Soil wildfires

1. Introduction

In past decades, Atlantic ecosystems have been very much affected by wildfires. In the NW of Spain, more than one million hectares were burnt in the last 20 years [1]. These fires have caused high economic loss and great environmental impact.

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Most of the soils from this region are sandy, acid and desaturated. In general they have a high content of organic matter, the amount and characteristics of which are the factors that determine the physical and biochemical soil properties. Therefore, this soil component is a critical factor in the recovery of the burnt soils [2].

The destruction of the structure and the loss of organic matter, together with the erosion of the surface layer and the alteration of the biological cycle of the nutrients, are the main effects of the fire [3, 4]. Soil fertility is thus modified. Forest productivity is also affected since the vegetation cover is destroyed and the forest vegetation is changed.

The temperatures which can develop in a forest wildfire vary within a wide range, but the changes induced in the soil by temperatures higher than 230°C are irreversible since they dramatically affect the soil organic matter [5].

To study the effect of forest wildfires on the soil, the loss of organic matter in the soils as a result of the high temperature of the fires was determined. The ignition temperature of each soil was also estimated.

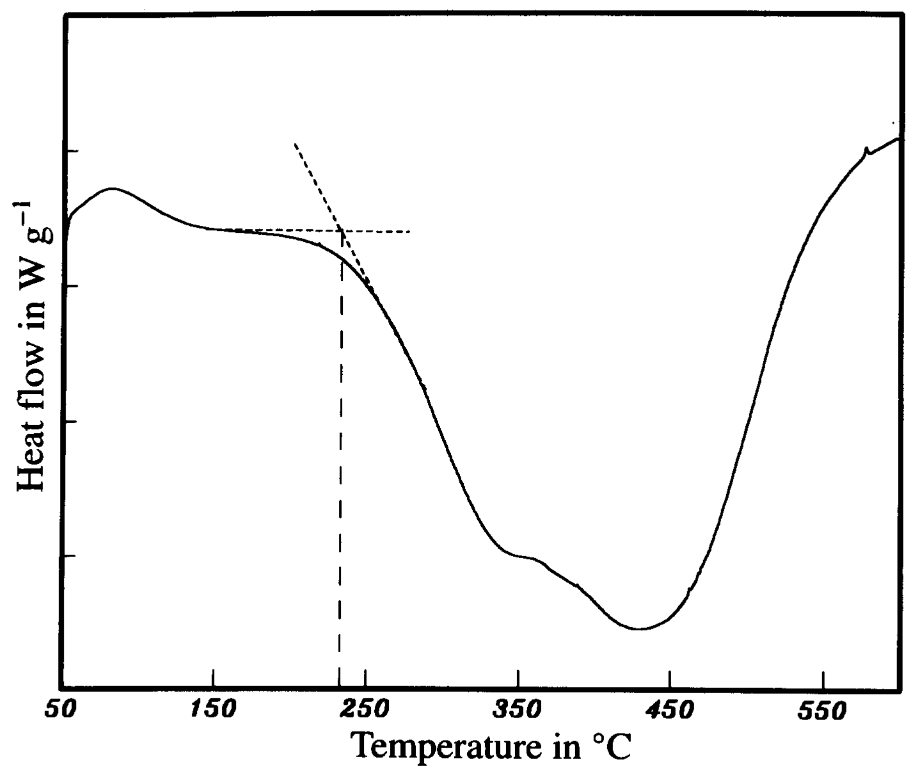

Fig. 1. Ignition temperature calculation.

