POSTFIRE EFFECTS ON SOIL PROPERTIES AND NUTRIENT LOSSES

V. Andreu, J.L. Rubio, J. Forteza & R. Cerni

Department of Desertification. IATA-CSIC. Jaime Roig, 11. 46010-Valencia, SPAIN.

SUMMARY

The effects of a wildfire, occurred in August 1992, on nutrient losses by water erosion have been studied. The fire affected an area of 9498 ha of Pine forest and shrub, located in Sierra Calderona (Valencia, Spain). In the burned area, six stations of erosion measurement were set up immediately after the end of the fire. The results obtained in these stations are reported. Topographical, edaphological and vegetation characteristics of each station are described. Fourteen episodes of erosive rain with production of runoff and sediments, between August 1992 and November 1993, were studied, mainly in relation to changes in the soil chemical characteristics. Data show that the highest soil and nutrient losses were produced in the period immediately after the fire. However, fire intensity is the factor that determines the soil *status* with respect to its response to nutrient losses.

INTRODUCTION

In the last years the Spanish forest ecosystems have suffered the incidence of repeated wildfires, most of them caused by human action. This situation results in an important reduction of the vegetation cover and the intensification of land degradation processes. The continuous impact of fires, reducing progressively the recovery periods, together with the incidence of torrential rains characteristics of the Mediterranean climate favors the intensification of the erosive processes (Giovannini et al., 1990).

In fires of medium and high intensity, the degradation of the vegetation cover and soil organic matter produce the surface accumulation of hydrophobic substances that reduce infiltration and increase runoff (Imeson et al., 1992). This situation causes an increase of runoff production and soil removal, which favors the loss of nutrients associated with them or solubilized by runoff water. Soil and vegetation types, slope, lithology, physiography and other natural factors could influence the effect of fire and the ecosystem recovery.

In this paper, the effect of different fire intensities on soil chemical properties and their temporal variation has been studied. The incidence of water erosion in nutrient losses after fire has been also studied. Six stations were established covering the most representative soils and ecological characteristics of the studied area.

MATERIALS AND METHODS

The area, burned in August 1992, has an extension of 9498 ha and is located in Sierra Calderona. It is a mountainous area between the provinces of Castellón and Valencia, at the Mediterranean coast of Spain. The different speeds and directions of fire propagation, together with the complex topography of the area originates an irregular and diverse pattern of fire impacts. Of the whole zone, 6007 ha were of typical Mediterranean pinewood forest and, occasionally, cork oaks (*Quercus suber L.*). The remainder area showed shrub vegetation of the Rosmarino-Ericion association (Stübing, 1985), and some agricultural plots.

To monitor the erosion patterns in this burned area, six control stations were selected and located according to the most representative lithologies, vegetal cover and soil types. In these stations sediment and runoff collector systems were set up to evaluate the soil erosion processes and the loss of nutrients. Intensive field surveys were carried out to select areas with a natural pattern of a close microcatchment and with a point of downslope flows concentration. This configuration avoids the disturbance derived from the construction of artificial boundaries.

Besides the appropriate geomorphological characterization, the other factors considered for selecting the study stations were the different fire intensities, lithologies and soil types. The equipment of the stations includes a pluviometer and a system of runoff and sediment collection based in a modification of the Gerlach trap (Gerlach, 1967).

Table 1 shows the topographical and morphological characteristics of the studied zones including slope, orientation, lithology, soil type and altitude. Characteristics of the previous vegetation and the intensity and type of fire occurred in each station are reported also in Table 1. The degree of fire intensity was established according to the method of Moreno and Oechel (1989) based on correlating estimates of fire intensity with the minimum diameter of branches that remains after the fire.

Four soil samples were taken periodically from each station. The samples correspond to the first five centimeters of soil, removing previously the superficial layer of ashes and vegetable

residues. Samples were air dried, sieved, mixed and homogenized. From each global sample four subsamples were taken for analysis.

Organic matter content was determined by oxidation with potassium dichromate (Jackson, 1958) and cation exchange capacity by extraction with 1M ammonium acetate solution (Rhoades, 1986). Total and mineral nitrogen were determined by a Kjeltec Auto 1030 Analyzer using the Bremmer method (Black, 1965), and total carbonate content using the Bernard calcimeter method (Duchaufour, 1965). Electrical conductivity was measured in soil saturation extracts by the method of Richards (1964). Available phosphorous was measured by colorimetry according to the method of Olsen and Dean (Black, 1965).

Fourteen rain events with runoff production were registered from September 1992 until November 1993 (Figure 1). The sediments and runoff collected in each trap were quantified and analyzed. The total amount of sediment in the collectors of each station was recovered and, before their analysis, processed in the same way that the soil samples.

RESULTS AND DISCUSSION

The incidence of fire in the studied soils is reflected clearly in Table 2. Data of

Figure 1: Rain events with runoff production in the studied period.

“unburned” soil refers to areas close and similar to the stations but not affected by fire. It shows some chemical parameters related to soil fertility and erodibility, before and after the fire.

