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SOIL QUALITY ASSESSMENT THROUGH A MULTI-APPROACH ANALYSIS IN SOILS OF ABANDONED TERRACED LAND IN NE SPAIN

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ABSTRACT. *The abandonment of agricultural land in mountainous areas has been an outstanding problem along the last century and has captured the attention of scientists, technicians and administrations, for the dramatic consequences sometimes occurred due to soil instability, steep slopes, rainfall regimes and wildfires. Hidromorfológical and pedological alterations causing exceptional floods and accelerated erosion processes has therefore been studied, identifying the cause in the loss of landscape heterogeneity. Through the disappearance of agricultural works and drainage maintenance, slope stability has resulted severely affected. The mechanization of agriculture has caused the displacement of vines, olives and corks trees cultivation in terraced areas along the Mediterranean catchment towards more economically suitable areas. On the one hand, land use and management changes have implicated sociological changes as well, transforming areas inhabited by agricultural communities into deserted areas where the colonization of disorganized spontaneous vegetation has buried a valuable rural patrimony. On the other hand, lacking of planning and management of the abandoned areas has produced badlands and infertile soils due to wildfire and high erosion rates strongly degrading the whole ecosystems. In other cases, after land abandonment a process of soil regeneration has been recorded. Investigations have been conducted in a part of NE Spain where extended areas of terraced soils previously cultivated have been abandoned in the last century. The selected environments were semi-abandoned vineyards, semi-abandoned olive groves, abandoned stands of cork trees, abandoned stands of pine trees, scrubland of Cistaceaea, scrubland of Ericaceaea, and pasture. The research work was focused on the study of most relevant physical, chemical and biological soil properties, as well as runoff and erosion under soils with different plant cover to establish the abandonment effect on soil quality, due to the peculiarity and vulnerability of these soils with a much reduced depth. The period of observation was carried out from autumn 2009 to autumn 2010. The sediment concentration of soil erosion under vines was recorded as 34.52 g/l while under pasture it was 4.66 g/l. In addition, the soil* *under vines showed the least amount of organic matter, which was 12 times lower than all other soil environments. The carbon dioxide (CO_2) and total glomalin (TG) ratio to soil organic carbon (SOC) in this soil was 0.11 and 0.31 respectively. However, the soil under pasture contained a higher amount of organic matter and showed that the CO_2 and TG ratio to SOC was 0.02 and 0.11 respectively indicating that the soil under pasture better preserves the soil carbon pool. A similar trend was found in the intermediate soils in the sequence of land use change and abandonment. Soil structural stability increased in the two soil fractions investigated (0.25-2.00 mm, 2.0-5.6 mm) especially in those soils that did not undergo periodical perturbations like wildfires. Soil quality indexes were obtained by using relevant physical and chemical soil parameters. Factor analysis carried out to study the relationship between all soil parameters allowed to related variables and environments and identify those areas that better contribute to soil quality towards others that may need more attention to avoid further degradation processes.*

Evaluación de la calidad del suelo a través de un análisis multidisciplinar en suelos de bancales abandonados en el NE de España

RESUMEN. *El abandono de tierras agrícolas en el último siglo ha captado la atención de científicos, técnicos y administraciones por las consecuencias, a veces dramáticas, que se han manifestado en función del tipo de terrenos, pendientes, regimenes de lluvia, e incendios forestales. Las alteraciones hidromorfológicas y edáficas, causantes de riadas y procesos de erosión acelerada, se ha identificado principalmente en la pérdida de la heterogeneidad del paisaje, fruto de un trabajo duro pero necesario para el mantenimiento de la estabilidad de las vertientes con prácticas agrícolas ancestrales y obras de drenajes. Con el avance de la tecnología agraria los cultivos de viña, olivo y alcornoque en bancales de muchas zonas de la cuenca Mediterránea han sido desplazados hacia zonas económicamente más rentables. Por una parte los cambios de uso y gestión de los suelos han implicado cambios sociológicos importantes al constatarse que extensas áreas previamente habitadas por comunidades agrícolas se han convertido en zonas desérticas donde la vegetación se ha extendido de forma desorganizada enterrando un patrimonio rural muy valioso. Por otra, la falta de planificación y manejo de zonas abandonadas ha convertido muchas de estas áreas en zonas abarrancadas o infértiles, a menudo debido a incendios forestales y altísimas tasas de erosión que repercuten degradando los varios ecosistemas. En otros casos, más positivos, tras el abandono se ha registrado un proceso de regeneración de los suelos.*