2. Material and methods

Three pine stands located at Requeixo (REQ) and Retortas (RET) (province of Pontevedra) and at Manzaneda (MNZ) (province of Orense) in Galicia (NW Spain), which had been affected by wildfires within one month before sampling, were selected for this study. The soils were humic cambisols developed over granite, with a high content of organic matter in the A horizon [2]. All the burnt soils clearly showed morphological signs of the fire from the surface (white ashes) down to 5 cm (black ashes) with an irregular boundary at this depth [2]. Samples from the surface (0–5 cm for REQ and MNZ; 0–2 cm for RET) and the subsurface (5–10 cm) layers of the burnt and the corresponding unburnt soils were collected by Carballas et al. (1993) [2]. Sample collection, preparation and chemical analyses were described elsewhere [2, 3]. Samples for this study were sieved at 4 mm. The fraction less than 4 mm was homogenized and used for all the analyses. Components of the mineral fraction were separated using the International Mechanical Method [6].

Thermograms of the burnt and unburnt soil samples were carried out using a differential scanning calorimeter (DSC) (Perkin-Elmer, series 7). The RET soil was

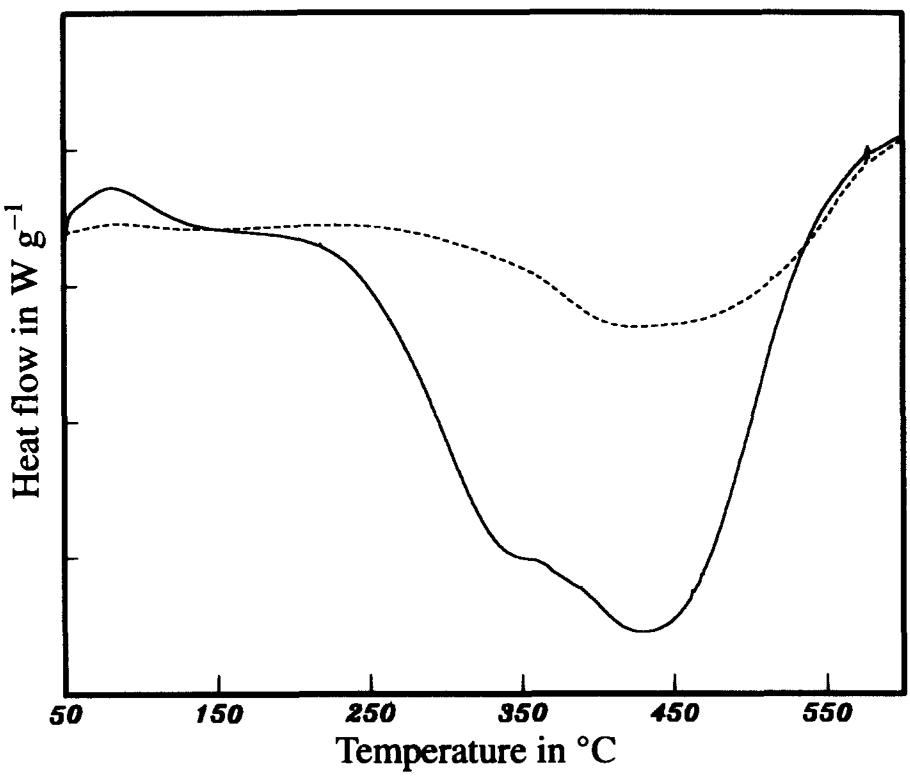

Fig. 2. Thermograms of the surface layer (0–2 cm) of the RET burnt soil --- and the corresponding RET unburnt soil —.

only studied at the surface layer whereas REQ and MNZ were studied at the surface and the subsurface layers.

The thermograms were obtained using samples of between 6 and 30 mg of soil, pierced aluminum crucibles of 50 μl capacity, under dry air flowing at 2.1 kg cm^{-2} and a scanning rate of 10°C min^{-1} [7]. The range of temperatures studied was between 50 and 600°C. Samples of In (mp = 156.6°C) and Zn (mp = 419.47°C) were used to calibrate the calorimeter.

