

# Rainfall/runoff/erosion relationships and soil properties survey in abandoned shallow soils of NE Spain

Giovanni Pardini<sup>1</sup> · Maria Gispert<sup>1</sup> · Mohamed Emran<sup>2</sup> · Serena Doni<sup>3</sup>

Received: 24 August 2015 / Accepted: 18 August 2016 / Published online: 31 August 2016  
© Springer-Verlag Berlin Heidelberg 2016

## Abstract

**Purpose** Shallow soils previously cultivated under terraced systems may change their properties after agricultural release and spontaneous plant colonization. Investigations were conducted in terraced fields (NE Spain) to prove that vegetation installed after the abandonment may generally improve soil properties by the formation of stable organic horizons. However, restriction in plant species along the natural vegetation succession and intensification of erosion processes may occur after abandonment depending on fire frequency and soil use history.

**Materials and methods** Ten environments with different plant covers under a Lithic Xerorthent were selected and erosion plots (Gerlach type) installed providing their best adaptability at the terrace scale. Selected soil environments represented the sequence of abandonment: from current poorly cultivated soils, soils under pasture, soils under shrubs, and soils under stands of pine and cork trees. Relevant rainfall events producing runoff and erosion were recorded from November 2011 to May 2012. Erosion rates and erosion components were analysed in sediments and water in order to monitor carbon,

nitrogen and other nutrient removal by overland flow. Similarly, the physical and chemical properties of the soil environments under study were determined at the same time interval of runoff erosion.

**Results and discussion** Soils under pasture, vines and recently burnt pine forest produced the highest runoff followed by soils under shrubs and forest. However, eroded soil yields and nutrient removal were much higher in cultivated soils and soils in recently burnt sites, which had shown poorer soil properties with respect to soils abandoned for longer and preserved by fire. Fire-affected soil environments also showed a thinner organic horizon and reduced water retention. Although erosion rates and nutrient depletion were low in all environments with respect to other areas of Spain, higher splash than water erosion was an early warning indicator of the high susceptibility to degradation of these shallow soils.

**Conclusions** Results outlined that the renaturalization dynamics after agricultural abandonment are complex biophysical processes involving the parent material, depth to bedrock and other soil properties as well as the succession of vegetative cover and plant associations responsible for building a new soil mantle contrasting with erosion processes. Planning for management of land abandonment is strongly recommended.

---

Responsible editor: Richard K. Shaw

✉ Giovanni Pardini  
giovanni.pardini@udg.edu

<sup>1</sup> Soil Science Unit, Department of Chemical Engineering, Agriculture and Food Technology, University of Girona, Campus Montilivi, 17003 Girona, Spain

<sup>2</sup> Land and Water Technologies Department, Arid Lands Cultivation Research Institute, City for Scientific Research and Technological Applications, New Borg El-Arab, Alexandria 21934, Egypt

<sup>3</sup> Institute of Ecosystem Study, Section of Soil Chemistry, National Research Council (CNR), Via Moruzzi 1, 56124 Pisa, Italy

**Keywords** Land abandonment · Nutrient removal · Organic matter · Plant cover · Sediment yield · Terraced fields

## 1 Introduction

Hillside soils in the Mediterranean region were exploited for centuries and then progressively abandoned when industrial agriculture shifted to the best plots of plain areas (Lasanta et al. 2000). After land abandonment, the

spontaneous plant colonization tends to occupy the previously cultivated sloping fields, though periodical wildfire occurrence may cause set-backs to natural vegetation succession, delaying the improvement of soil properties (Pardini et al. 2004a). Thus, severe erosion processes are likely to occur after fire, especially when poor soil conditions prevail at agricultural release (Pardini et al. 1991). A major aim in studying the ability of an ecosystem to return to the original state after disturbance is the prediction of the response of such a system to a variety of natural and human-induced disturbances. Cultivation followed by abandonment may make the recovery of soil properties difficult because of the elimination of autochthonous vegetation which in turn favours the colonization of opportunistic species. Puigdefabregas (1995) inferred that depending on physiographic characteristics, climate and soil use history, land abandonment may trigger desertification processes and ultimately loss of the soil resource especially under shallow profile conditions and reduced organic matter input. Other authors reported of positive effects after land abandonment from the development of renewed biodiversity at the plant and soil scale (Lesshen et al. 2007). In the North Eastern part of the Spanish Pyrenees, land abandonment of the mid-mountainous areas has been the general direction over the last decades. Previously cultivated terraced soils are currently covered by different stages of spontaneous vegetation due to wildfire frequency, with the result of a disorganized and fragile territory and a considerable loss of landscape heterogeneity. An understanding of the process of plant recolonization and biological diversity is paramount to facilitate the recovery of an ecological role by environments which have undergone stress caused by land abandonment (Flinn and Vellend 2005). In the overall area, only small patches are still cultivated with vineyards and olive groves and have proved to be efficient firebreaks reducing the propagation and severity of wildfires, which may cause restrictions in plant species, reduction of recovery periods and intensification of erosive processes (Pardini et al. 2003; Pardini et al. 2004b). When the effects of land abandonment and wildfire occurrence on the Mediterranean landscape are evaluated, the evolution of soil properties is often neglected (Scarascia-Mugnozza et al. 2000). In spite of this, understanding the rainfall/runoff/erosion relationships and related nutrient dynamics is of great relevance in terms of soil quality, especially in the shallow soils with low organic matter content existing in the area of study. In this paper, we propose to investigate the soil response to seven natural rainfall events generating runoff at the plot scale with the objective to compare soil properties, runoff erosion rates and related components in abandoned and cultivated soil environments differing in land use and cover change. Those soils resulting as

less susceptible to erosion and degradation may trace appropriate management of this territory after land abandonment.

## 2 Materials and methods

### 2.1 Area of study

The area of study is located in the Serra de Rodes catchment, Natural Park of Cap de Creus, Catalonia, NE Spain (42° 18' 4" N, 3° 12' 22" E) and covers approximately 30 km<sup>2</sup>.

The site has a Mediterranean xerotheric climate, with hot summers and mild winters, annual average temperature of 16 °C (minima of 3 °C and maxima of 36 °C) and a mean annual rainfall of 450 mm mainly distributed in spring and autumn. Ninety percent of the territory is covered by dense shrub growth, mostly occupied by the *Cistus monspeliensis*, *Cistus albidus*, *Calicotome spinosa* and *Ulex parviflorus* association, with a minor extension of *Erica arborea* shrub and *Quercus coccifera* which represent the most mature stage of vegetation succession more preserved by fire. While the herbaceous cover under the Cistaceae is scant, probably because of allelopathic effect of the exudates secreted by *Cistus* leaves and roots, under Ericaceae and Fagaceae, an abundant herbaceous cover is detected. The residual 10 % is divided into still cultivated vines and olive trees, pasture covered with herbaceous plants partially abandoned and in transition into *Cistus* association, pine forest (*Pinus halepensis*) corresponding to a plantation of 1954 after a devastating fire and stands of cork trees (*Quercus suber*) representing the residual of ancient cork tree cultivation oriented towards the optimization of cork production. Both stands of pine and corks trees have understory composition mainly composed by *Lavandula stoechas*, *Asparagus officinalis* and *Brachypodium retusum*. The abandoned areas either covered with shrubs or both pines and cork trees receive neither periodical clearing nor forest management resulting in a very disorganized and vulnerable landscape. However, grazing activity is often observed especially under cleared stands of pines.

Ten different land use/land cover types were selected in this area, representing soils under (1) *Vitis vinifera* (V); (2) *Olea europaea* (O) cultivation maintained under insufficient agricultural management; (3 and 4) pasture (PRa, PRb) mainly covered by species adapted to the strong North wind called *Tramuntana* such as *Brachypodium retusum*, *Dactylis glomerata*, *Trifolium stellatum*, *Stipa capensis*, *Plantago lanceolata*, *Eryngium campestre*, *Astragalus massiliensis*, *Seseli farrenyi*, *Limonium geronense* and early invasion of Cistaceae; (5) *Erica arborea* shrub (MB); (6) *Cistus monspeliensis* shrub (MC); soils (7) stands of *Pinus halepensis* (PI); (8) stands of *Quercus suber* (S); (9) a recently burnt area covered with *Pinus halepensis* (PIC) now

completely destroyed, with growing undergrowth of *Cistus monspeliensis*; and (10) a recently burnt area covered with *Quercus suber* (SC) also with Cistaceae understory. After the fire occurred in August 2008, burnt cork trees (SC) have largely sprouted and recovered. All soils, formed on Palaeozoic slates and classified as Lithic Xerorthents (Soil Taxonomy 2010), present A, C/R horizon development, are shallow (0–40 cm depth) and poorly developed. Site and soil characteristics are listed in Table 1.

## 2.2 Experimental layout

Rainfall events were recorded by a meteorological station (Davis Instruments, Hayward, CA, USA, Vantage Pro-Plus model) installed in the area and collecting data every 15 min. Runoff and erosion were quantified by means of 20 (2 per soil environment) open plots (Gerlach 1967) formed by two 2-m-long strips of iron sheeting, connected on each side with an erosion tank (50 cm wide × 30 cm high × 30 cm deep), equivalent to 45 l of runoff collection capacity. Moreover, a hole in the rear part of the tank was equipped with a turncock connected to another reservoir of 20-l capacity. The total width of each plot was of 4.5 m and the plot area was 36 m<sup>2</sup> considering the 8-m distance from one terrace to another. The erosion tank borders the terrace and the iron strips are collecting runoff and eroded soil from the soil surface above into the reservoir. An example of some environments under study and detail of erosion plots is reported in Fig. 1. Hydraulic conductivity was determined by using a handheld minidisk infiltrometer (Decagon Devices, Pullman, WA, USA) at 2-cm suction capacity (Zhang 1997).

Three composite soil samples of the A horizon (0–10 cm depth) were collected at any selected rainfall event (from November 2011 to May 2012) in an area of approximately 0.5 ha as representative of each land use/land

cover type. The total number of processed samples was 210. Rainfall characteristics during the observed period are reported in Table 2.