Immediately after the wildfire a generalized increase in the content of soluble salts was observed, which is reflected by the values of electric conductivity (Table 2). These values were, as a mean, three times higher than the unburned soil. In the stations that suffered a fire of lower intensity, this increment is greatly minor, reaching 2.11% in the station 3 (low fire intensity) whereas in the station 2 (high intensity of fire) was 775.96%. These phenomena are mainly due to the accumulation of ashes and mineral elements that comes from the combustion of the vegetation, and the mineralization of the organic layers of soil (Sanroque et al., 1985). It is associated with changes in the pH, which in some cases (station 4) reaches an increment of almost a unit. With time, pH values reach nearly the same level than before the fire and the electric conductivity gradually decreases.

Organic matter content strongly decreases immediately after medium-intense fires (stations 1, 2 and 4), increasing after that slightly with time. But in zones that suffer a medium fire intensity its values increase (station 3 reached an increment of 6.47% to 11.20%). This could be due to the accumulation of vegetable residues, not completely burnt, according to the studies of Christensen (1987). For the contrary stations 5 and 6, medium to low fire intensity, maintain their values almost constant (Table 2).

Mineral nitrogen and available phosphorous contents were also increased after the fire in the same manner by the mineralization processes and the contribution of ashes. Jurgensen et al. (1981) found similar results in a burned Douglas-fir forest. A year after, in all cases, the values are similar to the previous before the fire.

Total nitrogen content rise its original values after six months, in all cases, then starts to diminish gradually. Generally, the exchangeable cations maintain estable values, with slight variations in zones that suffered high intensity of fire, except Ca that have a variable behavior. It is according to the studies of Giovannini et al. (1990) which observe that depending on the fire intensity CaCO_3 could suffer a breakup and change to CaO or Ca^{+2} . On

the other hand, potassium shows low variations after the fire, which contrast with the observations of Trabaud (1990). The cation exchange capacity shows few variations in its values during the studied period in all de stations, only diminishing lightly in station 4.

Figure 1 shows the total amount of rain in each studied event. The mean value of rains on the different stations is similar, around 55 mm. The effect of the physiographic position of the stations is clearly observed in the distribution of precipitations. Station 3 shows the highest amount of rain, probably due to its southern exposition, face to the sea, and with no intercalate mountainous barriers.

In production of runoff and sediment (Table 3) the different stations show similar courses, except the zone burnt with high intensity fire (station 4), which shows the highest values (224.58 l and 1110.29 g/m² respectively). The rates of soil loss are, generally, higher than the reported in the bibliography for zones that have suffered medium and high intensity fires. Thus, Andreu et al. (1994) in burned areas, of similar ecological characteristics, report lower values of runoff and soil loss.

The presence of a clayey compact B horizon at 30-50 cm depth in the soil profile of station 4, and one strongly sandy A horizon (>51%), favors the rapid water saturation of soil and the subsequent increase of runoff yield with loss of materials, giving the highest values in these parameters. A similar phenomenon, although less accentuated, occurs in the station number 5. Stations 1, 2 and 3 show a balanced textural composition through the soil profile that allows better drainage and subsequently a decrease in soil loss. This is reflected by their values of runoff

STATION	RAIN (l/m ²)	RUNOFF (l)	RUNOFF YIELD (l/m ²)	*RUNOFF COEF. (%)	SEDIMENT (g)	EROSION (t/ha)
1	493.70	128.98	3.78	10.82	849.48	0.24
2	726.80	65.45	2.66	5.93	559.82	0.23
3	895.11	76.86	3.00	4.13	588.12	0.23
4	745.44	224.58	9.79	23.59	25470.13	11.10
5	776.31	144.42	13.18	30.93	3098.11	2.83
6	790.30	196.10	7.99	15.31	509.16	0.21

* Runoff Coefficient.

Table 3: Total values of the erosión parameters in the studied period.

coefficient and runoff yield (Table 3).

The values of the analyzed parameters in the collected sediments are reported in Figures 2 and 3. The greatest enrichment of phosphorous is observed in the zones that have suffered a high fire intensity. The sediments of station 2 and 4 shows the maximum value on available phosphorous in sediments, 41.09 mol/kg (Figure 2). This seems to be due to the removal of ashes and burned materials by runoff after the wildfire that was most intense in the zones of these stations. For the contrary, sediments from zones slightly affected by fire (stations 3 and 6) give the highest levels of organic matter.

Figure 2: Values of organic matter, available phosphorous and mineral and total nitrogen in sediments of the different stations.

Figure 3: Values of exchangeable cations determined in the sediments of the stations.

As occurs with phosphorous, sediments show an important enrichment in mineral nitrogen in zones that suffered a strong fire impact, being higher in the station 2 with a maximum of 8.12 mol_c/kg. The contents in the soil surface of these elements, induced by effect of fire are reduced progressively in each episode of rain by removal or solubilization (Jurgensen et al., 1981). So, in the zones where the erosive processes are more intense, the enrichment of sediment and runoff in these elements is more clear (stations 4 and 5).