The enthalpy of combustion of the soil organic matter was calculated directly from the thermograms as the area of the combustion peak. The difference between the combustion enthalpies of the burnt and the corresponding unburnt soils is the energy (in J g^{-1}) liberated by the soil during the fire. Taking into account that the energy liberated is approximately proportional to the organic matter destroyed in each soil because of the high temperature reached by soil during the burning, the loss of organic matter can be calculated from the combustion enthalpy values using the equation

$$L(\%) \approx \frac{\Delta H_u - \Delta H_b}{\Delta H_u}$$

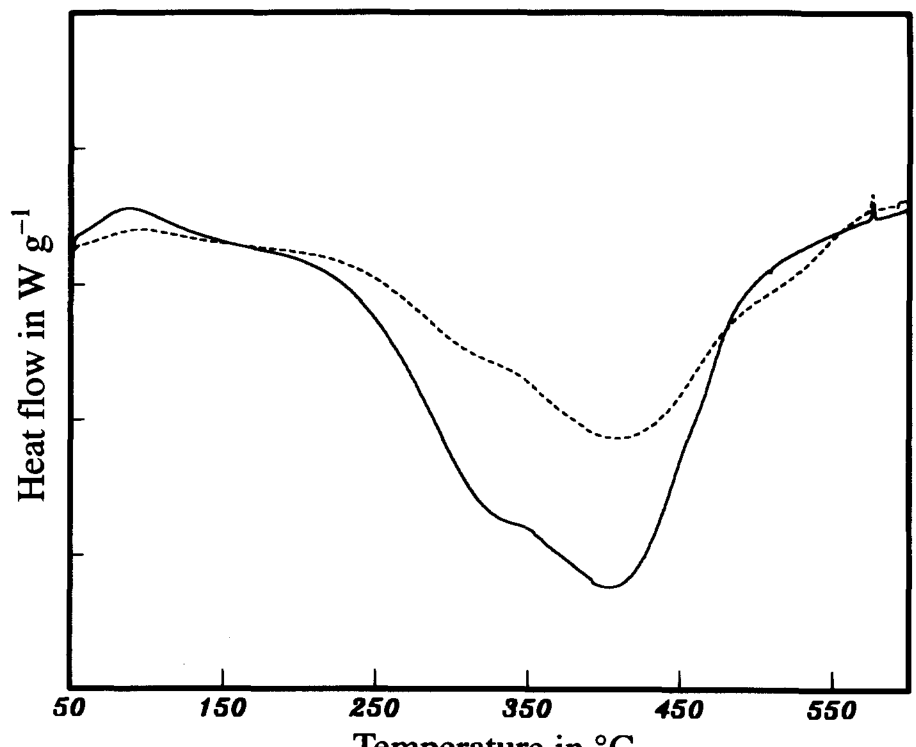

Fig. 3. Thermograms of the surface layer (0–5 cm) of the REQ burnt soil --- and the corresponding REQ unburnt soil —.

where $L(\%)$ is the percentage of organic matter lost during the fire, ΔH_u is the combustion enthalpy of the unburnt soil, and ΔH_b is the combustion enthalpy of the burnt soil.

The ignition temperature is that from which the combustion of the soil organic matter is continuous. When the soil reaches this temperature the losses of organic matter are irreversible. The ignition temperature was estimated from the thermograms. This temperature coincided with the beginning of the combustion peak. For the calculation of the ignition temperature, a computer program using "C" language was used. This temperature was obtained from the interception point between the baseline of the thermograms and the tangent to the inflexion point of the left side of the combustion peak (Fig. 1).

To determine the enthalpies of combustion and the ignition temperature seven samples were used for each soil. The mean values of these parameters (at 95% of confidence level) were computed from the standard deviations.