Bulk samples were air-dried and gently crushed to pass through 5.6- and 2.0-mm sieves for subsequent analysis. The fraction 5.6–2.0 mm was reserved for aggregate stability. Other soil parameters were analysed in the 0–2.0-mm fraction. Particle size distribution was determined by the pipette method. Measurements of pH were carried out on 1:2.5 (p/v) soil-water suspensions by means of a Dyson pH-meter. Cation exchange capacity (CEC) was determined according to the method of Gillman (1979). Organic carbon (SOC) was determined by using the wet-combustion method (Walkley and Black 1934). Total soil nitrogen (N<sub>T</sub>) was determined according to the Kjeldhal method (Bremner and Mulvaney 1987). Available phosphorus (P<sub>AV</sub>) was determined by using the Olsen method (Olsen and Sommers 1987). The Eijkelkamp wet-sieving apparatus was used to determine the structural stability of aggregates (Kemper and Rosenau 1986). Aliquots of previously separated and air-dried 5.6–2.0-mm fraction aggregates were placed in a 2.0-mm sieve and subjected to mechanical vertical immersion-emersion cycles (34 cycles min<sup>-1</sup>) in cans with deionized water for 3 min. Soil aggregates surviving disruption and detachment were dried at 105 °C and weighed. The stability of aggregates to water (WSA) was calculated as following:

$$WSA(\%) = \frac{M(a+s) - M_s}{(M_t - M_s)} 100$$

with WSA representing the percent of water-stable aggregates,  $M(a+s)$  the mass of the resistant aggregates plus sand (g),  $M_s$  the mass of the sand fraction alone (g), and  $M_t$  the total mass of the soil sample (g).

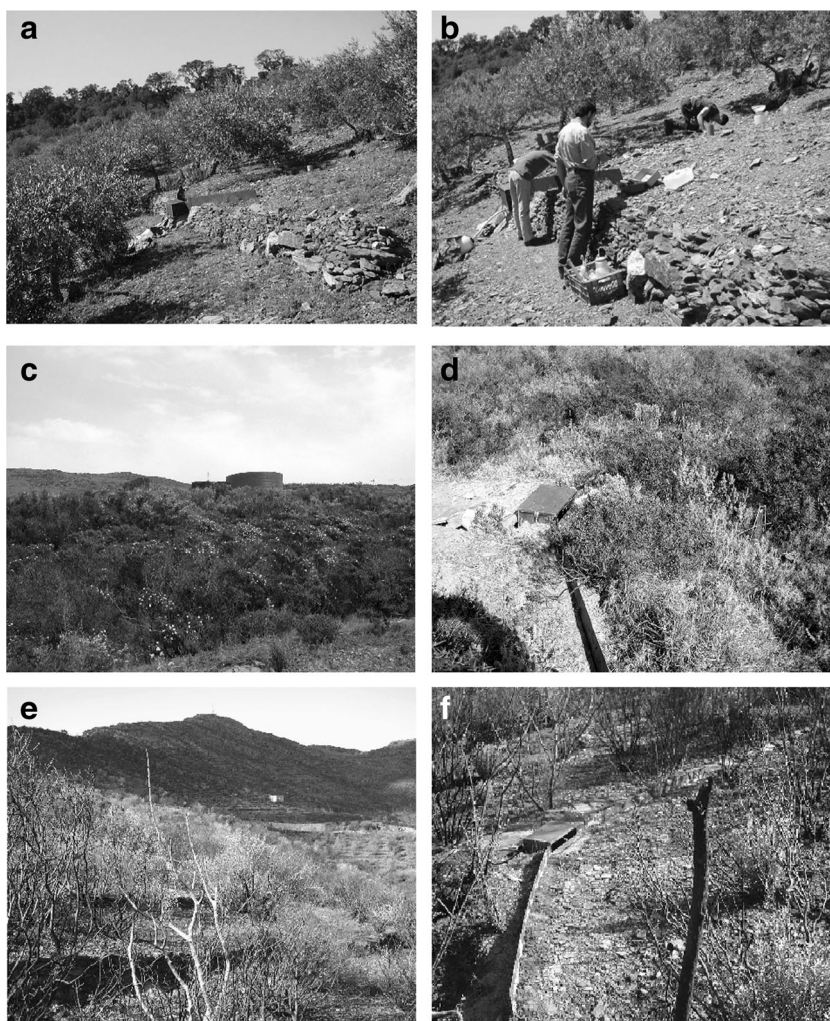
Both eroded soil and runoff water were collected after each rainfall event that is on November 16 and after 105, 7, 25, 5, 5,

**Table 1** Site and soil characteristics of selected land cover/land uses

Soil	Surface [ha]	Plant cover [%]	Slope [%]	Depth [cm]	Horizon development	Sand [%]	Silt [%]	Clay [%]
V	0.50	10	17	39	Ap, C/R	81.54 (10.65)	12.34 (3.42)	6.12 (1.88)
O	0.50	20	18	38	Ap, C/R	79.20 (8.65)	13.98 (2.06)	6.82 (2.13)
PRa	0.50	60	17	32	Ap, C/R	70.88 (10.92)	17.06 (2.96)	12.06 (2.33)
PRb	0.50	60	17	33	Ap, C/R	71.73 (9.74)	16.45 (4.22)	11.82 (3.51)
MB	0.50	70	18	35	Ap, C/R	72.48 (6.19)	16.16 (5.12)	11.36 (5.23)
MC	0.50	50	18	33	Ap, C/R	78.62 (12.45)	15.08 (4.98)	6.30 (3.55)
PI	0.50	40	17	30	Ap, C/R	72.66 (10.64)	19.66 (6.17)	7.68 (1.66)
S	0.50	50	18	41	Ap, C/R	75.45 (7.47)	16.13 (4.19)	8.42 (2.35)
PIC	0.50	5	19	38	Ap, C/R	73.92 (12.45)	17.82 (6.06)	8.26 (2.52)
SC	0.50	20	18	40	Ap, C/R	76.18 (9.44)	15.25 (5.08)	8.57 (3.10)

Soil. V under vines, O under olive groves, PRa,b under pasture, MB under *Erica* shrub, MC: under *Cistus* shrub, PI under pine trees, S under cork trees, PIC under burnt pines, SC under burnt corks

**Fig. 1** Examples of studied soil environments: **a, c, e** represent the soil under vines (V), under *Cistus monspeliensis* dominated shrub and under burnt pines (PIC); **b, d, f** show the Gerlach plots installed in the area



and 26 days (corresponding to rainfall generating runoff) and analysed soon after. Moreover, splash erosion was measured at each rainfall event by collecting the splashed particles in  $5 \times 8$  cm cylindrical pots placed around each plot. Splashed particles were oven dried, weighed and reported as gram per metre square. Runoff water was stored in plastic bottles to determine dissolved organic carbon (DOC) according to the method of Vance et al. (1987) and total dissolved nitrogen (TDN) by the Kjeldhal method. Phosphate ( $\text{PO}_4^{-3}$ ), nitrate

( $\text{NO}_3^-$ ) and ammonium ( $\text{NH}_4^+$ ) content were also measured in runoff water by using the CADAC 200 spectrophotometer equipped with the Dr. Lange test for rapid analytical determination of these compounds. Eroded soils were analysed for eroded organic carbon (EOC) and total eroded nitrogen (TEN) content with the Walkley and Black method and the Kjeldhal method respectively. After each recorded rainfall, the field measurements of surface mechanic impedance (MI) with a static cone penetrometer Terzaghi UFL-031 model and bulk

**Table 2** Rainfall characteristics of the seven recorded events from November 2011 to May 2012

Rainfall number	1	2	3	4	5	6	7
Date	11/16/11	02/27/12	03/06/12	04/04/12	04/09/12	04/12/12	05/10/12
DOY	320	58	66	95	100	103	131
Rainfall [mm]	60.10	12.30	18.90	139.70	23.30	57.90	79.60
Rainfall duration [h]	24	38	29	24	15	62	30
Average rainfall intensity [ $\text{mm h}^{-1}$ ]	2.55	0.34	0.65	5.82	1.55	0.93	2.65
Total kinetic energy [ $\text{J m}^2$ ]	936	69	174	2462	189	484	1260

DOY day of the year

density (BD) with the core method (Forster 1995) were also carried out around the erosion plots. Soil moisture was derived from bulk density measurements after drying the samples overnight at 105 °C.

### 2.3 Statistical analyses

Statistical analysis was carried out by using the program Statistics (version 7.1, 2007, Statsoft Inc., Tulsa, OK, USA). ANOVA was used to investigate the data variations into and among soil environments along the recorded rainfall events. Accordingly, ANOVA was run by using the number of replications (3), mean and standard deviation of a given parameter at any rainfall event (7) when comparing data variability into one environment. Likewise, to compare data variability among environments, the mean of three values of a given parameter per each rainfall (7) and all environments (10) were run.

Patterns of runoff, erosion and nutrient removal along the different land uses/soil environments under the effect of selected rainfall events were investigated by means of regression equations. Principal component analysis (PCA) was performed to provide information on the relationships between the measured variables and soil environments. Components were selected by using the eigenvalue which measures the variance in all the variables accounted for by one component. The Kaiser criterion allowed dropping all components with eigenvalues under 1.0. Components were named according to variable's loadings and the correlation coefficients between the original variables and each component. Scores for components assisted in determining the relevance of each soil environments for contributing to soil properties improvement.

## 3 Results and discussion

### 3.1 Influence of soil environments on soil characteristics

Soil properties differed largely according to land use/land cover type. As may be observed in Table 1, the sand fraction was predominant within the particle size separates and the textural class ranged from loamy sand (V, O, MC soils) to sandy loam (PRa, PRb, MB, PI, S, PIC and SC soils) for the Ap horizon. The total profile depth varied from 30 cm in soils under pines to 39 cm in soils under vines; all soils developed over compacted slates. The A horizon scarcely reaches 10 cm in depth. Selected soil parameters were analysed at each rainfall event and mean values of three replicates with the standard deviation are reported in Table 3.