La investigación se ha desarrollado en una zona del Noreste de España donde existen extensas áreas de bancales previamente cultivados y abandonados progresivamente desde el siglo pasado. Los ambientes seleccionados fueron viñedo semi-abandonado, olivar semi-abandonado, alcornocal abandonado, pineda abandonada, matorral de jara, matorral de brezo y pastos. El trabajo fue orien-

tado a estudiar las propiedades físicas, químicas y biológicas más relevantes, así como los procesos de escorrentía y erosión en ambientes edáficos con diferente cubierta vegetal, con la finalidad de establecer los efectos del abandono sobre la calidad del suelo, basándose en la peculiaridad y vulnerabilidad de los mismos dada su escasa profundidad. El periodo de observación ha sido de un año, desde el otoño 2009 al otoño 2010. Analizando dos ambientes extremos, encontramos una concentración de sedimentos en los suelos bajo viñedo semi-abandonado de 34.52 g/l mayor que en los suelos bajo pasto con 4.66 g/l. Asimismo, los suelos bajo viñedo mostraron siempre el contenido más bajo de materia orgánica, en media 12 veces inferior que los otros suelos. La relación CO_2 *y glomalina total (TG) sobre carbono orgánico (SOC) en este suelo fueron de 0.11 y 0.31 respectivamente. El suelo bajo pasto, con un contenido mayor de materia orgánica mostró una menor relación entre* CO_2 *y SOC y TG y SOC siendo 0.02 y 0.11 respectivamente, e indicando que puede haber una mayor capacidad de almacenar carbono orgánico en ciertos ambientes. Un comportamiento similar se demostró en otros suelos a lo largo de la secuencia de abandono. La estabilidad estructural del suelo a la acción del agua se incrementó en las dos fracciones de agregados analizadas (0.25-2.00 mm, y 2.00-5.60 mm) especialmente en los suelos que no sufrieron perturbaciones como frecuentes incendios forestales. Los índices de calidad del suelo se obtuvieron utilizando propiedades físicas y químicas del suelo relevantes para esta finalidad. Un análisis factorial de todos los parámetros analizados permitió identificar aquellos ambientes que mas contribuyen a mantener la calidad de los suelos frente a aquellos que deberían recibir una mayor atención para evitar futuros fenómenos de degradación.*

Key words: land use change, land abandonment, soil depth, canopy cover, soil organic carbon, soil structure, glomalin, soil erosion.
Palabras clave: cambio de uso y gestión del suelo, abandono de tierras agrícolas, profundidad del suelo, cubierta vegetal del suelo, carbono orgánico del suelo, estructura del suelo, glomalina, erosión del suelo.

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1. Introduction

Soil quality is the ability of a soil to perform functions that are essential to human requirements and the environment. The term soil quality is not only related with the improvement of some physical, chemical, or biological soil properties, but also with water quality and air quality and must be seen in a global change context under perspectives of sustainability.

Neverthless, whilst water and air have received much attention because strictly related to human health, soil has been traditionaly considered as the 1.5 m layer of the earth surface, taken for granted. Despite that soil is a very heterogenous complex system, hardly succeding its climax completion and also easily subjected to degradation depending on its use and management. Land use change and more evidently land abandonment represent a threat to soil quality, especially in the mediterranean region with changing climatic conditions (Dunjó *et al.,* 2003).

Along the Mediterranean region, land abandonment has been an outstanding characteristic, inferring strong changes to soil properties. In some clear instances soils with the same textural classes have showed very contrasting properties as a result of differences in soil management or abandonment. Often, the shallow nature of these soils and periodical perturbations (wildfire, downpours) in absence of proper land management increase soil erosion and degradation (Pardini *et al.,* 2003; Pardini and Gispert, 2006). The post abandonment management in order to survey soil and ecosystem quality is therefore paramount.

After farmland abandonment the evolution of soil properties depend on i) the condition of the soil at the agricultural release, ii) the sequence of spontaneous colonization of vegetation and, iii) the vegetation succession in the presence of natural or induced perturbations. When agricultural plots are maintained at minimal management to avoid complete abandonment decrease in the soil organic matter content with subsequent nutrient impoverishment and loss of fertility may occur. Soil structural stability may be also affected increasing the susceptibility to erosion processes. The type of vegetation in differently aged abandoned environments influences the soil organic matter, the most important soil quality parameter, especially in soils with the minor amount of clay. It is well known that a low percentage of clay in soil environments may reduce its contribution to the formation of organo-mineral complexes, enhancing the role of humic fraction alone in particle aggregation and water storage (Oades, 1984).