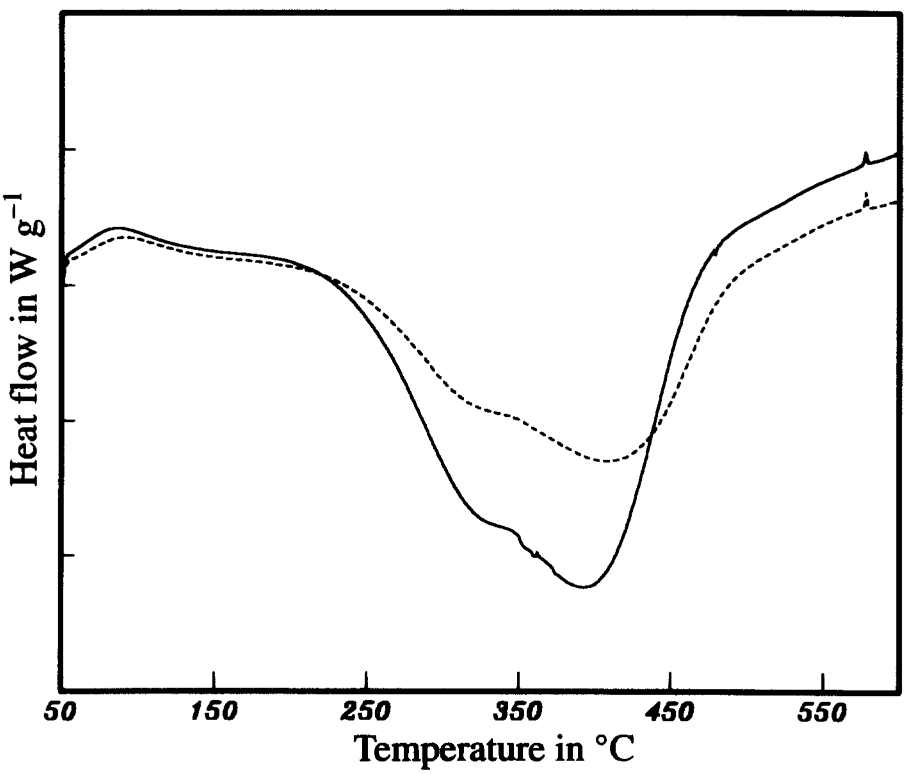

Fig. 4. Thermograms of the subsurface layer (5–10 cm) of the REQ burnt soil --- and the corresponding REQ unburnt soil —.

3. Results and discussion

All the thermograms obtained presented three well-differentiated peaks (Figs. 2–6). The first peak (I), which was endothermic, was between 50 and 150°C; the second (II and III) was a large exothermic peak between 180 and 550°C, and the third was a small endothermic peak (IV) between 570 and 580°C. Due to the scarcity of data using DSC in soils, the thermograms were compared with those obtained by other authors using differential thermal analysis (DTA); both types of thermograms are similar [8–10].

The first peak was attributed to dehydration and loss of volatile substances. Fig. 7 shows a thermogram of a sample previously dehydrated in an oven at 110°C for 2 h. It can be observed that this peak virtually disappeared in the thermogram performed after dehydration.

The exothermic peak was due to degradation and combustion of the soil organic matter. This was confirmed by a supplementary experiment using a soil sample which,