Along the seven rainfall events, soils under cultivated vines (V) and olive groves (O) showed the lowest organic carbon (average  $3.70 \pm 0.41$  and  $12.23 \pm 1.20$  g kg<sup>-1</sup>), total nitrogen (average  $0.51 \pm 0.04$  and  $1.45 \pm 0.06$  g kg<sup>-1</sup>), structural stability of aggregates (average  $25.52 \pm 8.30$  and

$47.22 \pm 15.87$  %) and cation exchange capacity (average  $5.47 \pm 0.46$  and  $6.55 \pm 0.13$  cmol kg<sup>-1</sup>), while values of these parameters increased progressively according to the extent of vegetative cover and fire occurrence (Table 3). The highest values of these parameters were recorded in soils PRa, PRb and MB, though WSA resulted somewhat higher in recently burnt soils, probably due to a hardening effect of temperature on soil aggregates (Mataix-Solera and Doerr 2004). Likewise, considerable differences were noticed in soil properties of MB, MC, PI and S environments. The soil under *Erica arborea* shrub (MB) seems to contribute to better physico-chemical properties than the MC soil, as in the former, the average increase of SOC and CEC was 104 and 152 % with respect to the latter. Lower organic carbon (SOC), total nitrogen (N<sub>T</sub>) and cation exchange capacity (CEC) of MC soil may be ascribed to frequent forest fires, interrupting the succession of heterogeneous spontaneous vegetation along the renaturalization processes. Fire-affected areas are rapidly colonized by opportunistic plants like *Cistus* species, competing against other species (Jackson et al. 2002). Trabaud and Oustric (1989) reported that in frequently fire-affected areas, the undergrowth germinating plants (through fire-resistant seeds, like Cistaceae) may overwhelm sprouting plants (like Ericaceae) with stumps repeatedly affected by fire and gradually losing their sprouting ability. This substitution is detrimental to soil properties and represents a step back in the renaturalization process (Pardini et al. 2004a). A similar trend was observed in PI and S environments, where soils under stands of cork trees (S) increased SOC and N<sub>T</sub> content by 220 and 101 % with respect to soil PI, suggesting that less degradable pine litter may delay C and N entry into soil. However, WSA increased on average only by 17 % in soil MB and S with respect to soil MC and PI probably indicating the complexity of aggregate stability evaluation in abandoned soils periodically affected by fire. Mataix-Solera et al. (2011) hypothesized different fire effects on soil aggregation depending on the soil surface exposition to temperature: from almost no effect to a sharp increase of WSA due to the recrystallization of Fe and Al oxyhydroxides. The recently burnt sites PIC and SC showed rather similar values of pH, which were higher with respect to other environments because of the ash effect, buffering the acidic nature of the investigated soils (Noble et al. 1996). The average values of available phosphorus (P<sub>AV</sub>) were consistent with amounts expected in cultivated, abandoned and burnt environments though numbers differed slightly (Table 3). Soil V showed a mean value of 37.41 mg kg<sup>-1</sup> against 35.88 mg kg<sup>-1</sup> of soil O, i.e., 4 % higher; a 2.6 % difference was found between PRa and PRb, 6 % between MB and MC, 5 % between S and PI, and 1 % between SC and PIC. The lowest P<sub>AV</sub> values were found in soils MB and MC while values increased sharply in PIC and SC soils probably because of the intense mineralizing effect on organic P produced by fire with a consequent increase of

**Table 3** Physicochemical characteristics of the studied soils

Soil <sup>a</sup>	Rainfall number	N <sup>b</sup>	WSA <sup>c</sup> [%]	pH	SOC <sup>d</sup> [g kg <sup>-1</sup> ]	N <sub>T</sub> <sup>e</sup> [g kg <sup>-1</sup> ]	P <sub>AV</sub> <sup>f</sup> [mg kg <sup>-1</sup> ]	CEC <sup>g</sup> [cmol kg <sup>-1</sup> ]
V	1	3	22.8 (3.7)	6.1 (0.5)	3.5 (0.8)	0.5 (0.1)	22.6 (6.3)	5.1 (1.1)
	2	3	39.6 (6.8)	6.4 (0.5)	3.8 (0.9)	0.4 (0.1)	43.7 (11.5)	5.3 (1.0)
	3	3	32.2 (4.9)	6.2 (0.6)	4.1 (0.9)	0.5 (0.1)	35.2 (12.5)	6.1 (0.1)
	4	3	13.8 (3.0)	6.2 (0.6)	2.9 (0.4)	0.5 (0.1)	26.1 (13.2)	5.0 (0.9)
	5	3	22.6 (9.2)	6.2 (0.9)	3.8 (0.7)	0.6 (0.1)	50.3 (12.5)	5.8 (0.7)
	6	3	26.2 (5.2)	6.3 (0.6)	3.9 (0.2)	0.5 (0.1)	54.6 (14.1)	5.9 (0.9)
	7	3	21.5 (8.6)	6.3 (0.8)	4.0 (0.3)	0.6 (0.1)	29.5 (12.6)	5.1 (0.8)
O	1	3	38.7 (9.5)	6.2 (0.8)	11.9 (2.1)	1.4 (0.3)	35.3 (10.3)	6.4 (1.2)
	2	3	71.8 (7.2)	6.2 (0.7)	13.2 (2.1)	1.6 (0.5)	37.5 (10.2)	6.8 (1.0)
	3	3	56.9 (4.4)	6.2 (0.7)	12.0 (1.8)	1.4 (0.3)	38.5 (12.5)	6.5 (1.0)
	4	3	22.6 (5.4)	6.3 (0.5)	12.2 (1.1)	1.4 (0.3)	34.2 (13.4)	6.6 (1.1)
	5	3	38.9 (6.8)	6.2 (0.6)	14.1 (2.0)	1.5 (0.3)	35.9 (10.8)	6.6 (1.2)
	6	3	55.1 (9.2)	6.2 (0.5)	10.2 (1.9)	1.4 (0.4)	36.5 (11.9)	6.6 (0.9)
	7	3	46.6 (11.8)	6.2 (0.6)	12.1 (1.7)	1.5 (0.4)	33.8 (13.4)	6.4 (0.9)
PRa	1	3	86.4 (10.3)	5.8 (0.7)	34.8 (9.2)	3.2 (0.9)	38.9 (14.1)	18.7 (2.5)
	2	3	88.4 (7.5)	5.8 (0.8)	38.4 (11.3)	3.3 (0.8)	20.1 (6.6)	20.1 (3.5)
	3	3	95.3 (13.9)	5.9 (0.5)	37.5 (10.5)	3.3 (0.8)	39.3 (11.7)	19.4 (2.7)
	4	3	95.8 (8.3)	6.0 (0.6)	35.1 (12.2)	3.2 (0.7)	17.4 (9.5)	18.6 (2.0)
	5	3	84.7 (5.3)	5.7 (0.7)	36.9 (10.7)	3.0 (0.6)	37.6 (4.3)	17.9 (3.0)
	6	3	89.5 (10.3)	5.9 (0.6)	34.8 (8.9)	3.0 (0.8)	28.2 (12.6)	20.9 (2.3)
	7	3	89.5 (4.1)	5.9 (0.6)	36.6 (14.1)	3.2 (0.8)	40.4 (6.9)	19.6 (2.5)
PRb	1	3	87.1 (7.2)	5.9 (0.7)	36.8 (11.7)	2.9 (0.8)	37.4 (10.1)	16.4 (3.8)
	2	3	90.2 (15.4)	6.0 (0.6)	38.2 (13.1)	3.0 (0.7)	39.2 (13.6)	17.1 (4.6)
	3	3	98.4 (2.5)	5.9 (0.5)	34.6 (9.2)	3.1 (0.7)	28.1 (4.9)	16.9 (3.5)
	4	3	86.1 (1.4)	5.9 (0.6)	39.2 (12.1)	2.9 (0.7)	27.6 (5.5)	17.5 (4.0)
	5	3	91.1 (4.5)	5.9 (0.6)	39.5 (13.5)	2.9 (0.6)	19.1 (3.2)	18.0 (2.9)
	6	3	88.5 (6.1)	6.0 (0.5)	37.2 (14.3)	3.1 (0.7)	26.8 (6.2)	17.2 (3.1)
	7	3	82.7 (3.9)	6.0 (0.6)	36.5 (10.7)	3.1 (0.8)	38.1 (2.4)	16.8 (2.8)
MB	1	3	86.9 (7.9)	6.2 (0.5)	47.7 (13.1)	3.1 (0.8)	23.7 (8.9)	18.4 (6.1)
	2	3	92.4 (5.1)	6.2 (0.7)	45.9 (12.6)	3.2 (0.8)	25.1 (10.1)	20.1 (3.6)
	3	3	88.2 (1.8)	6.1 (0.3)	49.1 (15.2)	3.2 (0.8)	24.7 (9.9)	19.5 (3.8)
	4	3	89.4 (6.0)	6.2 (0.5)	44.7 (13.5)	3.2 (0.9)	26.2 (11.0)	21.2 (2.9)
	5	3	85.2 (2.6)	6.3 (0.5)	46.8 (18.7)	3.0 (0.7)	22.9 (9.8)	18.4 (4.1)
	6	3	90.1 (3.5)	6.2 (0.4)	48.7 (11.7)	3.1 (0.7)	23.8 (10.2)	19.4 (3.9)
	7	3	84.3 (5.0)	6.2 (0.4)	45.2 (13.5)	3.2 (0.6)	25.1 (10.8)	19.4 (5.1)
MC	1	3	63.5 (1.9)	6.0 (0.9)	23.8 (10.1)	1.8 (0.7)	26.6 (9.2)	7.5 (2.7)
	2	3	82.5 (3.4)	6.1 (0.5)	18.9 (8.3)	2.2 (0.6)	20.5 (9.8)	8.1 (2.2)
	3	3	88.5 (0.4)	6.1 (0.3)	21.7 (10.5)	2.2 (0.7)	21.7 (10.1)	7.2 (3.1)
	4	3	57.6 (1.2)	6.2 (0.6)	22.2 (11.7)	1.9 (0.8)	25.9 (9.0)	7.3 (3.1)
	5	3	77.1 (4.6)	6.2 (0.67)	24.8 (9.2)	1.9 (0.6)	20.9 (9.5)	8.1 (2.5)
	6	3	80.3 (3.8)	6.1 (0.5)	26.1 (9.8)	1.9 (0.70)	18.8 (9.7)	8.2 (3.2)
	7	3	78.6 (5.2)	6.1 (0.8)	23.4 (10.3)	1.8 (0.6)	26.8 (10.1)	7.8 (2.0)
PI	1	3	76.3 (1.9)	6.0 (0.7)	8.5 (3.1)	1.6 (0.3)	28.8 (10.6)	10.3 (2.3)
	2	3	82.2 (3.6)	6.1 (0.7)	10.2 (4.5)	1.5 (0.4)	29.1 (10.1)	11.4 (2.0)
	3	3	77.4 (1.1)	6.0 (0.2)	9.5 (3.2)	1.4 (0.3)	27.8 (13.5)	10.7 (3.6)
	4	3	66.8 (1.3)	6.1 (0.3)	10.5 (6.6)	1.5 (0.4)	28.4 (9.2)	11.9 (3.1)
	5	3	75.3 (3.6)	6.1 (0.7)	11.4 (5.1)	1.5 (0.3)	29.3 (10.3)	10.8 (4.1)
	6	3	79.6 (2.9)	6.0 (0.6)	10.8 (3.6)	1.6 (0.5)	27.9 (10.4)	12.0 (3.7)