Soils on stable landscape and under suitable plant cover conditions may improve with time by accumulating organic compounds, increasing floral and faunal activity, enhancing better structure and porosity thus infiltration capacity, and decreasing erosion potential (Trimble, 1990; Dunjó *et al.,* 2004). Soil erosion is considered the main land degradation process causing desertification, leading to the progressive inability of the vegetation and soils to regenerate, affecting the resilience status of these ecosystems (Mainguet, 1994). Different factors influence soil organic matter levels in soil having negative or positive effects on soil's ability to withstand degradation. The content of organic matter in the soils and its quality is related to the type of land use, the agrotechnical procedures used in soils of agroecosystems and also the evolution of farmland abandonment dynamics (Semenov *et al.,* 2006). As organic matter is the content of carbon available for microorganisms, microbial biomass is a key component of the active organic matter pool and a sensitive indicator of changes in the biological quality of the organic matter, changed by natural and agrogenic factors. The carbon dioxide flux from soil is the end product of respiration processes and combustion of soil organic matter which, in turn, should be replaced by new input of organic decaying debris. Carbon dioxide release from soil is therefore indicating loss of carbon by microbial activity and may be considered a suitable parameter to evaluate the capacity of soil to preserve organic compounds in structure's microsites against mineralization. Factors like agricultural practices and land management, together with soil attributes like temperature, water content, and amount of readily decomposable organic matter, among others, may stimulate microbial activity in soil promoting the increase of soil respiration rates and consequent soil carbon loss (McLaren and Cameron, 1996). Despite natural events, carbon dioxide production has been strongly related to soil management and considered an essential component of terrestrial carbon budgets (14% of worldwide CO_2 emissions comes from soils) and an important component in models of ecosystem carbon cycling (Grogan, 1998). Critical soil management including abandonment may thus affect the soil physical properties, i.e. structure and aggregate stability and alter the network around soil particles in which soil microorganisms live, thereby affecting their number, diversity and activity. In recent years different authors have related soil management and abandonment with the production of glomalin, a microbial protein produced from arbuscular mycorrhizal fungi (AMF) in the soil (Wright *et al.,* 1999; Wright and Anderson, 2000; Borie *et al.,* 2006), that is able to act as a glue and bind soil particle together enhancing the formation and maintenance of a stable structure. By means of the soil structure protection, glomalin is thought to contribute to carbon sequestration on a global scale (Treseder and Turner, 2007). The objective of the present research work was focused on establishing how different stages of land abandonment affected changes in physical, chemical, and biological soil properties, as well as erosion processes, and identify current conditions in the environments under study that better contribute to soil quality.

2. Materials and methods

2.1. Description of the study area

The study area is located in the Romanya catchment, Cap de Creus peninsula, Province of Girona, Catalunya, NE Spain. It's enclosed in the Natural Park of Cap de Creus, occupies an area of 30 km^2 and represents a typical Mediterranean ecosystem. It has a Mediterranean xeroteric climate, with hot summers and mild winters, an annual average temperature of 16ºC with maxima and minima of 30ºC and 5ºC in summer and winter respectively, and a mean annual precipitation a round 450 mm (Franquesa, 1995; Dunjó *et al.,* 2003).

Soils are shallow (0-40 cm depth) with an Ap, C/R horizon development. According to Soil Taxonomy System are classified as Lithic Xerothent. The majority of soil environments are completely covered by old terraces created by ancient hillside agriculture thereafter exploited for many centuries and then abandoned (Pardini *et al.,* 2004). Various

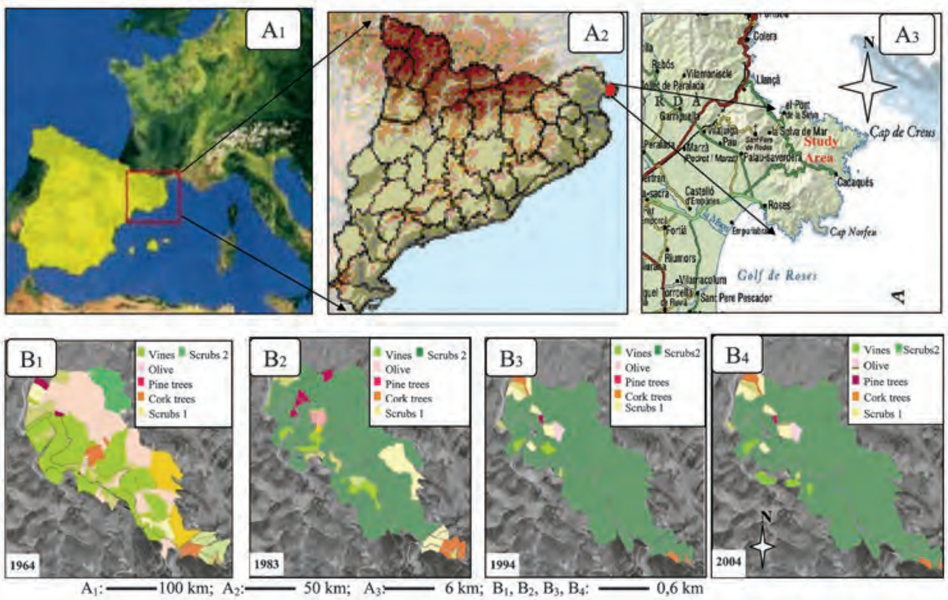


Figure 1. Location of the area of study: A_1, A_2, A_3, geographical approximation to the area of study; B_1, B_2, B_3, B_4, land use change sequence along the last decades in the area of study.

forms of current spontaneous vegetation depend on the period of abandonment and fire occurrence (Pardini *et al*., 2003).