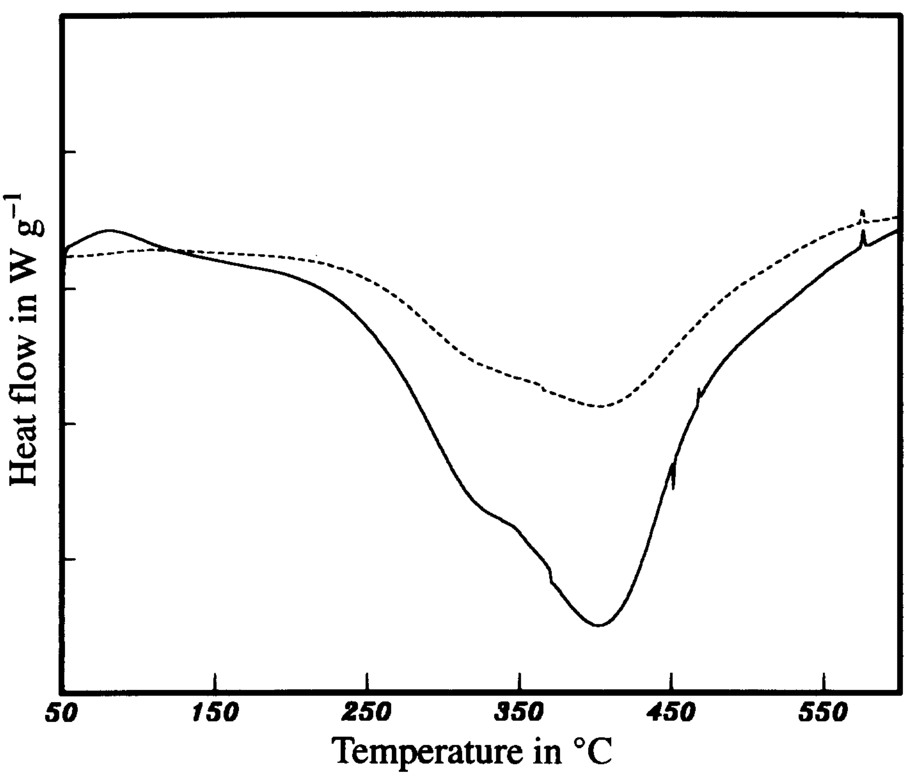

Fig. 5. Thermograms of the surface layer (0–5 cm) of the MNZ burnt soil --- and the corresponding MNZ unburnt soil —.

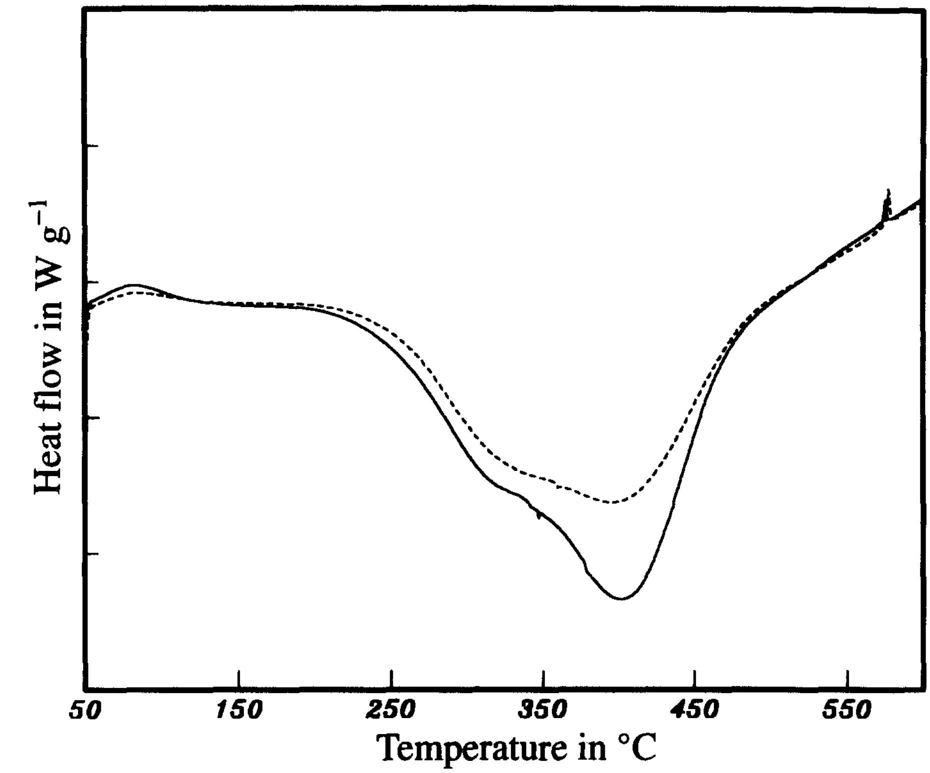

Fig. 6. Thermograms of the subsurface layer (5–10 cm) of the MNZ burnt soil --- and the corresponding MNZ unburnt soil —.