**Table 3** (continued)

Soil <sup>a</sup>	Rainfall number	N <sup>b</sup>	WSA <sup>c</sup> [%]	pH	SOC <sup>d</sup> [g kg <sup>-1</sup> ]	N <sub>T</sub> <sup>e</sup> [g kg <sup>-1</sup> ]	P <sub>AV</sub> <sup>f</sup> [mg kg <sup>-1</sup> ]	CEC <sup>g</sup> [cmol kg <sup>-1</sup> ]
S	7	3	73.2 (4.3)	6.1 (0.4)	12.3 (6.1)	1.4 (0.5)	28.1 (8.6)	11.3 (4.1)
	1	3	88.9 (6.5)	6.4 (0.8)	31.8 (14.1)	2.8 (0.5)	29.7 (9.5)	15.4 (3.5)
	2	3	94.3 (4.5)	6.3 (0.6)	30.8 (10.4)	2.9 (0.4)	30.3 (10.1)	15.0 (2.2)
	3	3	92.5 (7.2)	6.2 (0.5)	33.5 (12.6)	3.0 (0.4)	31.3 (11.2)	14.8 (2.8)
	4	3	84.3 (1.9)	6.4 (0.2)	38.4 (11.3)	3.1 (0.4)	29.6 (9.4)	15.6 (2.4)
	5	3	87.6 (4.7)	6.4 (0.4)	34.2 (13.5)	3.1 (0.6)	29.8 (11.6)	16.0 (2.0)
	6	3	91.5 (2.7)	6.3 (0.5)	35.3 (10.7)	2.9 (0.5)	30.1 (8.8)	15.8 (2.2)
PIC	7	3	84.2 (3.6)	6.4 (0.4)	30.6 (11.5)	2.9 (0.4)	28.9 (9.9)	15.4 (2.1)
	1	3	93.2 (5.7)	7.7 (0.3)	27.4 (9.9)	2.4 (0.6)	73.9 (21.1)	10.3 (3.6)
	2	3	90.4 (3.1)	7.5 (0.4)	28.3 (11.2)	2.5 (0.6)	60.4 (16.4)	10.7 (2.8)
	3	3	89.6 (2.5)	7.5 (0.4)	26.6 (12.4)	2.4 (0.7)	66.2 (10.5)	19.1 (1.7)
	4	3	94.2 (4.6)	7.8 (0.5)	27.2 (10.5)	2.5 (0.6)	57.4 (7.4)	18.9 (2.4)
	5	3	88.7 (4.1)	7.7 (0.6)	29.4 (12.4)	2.5 (0.5)	59.2 (14.2)	10.4 (3.1)
	6	3	93.6 (1.9)	7.4 (0.7)	27.1 (12.6)	2.6 (0.6)	69.7 (17.8)	10.9 (3.6)
SC	7	3	90.3 (4.8)	7.5 (0.3)	30.1 (9.8)	2.5 (0.6)	71.6 (13.4)	11.9 (2.7)
	1	3	94.9 (10.1)	7.6 (0.6)	32.8 (11.1)	2.7 (0.8)	75.2 (15.9)	14.0 (3.1)
	2	3	89.5 (3.7)	7.7 (0.3)	29.4 (10.6)	2.7 (0.8)	67.1 (21.1)	13.9 (3.2)
	3	3	91.5 (6.8)	7.6 (0.6)	29.8 (10.3)	2.6 (0.7)	59.3 (9.5)	14.1 (2.6)
	4	3	90.6 (4.8)	7.7 (0.3)	31.5 (12.6)	2.9 (0.7)	76.4 (12.2)	14.3 (2.2)
	5	3	88.7 (2.1)	7.7 (0.8)	33.6 (9.9)	2.6 (0.6)	61.1 (13.9)	13.7 (3.9)
	6	3	92.4 (8.2)	7.6 (0.3)	30.3 (10.8)	2.9 (0.6)	54.4 (17.2)	14.2 (4.0)
	7	3	87.9 (3.4)	7.6 (0.5)	31.7 (11.6)	2.5 (0.8)	68.1 (14.7)	14.3 (4.1)

Results are the mean of three replications per recorded rainfall event (standard deviation in parenthesis)

<sup>a</sup> Soil environments. *V* under vines, *O* under olive groves, *Pra,b* under pasture, *MB* under *Erica* shrub, *MC* under *Cistus* shrub, *PI* under pine trees, *S* under cork trees, *PIC* under burnt pines, *SC* under burnt corks

<sup>b</sup> Number of soil replications per each soil environment at any rainfall event

<sup>c</sup> Water-stable aggregates

<sup>d</sup> Soil organic carbon

<sup>e</sup> Total nitrogen

<sup>f</sup> Available phosphorus

<sup>g</sup> Cation exchange capacity

inorganic P (Saa et al. 1993; Certini 2005). On average, P<sub>AV</sub> concentration in PIC and SC soils increased by 130 and 120 % with respect to soils PI and S (same type of environments but unburnt). The relatively high amount of available phosphorus found in cultivated sites was probably due to phosphate fertilization carried out in the past, which may last for longer periods. The overall data reported in Table 3 indicated that soils V, O, MC and PI present poorer soil properties with respect to other soils (P<sub>Ra</sub>, P<sub>Rb</sub>, MB, S), due to agricultural mismanagement (V, O), fire effect (MC) and probably unsuitable re-population (PI) for soil recovery.

The selected land use/land cover type reacted differently to the seven recorded rainfall events; characteristics for these are listed in Table 2. No significant difference was found in any of the land use/land cover types for MI, pH, SOC, N<sub>T</sub> and CEC, revealing that the different rainfall intensities did not cause

relevant changes in these parameters. Soil moisture (SM) data varied significantly only in soils O, S and SC, as bulk density did in soils V and O (Table 4). When values of SM were plotted against MI and BD, significant positive and negative correlations were obtained (Fig. 2a, b). The two linear regression equations point out some peculiarities already reported by Gispert et al. (2013), regarding the susceptibility to surface compaction of soils with higher organic carbon content such as P<sub>Ra</sub>, P<sub>Rb</sub> and MB, showing MI increasing in a range of 350–450 kPa at 35–45 % SM content (Fig. 2a). This pattern suggests that organic soils may be subjected to fast wetting-drying cycles causing strong particle packing at the surface. However, the negative correlation between SM and BD is logical, attributing higher SM values to soils with lower BD.

The relationships between eroded soil concentration, runoff, splash and hydraulic conductivity may reflect the

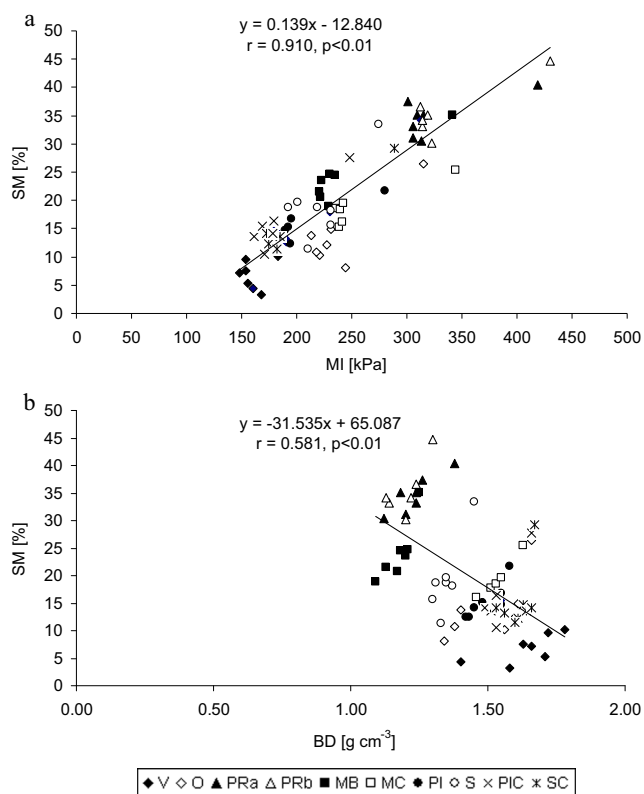
**Table 4** Analysis of variance (ANOVA) for physical and chemical data variability significance within and between soils following the seven recorded rainfall events

Soil <sup>a</sup>	Selected soil variables <sup>b</sup>																		
	SM [%]		BD [kg m <sup>3</sup> ]		MI [kPa]		WSA [%]		pH		SOC [g kg <sup>-1</sup> ]		N <sub>T</sub> [g kg <sup>-1</sup> ]		P <sub>AV</sub> [mg kg <sup>-1</sup> ]		CEC [cmol kg <sup>-1</sup> ]		
	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p	
Into each soil environment per rainfall																			
V	2.029	0.129	3.394	0.028*	0.070	0.998	5.196	0.005**	0.057	0.999	1.236	0.346	0.372	0.885	3.576	0.023*	0.874	0.535	
O	4.990	0.006**	4.113	0.014*	0.473	0.817	11.537	0.000**	0.028	1.000	1.278	0.328	0.091	0.996	0.058	0.999	0.047	0.999	
PRa	0.472	0.818	1.913	0.149	0.663	0.681	0.646	0.693	0.101	0.995	0.050	0.999	0.077	0.998	2.873	0.049*	0.316	0.918	
PRb	0.614	0.716	1.304	0.318	0.812	0.578	1.394	0.284	0.035	1.000	0.059	0.999	0.051	0.999	2.985	0.043*	0.065	0.999	
MB	1.223	0.352	0.656	0.686	1.622	0.213	1.000	0.463	0.033	1.000	0.044	1.000	0.038	1.000	0.036	1.000	0.150	0.986	
MC	0.791	0.591	1.132	0.394	1.518	0.243	31.822	0.000**	0.028	1.000	0.162	0.983	0.182	0.977	0.072	0.998	0.071	0.998	
PI	0.631	0.704	1.347	0.301	1.280	0.327	8.664	0.000**	0.018	1.000	0.206	0.969	0.104	0.995	0.010	1.000	0.113	0.993	
S	3.932	0.016*	0.665	0.679	0.627	0.706	2.052	0.126	0.097	0.996	0.160	0.983	0.172	0.980	0.016	1.000	0.091	0.996	
PIC	2.428	0.080	1.334	0.306	0.823	0.571	0.897	0.523	0.332	0.909	0.041	1.000	0.042	1.000	0.574	0.745	0.393	0.872	
SC	3.840	0.018*	0.421	0.853	1.831	0.165	0.447	0.836	0.042	1.000	0.060	0.999	0.082	0.997	0.230	0.960	0.011	1.000	
Among soil environments per rainfall																			
Average rainfall intensity [mm h <sup>-1</sup> ]																			
2.55	5.440	0.001**	6.205	0.000**	1.883	0.114	36.317	0.000**	3.475	0.010**	6.309	0.000**	7.033	0.000**	5.122	0.001**	7.004	0.000**	
0.34	4.343	0.003**	13.595	0.000**	1.861	0.119	16.447	0.000**	3.503	0.009**	6.306	0.000**	8.182	0.000**	4.429	0.003**	11.005	0.000**	
0.65	3.922	0.005**	9.220	0.000**	1.628	0.174	36.927	0.000**	4.911	0.001**	6.153	0.000**	8.263	0.000**	5.044	0.001**	10.923	0.000**	
5.82	6.552	0.000**	9.194	0.000**	3.271	0.013*	136.566	0.000**	5.842	0.001**	5.610	0.001**	7.451	0.000**	5.686	0.001**	13.909	0.000**	
1.55	6.338	0.000**	13.268	0.000**	2.334	0.047*	64.200	0.000**	3.617	0.008**	4.663	0.002**	8.832	0.000**	5.970	0.000**	8.045	0.000**	
0.93	7.339	0.000**	7.027	0.000**	2.030	0.090	38.413	0.000**	3.768	0.006**	6.495	0.000**	7.758	0.000**	5.488	0.001**	8.912	0.000**	
2.65	5.858	0.000**	11.864	0.000**	1.558	0.195	41.404	0.000**	3.417	0.011*	5.099	0.001**	8.347	0.000**	5.914	0.000**	8.891	0.000**	