Concerning to the exchangeable cations (Figure 3), as a whole, the highest values in sediments are shown in the zone that suffer high fire intensity (station 2), except sodium that

show similar mean values in all the stations. Anyhow, the incidence of erosion marks differences between stations in removal of chemical substances by runoff and sediments. Station 4 reflects clearly this effect, giving high levels of exchangeable cations, nitrogen and organic matter in sediments, without suffer previously a high intensity fire.

The observed values of organic matter and potassium in sediments are similar to the referred by Soler y Sala (1992) and Andreu et al. (1994) for zones of Mediterranean pinewood and matorral affected by wildfires of medium-low intensity.

CONCLUSIONS

The effect of fire on the soil depends in great manner of its intensity. It is observed that the incidence of high temperatures (stations 2 and 4) produce an increment on pH and electric conductivity, mainly because of the accumulation of ashes and release of nutrients. In the same way, the contents in mineral nitrogen and available phosphorous also increase, while organic matter and total nitrogen decreases. After the fire, the organic matter and total nitrogen levels increase progressively with time, whereas a decrease is observed in available phosphorous and soluble salts. In medium-low intensity fires, the organic matter content increases after the impact due to the accumulation of vegetable rests partially burned.

In the zones in which the fire intensity was low (zones 1,3,5 and 6) the changes in these parameters are attenuated or there are not variations in them. The temporal variation of the exchangeable cations in soil is very slight or is maintained almost constant after the fire.

When the vegetation cover was highly degraded by fire (stations 2, 4 and 5), the incidence of the erosive processes were most intense producing important losses in chemical elements removed with the sediments or solubilized by runoff. This is reflected by an enrichment of the sediments in phosphorous, mineral nitrogen and exchangeable cations.

The zones that suffered a medium fire intensity (stations 1 and 5) show different behavior, depending more of their intrinsic characteristics and its susceptibility to water erosion. Anyway, these zones show a clear enrichment in organic matter content in their sediments. The zones that suffered slightly the impact of fire (stations 3 and 6), show few variations in sediment chemical characteristics.

REFERENCES

- Andreu V., Rubio J.L., Forteza J. and Cerní R.** (1994). Long term effects of forest fires on soil erosion and nutrient losses. In: *Soil erosion as a consequence of forest fires*, (M. Sala and J.L. Rubio Eds.). Geoforma Ediciones. 79-90.
- Black C.A.** (1965). *Relaciones suelo-planta*. Hemisferio Sur. Buenos Aires.
- Christensen N.L.** (1987). The biogeochemical consequences of fire and their effects on the vegetation of the Coastal Plain of the southeastern United States. In: *The role of fire in ecological systems*, (L. Trabaud Ed.). SPB Academic Publishing. 1-19.
- Duchaufour P.** (1965). *Précis de Pedologie*. Masson et Cie. Paris.
- F.A.O.** (1988). *Soil map of the world 1:500.000 scale*. F.A.O. Rome.
- Gerlach T.** (1967). Hillslope troughs for measuring sediment movement. *Revue Géom. Dyn.* **4**: 173-175.
- Giovannini G., Luchesi S. and Giachetti M.** (1990). Beneficial and detrimental effects of heating on soil properties. In: *Fire in ecosystem dynamics*, (J.G. Goldammer and M.J. Jenkins Eds). SPB Academic Publishing. 95-102.
- Imeson A.C., Verstraten J.M., Van Mulligen E.J. and Sevink J.** (1992). The effects of fire and water repellency on infiltration and runoff under Mediterranean type forest. *CATENA* **19**: 345-361.
- Jackson M.L.** (1958). *Soil Chemical Analysis*. Prentice Hall Inc. London.
- Jurgensen M.F., Harvey A.E. and Larsen M.J.** (1981). *Effects of prescribed fire on soil Nitrogen levels in a cutover Douglas-fir/Western Larch forest*. USDA Forest Service. 1-6.
- Moreno J.M. and Oechel W.C.** (1989). A simple method for estimating fire intensity after a burn in California Chaparral. *Æcol. Plant.* **10(1)**: 57-68.
- Rhoades J.D.** (1986). Cation-exchange Capacity. In: *Methods of soil analysis. Part 2*. (A.L. Page De.). Agronomy Monographs 9, American Society of Agronomy. 149-157.
- Richards L.A.** (1964). *Diagnosis and improvement of saline and alkali soils*. USDA Agriculture Handbook 6, Government Printing Office. Washington D.C.
- Sanroque P, Rubio J.L. and Masanet J.** (1985) Efectos de los incendios forestales en las propiedades del suelo, en la composición florística y en la erosión hídrica de zonas forestales de Valencia (España). *Rev. Ecol. Biol. Sol* **22(2)**: 131-147.
- Soler M. and Sala M.** (1992). Effects of fire and of clearing in a mediterranean *Quercus ilex* woodland: an experimental approach. *CATENA* **19**: 321-332.

Stübing G. (1985). *Estudio fitosociológico de los matorrales termófilos valencianos*. Universidad de Valencia. Valencia.

Trabaud L. (1990). Is fire an agent of desertification?. In: *Strategies to combat desertification in Mediterranean Europe*. Commission of the European Communities. 104-129.