after heating at 600°C and cooling to room temperature inside the DSC to avoid any possible hydration, was submitted to identical scanning. The thermograms exhibited a straight line which almost coincided with the baseline of the DSC (Fig. 8). The exothermic peak was formed by superimposing two peaks, which were in the ranges 170–350°C (II) and 330–500°C (III). This behavior is in agreement with other publications [8–10].

The last endothermic peak, which appeared at approximately 575°C, seemed to be of inorganic origin. Taking into account that the soils were over granite and that the sandy fraction was mainly composed of quartz, the peak was attributed to the polymorphic transformation of hypothermic quartz to hyperthermic quartz which starts at that temperature (Fig. 9) [11].

The main differences between the thermograms of the burnt and unburnt soils appear in the exothermic peak. In the RET soil (Fig. 2) the exothermic peak dramatically decreased in the burnt soil due to a high loss of organic matter and peaks II and III joined together to give almost a single peak. Moreover, the ignition temperature increased.

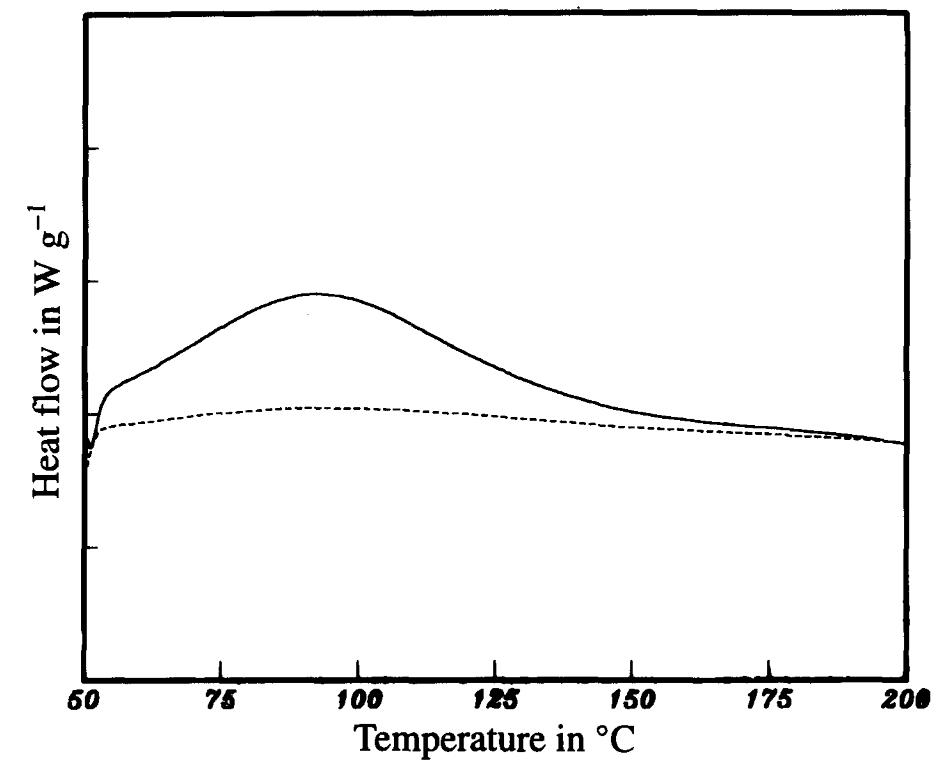

Fig. 7. Comparison between the first endothermic peak of a soil — and that of the same soil previously dehydrated ---.

Soils REQ and MNZ exhibited a decrease in the combustion peak although this decrease was not so high as in the RET soil. Other features of the thermograms from these soils were a slight variation in the ignition temperature and the existence of overlapping peaks II and III within the combustion peak of the burnt soils as well as in the unburnt soils (Figs. 3–6).