<sup>a</sup> Soil environments. V under vines, O under olive groves, PRa,b under pasture, MB under *Erica* shrub, MC under *Cistus* shrub, PI under pine trees, S under cork trees, PIC under burnt pines, SC under burnt corks

<sup>b</sup> SM soil moisture, BD bulk density, MI mechanic impedance, WSA water-stable aggregates, SOC soil organic carbon, N<sub>T</sub> total nitrogen, P<sub>AV</sub> available phosphorus, CEC cation exchange capacity  
\*\**p* < 0.01; \**p* < 0.05

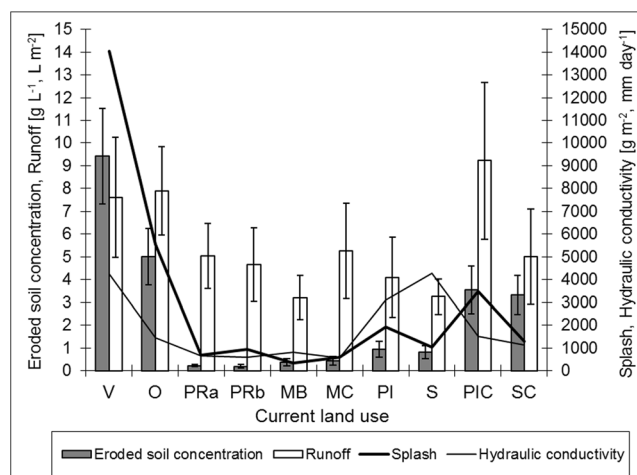




**Fig. 2** a, b Linear regression equations showing the positive and negative correlations between soil moisture (SM) and mechanic impedance (MI) and bulk density (BD) respectively for all the ten soil environments along the seven recorded rainfall events

behaviour of the studied soils (Fig. 3). The trend depicted by eroded soil concentration (grey bar) and runoff (white bar) agrees with poorer properties of soils V, O, MC and PI resulting in higher eroded soil yield even at comparatively lower runoff volume, with splash erosion (coarse line) following the same trend. However, hydraulic conductivity values (fine line) show an opposite trend with values decreasing in soils PRa, PRb and MB, corroborating that temporary surface particle packing may occur in these apparently more structured soils, thus limiting water entry and diffusion. Although reduced infiltration means increased runoff and erosion, soils do not seem to be affected by severe particle dragging by overland flow (Fig. 3). Nevertheless, these results may warn of long-term effects in such shallow soils under renaturalization because compacted surface layers may alter the soil carbon pool by limiting additions of fresh organic matter to the soil (Emran et al. 2012).

As expected, ANOVA established significant data variability for all soil properties among land use/land cover types at any rainfall event while in each land use/land cover type significance was scant (Table 4). Water stability of aggregate (WSA) data varied significantly in soils under vines ( $p = 0.005$ ), olive groves ( $p = 0.000$ ), *Cistus* shrub ( $p = 0.000$ ) and stands of pine trees ( $p = 0.000$ ) probably due to the effect of rainfall intensity on weaker soil surfaces



**Fig. 3** Trend of runoff in litre per metre (white bar), eroded soil concentration in gram per litre (grey bar), splash erosion in gram per metre (coarse line) and hydraulic conductivity in millimetre per day (fine line) for all the ten soil environments along the seven recorded rainfall events

with lower organic carbon content, where easier aggregate disruption by raindrop kinetic energy may have occurred (Dunjo et al. 2003). Significant data variability of  $P_{AV}$  were also found along the seven rainfall events in soil under vines ( $p = 0.023$ ) and pasture (PRa  $p = 0.049$ ; PRb,  $p = 0.043$ ), suggesting (i) different release of  $P_{AV}$  in previously fertilized vines at the time of full cultivation for wine production and (ii) recent grazing activity and manure addition in pasture soils, where alternate rainfall intensity may produce differential  $P_{AV}$  availability in soil. Though working with different soils, Swaine (1996) reported that rainfall gradient and nutrient availability strongly covary suggesting a clear effect on plants.

Previous data reported by Pardini et al. (2003) inferred that changes in soil properties under a similar environment subjected to natural evolution after abandonment may not be relevant over a short sequence of even strongly changing rainfall intensity, thus increasing statistical significance among soil environments. Besides that, mechanic impedance (MI) showed significant data variability among soil environments only at 5.82 and 1.55 mm h<sup>-1</sup> probably due to marked soil surface response to different raindrop impact.

### 3.2 Erosion and nutrients losses

Significant linear relationships were found between both recorded rainfall events and runoff and runoff and eroded soil (ES) for each soil environment (Table 5). Soil erosion was always higher at higher recorded rainfall intensity and runoff independently of total eroded soil yield, indicating that overland flow may also affect more stable soils. Erosion patterns may be seen in Fig. 4, depicting the susceptibility to erosion in the order V > O > PIC = SC while the erosion in soils PRa, PRb, MB, MC, PI and S was negligible. The soils V and O eroded together

**Table 5** Linear regression equations: runoff as a function of rainfall and eroded soil as a function of runoff in each soil type along the observed period

Soil environment	Equation	Correlation	Significance
Vineyards (V)	Runoff =6.997 Rainfall +11.505	0.965	**
Olive groves (O)	Runoff =4.714 Rainfall +14.830	0.967	**
Pasture (PRa)	Runoff =4.806 Rainfall +7.873	0.898	**
Pasture (PRb)	Runoff =6.216 Rainfall +10.616	0.864	**
<i>Erica arborea</i> shrub (MB)	Runoff =3.818 Rainfall +5.278	0.935	**
<i>Cistus monspeliensis</i> shrub (MC)	Runoff =4.825 Rainfall +8.203	0.934	**
Stands of pine trees (PI)	Runoff =4.273 Rainfall +7.383	0.932	**
Stands of cork trees (S)	Runoff =3.075 Rainfall +6.391	0.920	**
Burnt pine trees (PIC)	Runoff =5.381 Rainfall +15.954	0.974	**
Burnt cork trees (SC)	Runoff =4.303 Rainfall +8.360	0.963	**
vineyards (V)	Eroded soil =8.847 Runoff +19.003	0.925	**
Olive groves (O)	Eroded soil =5.038 Runoff +0.336	0.855	**
Pasture (PRa)	Eroded soil =0.073 Runoff +2.064	0.640	NS
Pasture (PRb)	Eroded soil =0.070 Runoff +2.236	0.869	**
<i>Erica arborea</i> shrub (MB)	Eroded soil =0.152 Runoff +2.826	0.956	**
<i>Cistus monspeliensis</i> shrub (MC)	Eroded soil =0.338 Runoff +1.967	0.910	**
Stands of pine trees (PI)	Eroded soil =0.294 Runoff +8.511	0.875	**
Stands of cork trees (S)	Eroded soil =0.174 Runoff +7.460	0.470	NS
Burnt pine trees (PIC)	Eroded soil =3.129 Runoff +10.736	0.889	**
Burnt cork trees (SC)	Eroded soil =0.904 Runoff +41.547	0.606	NS

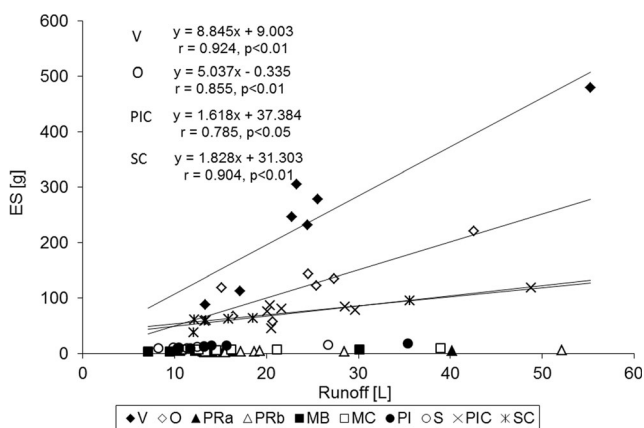
NS Not significant

\*\* $p < 0.01$

2606.87 g of soil along the seven rainfall events, equivalent to  $115.86 \text{ g m}^{-2}$ , though soil under vines (V) eroded 101 % more than soil under olive groves (O). Their total eroded soil yield increased by 5043, 3129, 2321 and 159 % with respect to PRa + PRb, MB + MC, PI + S, and PIC + SC soils. However, when analysing differences in each soil environment, the total erosion of soil PRb was 14 % higher than soil PRa accounting for rather similar soil response to rainfall impact. Soils MC, PIC and PI eroded 38, 29 and 19 % more than soils