The mean of the enthalpy of combustion of the organic matter of all the soils is shown in Table 1. The loss of organic matter calculated from the combustion enthalpy is indicated in Table 2. The losses of organic matter agree with the findings of Fernández et al. (1991) [12] and Carballas et al. (1993) [2] using chemical analysis. The content of organic matter after the fire is very important to the recovery of the soil.

The means of the ignition temperatures of the soils are shown in Table 3. The ignition temperature was practically the same for all the unburnt soils, ranging from 230 to 236°C. In the burnt soils the ignition temperature was similar for the REQ and MNZ soils (239 and 237°C respectively) and much higher for the RET soil (322°C). In the burnt soils the ignition temperatures were always slightly higher than those in the

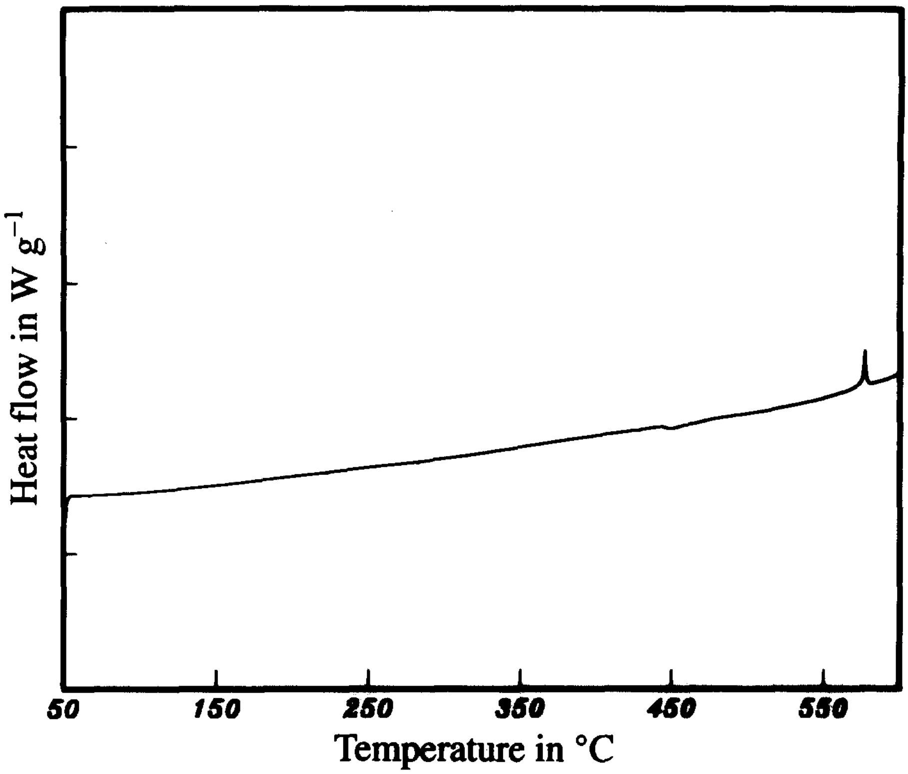

Fig. 8. Thermogram of a second heating in the DSC of a soil. The peak attributed to the combustion of organic matter has disappeared.

unburnt soils. This is probably due to the loss of organic matter during the fire, provoking a low concentration of fuel after the fire, with consequent increase in the ignition temperature.

Taking into account the morphological characteristics of the surface layer after the burning, the wildfire which affected the RET soil had been considered of

Table 1
Mean of the enthalpy of combustion of the soil organic matter (kJ g^{-1})

Soils	Surface layer		Subsurface layer	
	Unburnt $\Delta\bar{H}$	Burnt $\Delta\bar{H}$	Unburnt $\Delta\bar{H}$	Burnt $\Delta\bar{H}$
REQ	-2.28 ± 0.48 [a]	-1.82 ± 0.19 [a]	-2.80 ± 0.26 [a]	-2.21 ± 0.15 [a]
MNZ	-3.02 ± 0.36	-1.52 ± 0.41	-2.38 ± 0.17	-1.44 ± 0.10
RET	-8.65 ± 0.42	-3.03 ± 0.49		

[a] Uncertainties represent the bound on absolute error with the 95% confidence interval for mean.

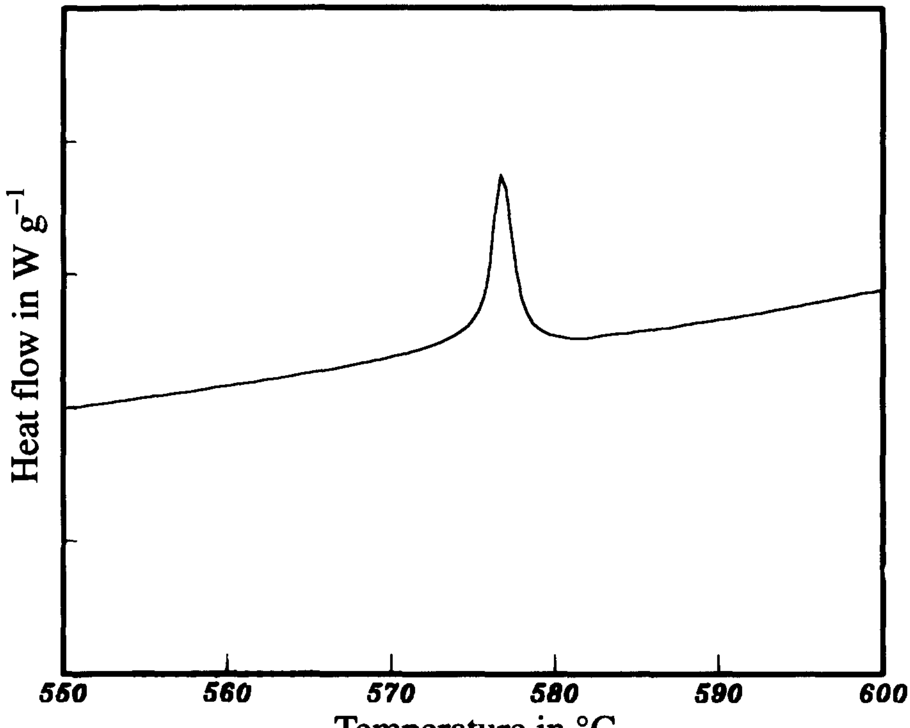

Fig. 9. Quartz peak.

Table 2
Loss of soil organic matter

Soils	Loss(%)
RET (0–2 cm)	65
REQ (0–5 cm)	12
REQ (5–10 cm)	18
MNZ (0–5 cm)	50
MNZ (5–10 cm)	30

Table 3
Ignition temperature (°C) of the soils

Soils	Unburnt	Burnt
REQ	235 ± 12 [a]	239 ± 13 [a]
MNZ	230 ± 15	237 ± 14
RET	236 ± 15	322 ± 13

[a] Uncertainties represent the bound on absolute error with the 95% confidence interval for mean.

medium intensity (black ashes) whereas the fires which had affected the REQ and MNZ soils were considered of high intensity (white ashes). The results of this study could seem to contradict this since a high intensity wildfire should have caused a higher degradation in the soils than a medium intensity wildfire. The explanation for this discrepancy could be that the soil depth affected by the fire was much higher in the REQ and MNZ soils (0–5 cm). Burnt samples were collected from these layers and were then homogenized. Soil is a very bad thermic conductor; because of this the effect of a high-intensity wildfire at 5 cm depth is much less than the effect of a medium intensity wildfire at 2 cm. This could explain the results of this study.

Acknowledgments

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