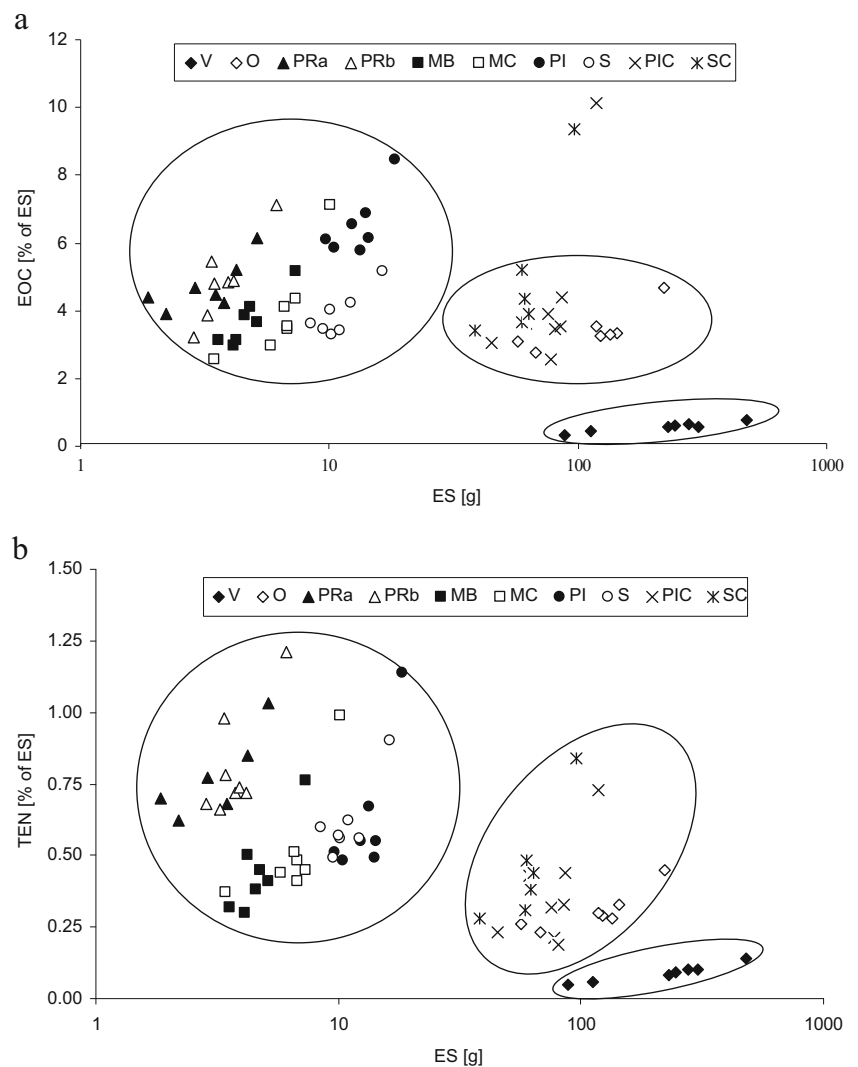
MB, SC and S respectively suggesting that plant species and recurrent fires in the former soils may cause higher susceptibility to erosion (Pardini et al. 2004b). Both the eroded organic carbon (EOC) and total eroded nitrogen (TEN) were expressed as percent of the eroded soil (Fig. 5a, b). EOC amount in eroded soils V, O, PRa, PRb, MB, MC, PI, S, PIC and SC increased by 45, 45, 15, 57, 48, 104, 36, 40, 191, and 132 %, respectively, at the highest recorded rainfall intensity ( $5.82 \text{ mm h}^{-1}$ ) with respect to the mean of the other recorded rainfall period.

The soils MC, PI, PIC and SC showed the highest EOC removal (Fig. 5a). Total eroded nitrogen (TEN) had a similar trend (Fig. 5b), except values of soil under pasture (PRa and PRb), with higher values probably due to recent grazing and deposition of animal. In general, EOC amount released with the eroded soil from each soil environment at any rainfall was higher than the SOC of the soil itself, except for the soil under *Erica arborea* shrubs which on average mobilized only 3.72 % of EOC from soil surface against 4.69 % of SOC stock (i.e. a negative balance of -26 %). Similar findings have been reported by De Nobili and Maggioni (1993) who stated that the partially humified decaying debris removed from the surface organic fraction may reach several times that of the soil. In fact, by averaging the values of SOC and EOC along the seven rainfall events, EOC was 521, 180, 74, 58, 53, 51, 30, 29, and 16 % higher than SOC in the following order: Soil PI, O, MC, PIC, SC, V, PRb, PRa, S, accounting for the



**Fig. 4** Linear regression of eroded soil in grammes vs runoff in litres to indicate the different response of soil environments to the recorded rainfall events

**Fig. 5** Scatter of eroded organic carbon (EOC) values (a) and total eroded nitrogen (TEN) values (b) expressed as % of eroded soil (ES) for all soil environments along the seven recorded rainfall events



impoverishment of organic debris from soil surface. According to Lal (2003), water erosion submits particulate organic carbon to detachment, breakdown, transport/redistribution and deposition elsewhere. This process preferentially removes the low density, labile organic fraction exposing this material to mineralization and causing severe depletion of the SOC pool, especially in more vulnerable soils.

Runoff data varied significantly within each soil environment at each rainfall event (Table 6). However, data variability of runoff products in each environment was random probably depending on many morphological and pedological factors. Eroded soil (ES) data varied significantly only in soils V, O and MC; EOC data in soils PRb, MC, PIC and SC, and TEN data in soils MB, MC, PI, PIC and SC. Besides that, ES, EOC and TEN data varied significantly among soil environments at each rainfall event (Table 6).

Dissolved organic carbon (DOC) data were not significantly different in each environment nor among environments for the recorded rainfall events (Table 6). By contrast, ANOVA

showed significant data variability for dissolved organic nitrogen (TDN) in V, O, PRa, PRb, MB, MC, PIC, and SC soils but not among environments, corroborating that C and N may undergo different erosion dynamics (Pardini et al. 2004b). While the significant data variability of EOC data in MC, PIC and SC soils may be explained through aggregation breakdown by raindrop impact and shearing force of runoff, EOC data in soil PRb (high WSA and SOC) may have changed significantly from periodical grazing impacts, causing differential removal of organic and mineral surface particles, accentuating the loss of previously protected organic matter. Celik (2005) found that water-stable aggregation data (WSA) were greater in the pasture and forest soils compared to the cultivated soils, while Abril et al. (2005) reported that soil carbon under undisturbed conditions was relatively constant throughout the year with respect to sites both burned and grazed where carbon values fluctuated markedly. The erosion dynamics may be more related to aggregate disruption and the dragging force of the overland flow

**Table 6** Analysis of variance (ANOVA) for erosion-related data variability significance within and between soils following the seven recorded rainfall events

Soil <sup>a</sup>	Selected soil variables <sup>b</sup>																		
	Runoff [L]		ES [g]		EOC [%]		TEN [%]		DOC [mg L <sup>-1</sup> ]		TDN [mg L <sup>-1</sup> ]		Ammonia [mg L <sup>-1</sup> ]		Nitrate [mg L <sup>-1</sup> ]		Phosphate [mg L <sup>-1</sup> ]		
	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p	F	p	
Into soil environments per rainfall																			
V	4.014	0.015*	8.676	0.000**	1.686	0.197	2.256	0.098	1.164	0.378	3.020	0.041*	0.766	0.608	1.827	0.165	1.565	0.229	
O	3.234	0.024*	3.092	0.038*	0.873	0.538	1.610	0.217	0.962	0.484	2.928	0.046*	0.978	0.476	0.854	0.550	1.768	0.178	
PRa	9.337	0.000**	1.754	0.181	1.322	0.311	1.589	0.222	0.687	0.664	4.473	0.011*	3.031	0.041*	0.745	0.623	0.657	0.685	
PRb	7.713	0.001**	1.513	0.245	3.694	0.021*	1.570	0.228	0.483	0.811	3.029	0.041*	2.789	0.048*	0.851	0.552	0.816	0.575	
MB	6.507	0.002**	0.862	0.546	1.780	0.175	5.399	0.004**	0.859	0.547	3.652	0.021*	0.767	0.608	0.651	0.689	0.924	0.507	
MC	7.947	0.001**	3.732	0.020*	7.215	0.001**	6.904	0.001**	1.027	0.448	5.538	0.004**	0.338	0.905	0.336	0.907	0.638	0.698	
PI	15.772	0.000**	0.617	0.714	0.628	0.706	12.362	0.000**	0.881	0.553	2.117	0.116	0.764	0.610	0.272	0.941	0.627	0.706	
S	9.136	0.000**	0.659	0.683	0.825	0.569	2.550	0.070	1.338	0.305	1.667	0.202	0.788	0.594	1.382	0.288	0.257	0.948	
PIC	5.955	0.003**	1.513	0.244	10.618	0.000**	11.065	0.000**	1.657	0.204	4.132	0.013*	0.759	0.613	0.472	0.818	0.491	0.804	
SC	9.634	0.000**	0.888	0.529	10.214	0.000**	6.494	0.002**	1.259	0.336	3.370	0.029*	0.621	0.711	0.548	0.764	0.096	0.996	
Among soil environments per rainfall																			
Average rainfall Intensity [mm h <sup>-1</sup> ]																			
2.55	4.039	0.004**	12.322	0.000**	5.604	0.001**	5.377	0.001**	1.659	0.165	1.575	0.190	3.944	0.005**	1.813	0.128	4.556	0.002**	
0.34	0.887	0.553	3.727	0.007**	4.350	0.003**	6.973	0.000**	1.633	0.173	1.548	0.103	6.796	0.000**	2.708	0.030*	7.517	0.000**	
0.65	0.860	0.574	6.993	0.000**	3.880	0.006**	5.615	0.001**	2.177	0.071	1.226	0.334	5.262	0.001**	3.152	0.016*	9.735	0.000**	
5.82	2.053	0.087	43.889	0.000**	14.084	0.000**	14.863	0.000**	1.884	0.114	0.664	0.731	1.884	0.114	2.947	0.021*	6.535	0.000**	
1.55	4.240	0.003**	26.651	0.000**	4.032	0.005**	9.842	0.000**	1.550	0.198	0.791	0.628	10.388	0.000**	3.122	0.016*	11.008	0.000**	
0.93	0.958	0.501	16.755	0.000**	4.726	0.002**	5.978	0.000**	1.524	0.207	0.804	0.618	6.133	0.000**	3.423	0.012*	7.748	0.000**	
2.65	2.589	0.037*	23.873	0.000**	4.743	0.002**	5.602	0.001**	1.412	0.248	0.891	0.550	4.997	0.001**	1.710	0.152	7.940	0.000**	

<sup>a</sup> Soil environments. V under vines, O under olive groves, PRa,b under pasture, MB under *Erica* shrub, MC under *Cistus* shrub, PI under pine trees, S under cork trees, PIC under burnt pines, SC under burnt corks

<sup>b</sup> ES eroded soil, EOC organic carbon as percent of eroded soil, TEN total nitrogen as percent of eroded soil, DOC organic carbon dissolved in runoff water, TDN total nitrogen dissolved in runoff water, Ammonia, Nitrate and Phosphate also collected from runoff water

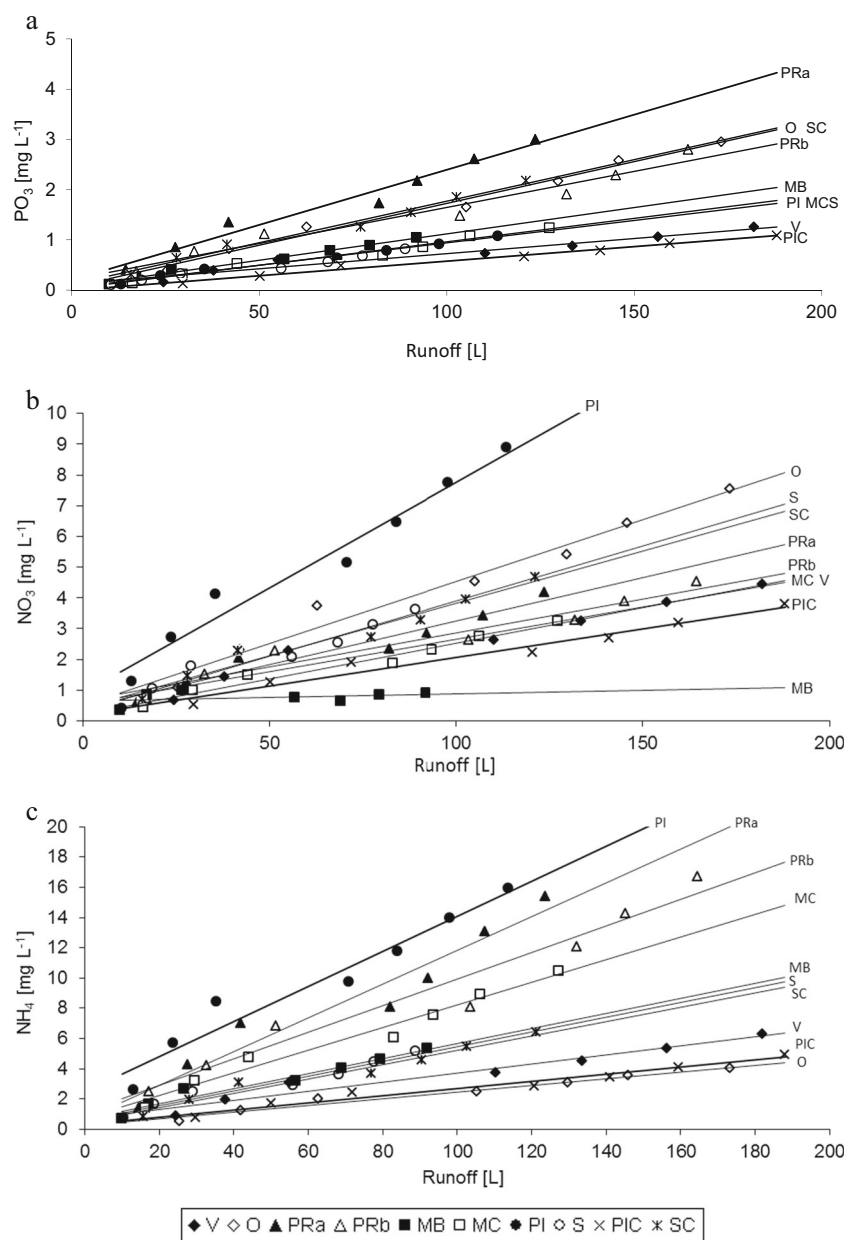
\*\* $p < 0.01$ ; \* $p < 0.05$

removing mineral particles, whereas C and N dynamics may be controlled by both abiotic and biotic processes and thus more difficult to explain (Pardini et al. 2003).

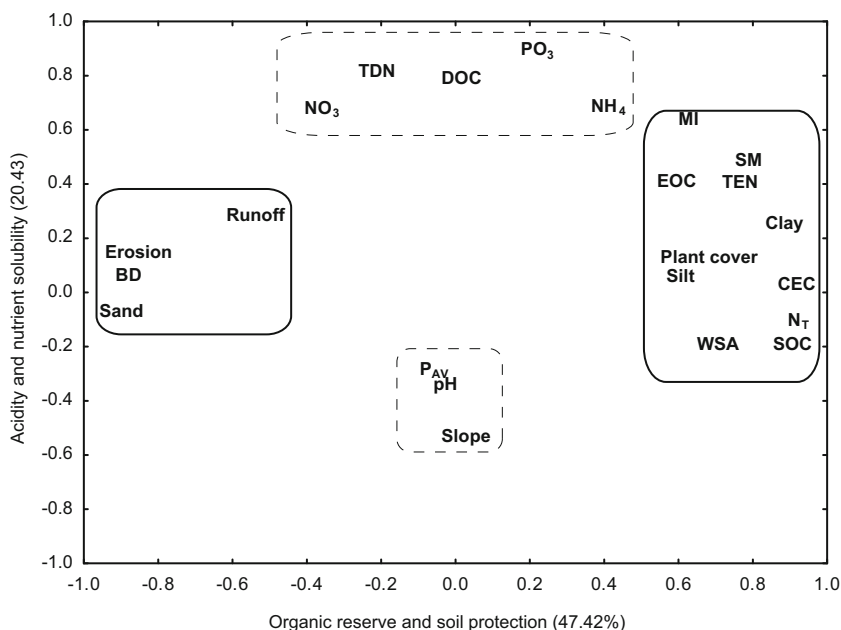
Significant variability of Phosphate, Nitrate and Ammonia data from runoff water was mainly found among environments at each rainfall event. However, ammonia concentration in runoff varied significantly in soil under pasture indicating its direct dependence on grazing activity. No significant data variability was found for nitrate and phosphate in runoff water in each environment indicating a roughly constant concentration along the seven rainfall events. Patterns of these compounds are shown in Fig. 6 where cumulated values are plotted against cumulative runoff for each environment. Soluble phosphate

concentration (Fig. 6a) was much higher in PRa ( $r = 0.985$ ), followed by environments such as o and SC ( $r = 0.991$ ), PRB ( $r = 0.979$ ), MB ( $r = 0.993$ ), PI, MC and S ( $r = 0.994$ ), V ( $r = 0.975$ ), while the lowest amount removed by runoff was detected in burnt pines (PIC). Recent grazing in pastured soils and fire effects in burnt pines may explain this trend. Linear regressions of cumulative nitrate and ammonia plotted against cumulative runoff (Fig. 6b, c) were highly significant ( $r > 0.900$  in all cases) and showed the highest values in soil under pines and the lowest in soils under burnt pines, indicating that the passage of fire may cause volatilisation of nitrogen forms (Certini 2005) in upper soil layers, its content being inconsistent during runoff washing.

**Fig. 6 a–c** Linear regression equations for cumulative values of runoff washed phosphate, nitrate, and ammonia vs cumulative runoff



**Fig. 7** Ordination plot showing the results of principal component factor analysis



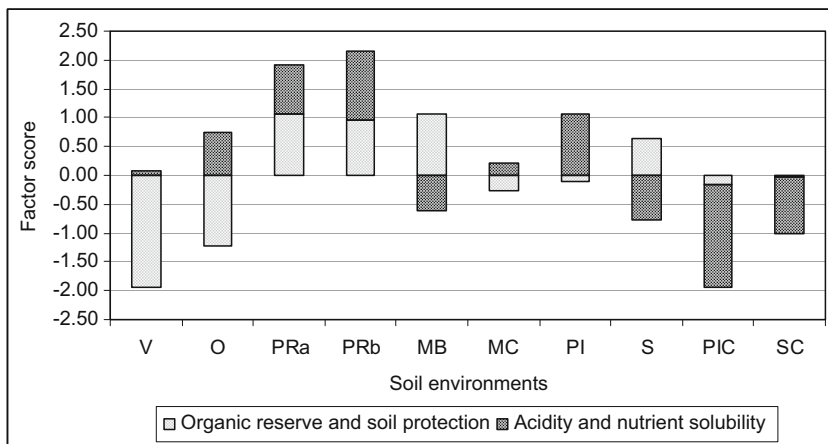
**3.3 Rainfall-runoff erosion relationships**

Seven rainfall events (Table 2) were analysed for runoff and eroded soil yield. Managing erosion research projects under natural rainfall is complex, labour-intensive, time-consuming and costly (Caroll et al. 2000). However, valuable data may be obtained to improve the knowledge of abandoned Mediterranean ecosystems in order to detect early warning indicators of land degradation and desertification (Kosmas et al. 2000).

According to Albaladejo et al. (1988), eroded soil yields ranging from 0 to 3 T ha<sup>-1</sup> year<sup>-1</sup> were considered negligible or low in areas of Southern Spain. The erosion rates calculated for V and O environments amounted 1.44 and 0.76 T ha<sup>-1</sup> year<sup>-1</sup> respectively, belonging to this range. In Fig. 3 that the amount of splashed particles was higher than that of eroded soil concentration. The ratio of total splashed soil to total eroded soil was 182 for vines (V) and 149 for olive

trees (O), accounting for the easy detachment of surface aggregates and the true potential for erosion under strong downpours. A much lower amount of eroded soil concentration was found for PRa, PRb, MB, MC, PI, and S environments, though splashed particles were always higher than eroded particles, warning of the fragility and vulnerability of apparently stable soils (Pardini and Gisbert 2006). As may be observed in Fig. 3, splashed particles are also higher in MC, PI and PIC environments suggesting that in each environment the difference in plant species and occupation may be relevant to organic matter impoverishment and potential erosion rates, especially when aiming at soil quality recovery after agricultural abandonment in hillside soils. Many authors have reported that soils beneath shrubs form fertile islands in fallow or abandoned land (Wezel et al. 2000; Bochet et al. 1998) due to their ability to capture nutrients and improve water retention. Nevertheless, little information is available on the difference between soils under *Erica arborea* (MB) and under *Cistus*

**Fig. 8** Factor scores for the two principal components explaining the negative or positive contribution of each soil environment to soil renaturalization



*monspeliensis* (MC). As may be observed from Table 3, soil parameters differed largely in these two environments and MB always resulted in improved soil properties (Pardini et al. 2004b). Replacement of *Erica arborea* by *Cistus monspeliensis*, due to repeated wildfire occurrence may lead to less favourable soil physicochemical conditions and, later on, increasing degradation and erosion.

Accordingly, accurate monitoring of these fragile areas is paramount to protect soil quality through organic carbon survey and detection of early warning indicators of degradation processes. Erosion preferentially removes soil organic carbon (SOC) concentrated in the vicinity of the soil surface (Lal 2005) and easier to be transported than the mineral fraction along changing rainfall.

#### 4 Factor analysis

The principal component factor analysis approach was carried out to relate the analysed variables with the natural dynamics occurring under the different studied land use/land cover types. Though three components were initially selected, accounting for 78.13 % of the total variance into variables (47.42 %, 20.43 % and 10.28 % respectively) we reported only the first two components which better explained the patterns of land use/land cover types (Fig. 7). Component 1 was named *organic reserve and soil protection* as it showed positive loadings on canopy, silt, clay, soil moisture (SM), mechanic impedance (MI), water stable aggregates (WSA), soil organic carbon (SOC), total nitrogen ( $N_T$ ), cation exchange capacity (CEC), eroded organic carbon (EOC) and total eroded nitrogen (TEN). Negative loads were recorded on sand, bulk density (BD), runoff and erosion. Component 2 was named *acidity and nutrient solubility* since it was characterized by positive loadings on runoff washed compounds such as dissolved organic carbon (DOC), dissolved total nitrogen (TDN), phosphate ( $PO_3$ ), nitrate ( $NO_3$ ) and ammonia ( $NH_4$ ), and negative loadings on slope, pH and available phosphorus ( $P_{AV}$ ). While the first component includes the majority of soil properties favourable to renaturalization along the process of abandonment, the second component remarks on the importance of slope and pH on nutrient depletion and availability. These indications were somewhat corroborated by scoring the components and associated variables with the studied land use/land cover types (Fig. 8). From the graph of the factor score, it can be observed that soil environments PRa, PRb, MB and S are mainly involved in securing organic reserve and soil protection. Scores for land use/land cover types of component 2 depicted more sensitivity to nutrient loss in soils V, O, PRa, PRb, MC and PI, with land use/land cover types subjected to grazing activity being more prone to nutrient washing by surface runoff. The negative contribution to nutrient loss of soils PIC and SC may be ascribed to fire effects, in

agreement with what is depicted in the graphs of Fig. 6. By contrast, the negative contribution to nutrient release by MB and S soils should be considered as related to enhanced soil properties avoiding loss of nutrients.

#### 5 Conclusions

Data proved that discontinuous and unmanaged vegetative cover may have beneficial or detrimental effects on soil properties and affect soil susceptibility to erosion. In general, erosion is reduced with increasing plant cover, though dynamics are complex and need further study in order to ascertain the real contribution to soil fertility and soil structural stability of diverse plant species and plant associations. Agriculture abandonment in mid-mountainous soils of the Mediterranean region and the lack of forestry management result in a serious erosion hazard for land degradation and desertification. The resulting scenario is aggravated by altered fire regimes bringing about a reduction in vegetative growth and competition between plant species, and causing progressive soil organic matter impoverishment and less favourable soil conditions. Reduced erosion rates in these areas may be misleading and cause erroneous evaluations of the real conditions of the soil systems, where regolith outcropping may occur in shallower soils after repeated degradation processes. This study showed that it is paramount to consider many factors in planning land use changes from arable to unmanaged pasture and complete abandonment, a relevant aspect in soils under a Mediterranean type of climate.

**Acknowledgments** We acknowledge the financial support for this study provided by the Research Project CGL2007-66644-C04-02 funded by the Spanish Government. The contribution of pre-doctoral grant BES-2008-010099 funded by the Ministry of Science and Innovation-MICIN enabled part of the research work and is also acknowledged.

#### References

- Abril A, Bartfeld P, Bucher EH (2005) The effect of fire and overgrazing on soil carbon balance in the dry Chaco forest. *Forest Ecol Manag* 206:399–405
- Albaladejo J, Chisci G, Gabriels D, Rubio JL, Stocking MA (1988) Soil degradation and its impact on desertification: a research design for Mediterranean environments. *Soil Technol* 1:169–174
- Bochet E, Rubio JL, Poesen J (1998) Relative efficiency of three representative matorral species in reducing water erosion at the micro-scale in a semi-arid climate (Valencia, Spain). *Geomorphology* 23: 139–150
- Bremner JM, Mulvaney CS (1987) Nitrogen-Total. In: Page AL, Miller RH, Keeney DR (eds) *Methods of soil analysis*. American Society of Agronomy Inc and Soil Science Society of America Inc Publisher, Madison, Wisconsin, pp. 595–623
- Carroll C, Merton L, Burger P (2000) Impact of vegetative cover and slope on runoff, erosion and water quality for field plots on a range of soils

- and spoil materials on Central Queensland coal mines. *Austr J Soil Res* 38:313–327
- Celik I (2005) Land-use effects on organic matter and physical properties of soil in a southern Mediterranean highland of Turkey. *Soil Till Res* 83:270–277
- Certini G (2005) Effects of fire on properties of forest soils: a review. *Oecologia* 143:1–10
- De Nobili M, Maggioni A (1993) Influenza della sostanza organica sulle proprietà fisiche del suolo. In: Nannipieri P (ed) *Ciclo della sostanza organica del suolo* Patron Editore, Bologna, Italy, pp. 43–54
- Dunjo G, Pardini G, Gispert M (2003) Land use change effects on abandoned terraced soils in a Mediterranean catchment. *Catena* 52:23–37
- Emran M, Gispert M, Pardini G (2012) Comparing measurements methods of carbon dioxide fluxes in a soil sequence under land use and cover change in north eastern Spain. *Geoderma* 170:176–185
- Flinn KM, Vellend M (2005) Recovery of forest plant communities in post-agricultural landscapes. *Front Ecol Environ* 3:243–250
- Forster J (1995) Soil sampling, handling, storage and analysis. In: Alef K, Nannipieri P (eds) *Methods in soil microbiology and biochemistry*. Academic Press, London, pp. 49–122
- Gerlach T (1967) Hillslope throughs for measuring sediment movement. *Rev Geol Dyn Geogr* 4:173–175
- Gillman GP (1979) A proposed method for the measurement of exchange properties of highly weathered soils. *Austr J Soil Res* 17:67–77
- Gispert M, Emran M, Pardini G, Doni S, Ceccanti B (2013) The impact of land management and abandonment on soil enzymatic activity, glomalin content and aggregate stability. *Geoderma* 202–203:51–61
- Jackson RB, Banner JL, Jobbágy EG, Pockman WT, Wall DH (2002) Ecosystem carbon loss with woody plant invasion of grasslands. *Nature* 418:623–626
- Kemper WD, Rosenau RC (1986) Aggregate stability and size distribution. In: Klute A (ed) *Methods of soil analysis*, Madison, Wisconsin, SSSA, pp. 425–441
- Kosmas C, Gerontidis S, Marathianou M (2000) The effect of land use change on soils and vegetation over various lithological formations on Lesvos (Greece). *Catena* 40:51–68
- Lal R (2003) Soil erosion and the global carbon budget. *Environ Int* 29:437–450
- Lal R (2005) Soil erosion and carbon dynamics. *Soil Till Res* 81:137–142
- Lasanta T, Garcia-Ruiz JM, Pérez-Rantomé C, Sancho-Marcén C (2000) Runoff and sediment yield in a semi-arid environment: the effect of land management after farmland abandonment. *Catena* 38:265–278
- Lesschen JP, Kok K, Verburg PH, Cammeraat LH (2007) Identification of vulnerable areas for gully erosion under different scenarios of land abandonment in Southeast Spain. *CATENA* 71(1):110–121
- Mataix-Solera J, Doerr SH (2004) Hydrophobicity and aggregate stability in calcareous topsoils from fire-affected pine forests in southeastern Spain. *Geoderma* 118:77–88
- Mataix-Solera J, Cerdà A, Arcenegui V, Jordà A, Zavala AM (2011) Fire effects on soil aggregation: a review. *Earth-Sci Rev* 109:44–60
- Noble AD, Zenneck I, Randall PJ (1996) Leaf litter ash alkalinity and neutralisation of soil acidity. *Plant Soil* 179:293–302
- Olsen SR, Sommers LE (1987) Phosphorus. In: Page AL, Miller RH, Keeney DR (eds) *Methods of soil analysis*. American Society of Agronomy Inc, Soil Science Society of America Inc Publishers, Madison, pp. 421–422
- Pardini G, Gispert M (2006) Impact of land abandonment on water erosion in soils of the eastern Iberian peninsula. *Agrochimica* 50:13–24
- Pardini G, Aringhieri R, Plana F, Gallart F (1991) Soil properties relevant to land degradation in abandoned sloping fields in Aisa Valley, central Pyrenees (Spain). *Pirineos* 137:79–93
- Pardini G, Gispert M, Dunjó G (2003) Runoff erosion and nutrient depletion in five Mediterranean soils of NE Spain under different land use. *Sci Total Environ* 309:213–224
- Pardini G, Gispert M, Dunjó G (2004a) Distribution patterns of soil properties in a rural Mediterranean area in North-Eastern Spain. *Mt Res Develop* 24:44–51
- Pardini G, Gispert M, Dunjó G (2004b) Relative influence of wildfire on soil properties and erosion processes in different Mediterranean environments in NE Spain. *Sci Total Environ* 328:237–246
- Puigdefabregas J (1995) Desertification: stress beyond resilience, exploring a unifying process structure. *Ambio* 24:311–313
- Saa A, Trasar-Cepeda MC, Gil-Sotres F, Carballas T (1993) Changes in soil phosphorus and acid phosphatase activity immediately following forest fires. *Soil Biol Biochem* 25:1223–1230
- Scarascia-Mugnozza G, Oswald H, Piussi P, Radoglou K (2000) Forests of the Mediterranean region: gaps in knowledge and research needs. *Forest Ecol Manag* 132:97–109
- Soil Survey Staff (SSS) (2010) *Keys to soil taxonomy*. SMSS Technical Monograph Pocahontas Press Inc, Blacksburg, Virginia
- Swaine M (1996) Rainfall and soil fertility as factors limiting Forest species distributions in Ghana. *J Ecol* 84:419–428
- Trabaud L, Oustric J (1989) Heat requirement for seed germination of three *Cistus* species in the garrigue of southern France. *Flora* 183:321–325
- Vance ED, Brookes PC, Jenkinson DS (1987) An extraction method for measuring microbial biomass C. *Soil Biol Biochem* 19:703–707
- Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci* 37:29–38
- Wezel A, Rajot JL, Herbrig C (2000) Influence of shrubs on soil characteristics and their function in Sahelian agro-ecosystems in semi-arid Niger. *J Arid Environ* 44:383–393
- Zhang R (1997) Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer. *Soil Sci Soc Am J* 61:1024–1030