Agricultural exploitation lasted until 1960 for wine and olive oil production, then diverse plant diseases and mechanization of agriculture induced the almost complete abandonment. Forest fires have increased since and 90% of the old terraced territory is covered with different stage of scrub according to wildfire occurrence. Stands of cork and pine trees and pastures are also present occupying small patches (5%), as small patches (5%) are still cultivated with vines and olive trees under insufficient agricultural practices. However, some new interest in recovering agricultural land has arisen recently. The sequence of land use change from 1964 to 2004 is showed in figs. 1 and 2.

Seven environments were selected, ranging from current cultivated soils at minimal agricultural management, soils under pine and cork trees, soils under pasture and soils under different stages of natural vegetation succession after abandonment. The environments were the following: (V) Vines (*Vitis vinifera*) in terraced soils at minimal agricultural management, (O) olive groves (*Olea europaea*) in terraced soils at minimal agricultural management, (S) stands of cork trees (*Quercus suber*) in terraced soils representing ancient cultivation for cork production and burned in July 2008, (PI) stands of pine trees (*Pinus halepensis*) in reforested terraced soils around 1955, (PR) pasture (*Braquipodium retusum, Trifolium stellatum, Dactylis glomerata, Lavadula stoechas*) currently in transition to cistaceaea association for gradual abandonment of grazing activity, (MC) cistus scrubs

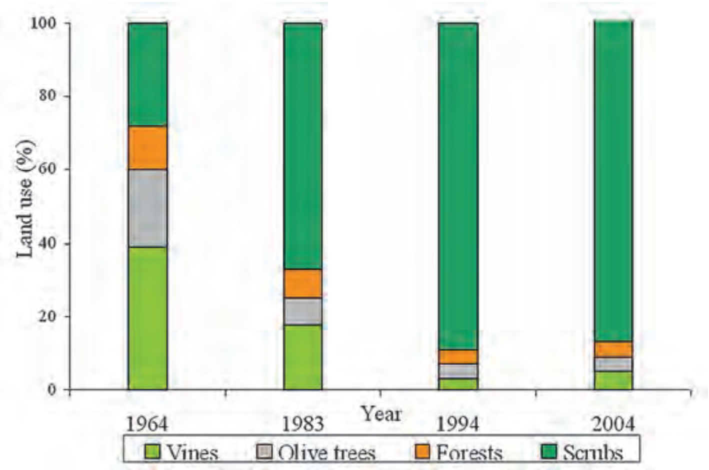


Figure 2. Percentage of land use change in the area of study.

cover on abandoned agricultural site with terraces covered mainly by *Cistus monspeliensis, Cistus albidus, Cistus salviifolius, Calicotome espinosa* and some patches of *Brachipodium retusum*; the scrub was devastated by fire repeatedly in 1988, 1990, and 1994, (MB) *Erica* scrub cover on abandoned terraced soils with *Erica arborea, Quercus coccinea, Lavadula stoechas, Brachipodium retusum*. The last fire affecting this scrub occurred in 1974. The main physiographical and pedological characteristics of the chosen environments are listed in table 1.

Table 1. Physiographical and pedological characteristics of the selected soil environments.

Environments	**Location**	**Plant cover (%)**	**Surface (Ha)**	**Slope (%)**	**Horizon Development**	**Soil depth (cm)**
V	N42º18’753”	5	1,8	15	Ap,C/R	40
O	E3º13’916”	4	1,7	18	Ap,C/R	38
S	E3º13’916”	70	1,7	15	Ap,C/R	37
PI	N42º20’114”	70	1,7	18	Ap,C/R	41
PR	N42º18’561”	35	1,7	18	Ap,C/R	30
MC	E3º13’455”	50	1,5	21	Ap,C/R	33
MB	N42º18’346”	55	1,6	17	Ap,C/R	35

2.2. Experimental layout

Experiments have been carried out by installing Gerlach plots (Gerlach, 1976) for surveying runoff and erosion in each environment. Each plot was 4.5 m wide armed with a box of 45 liter capacity and a tank of 10 liters capacity (fig. 3) both to collect soil eroded material and water runoff. The area corresponding to one plot resulted 36 m^2

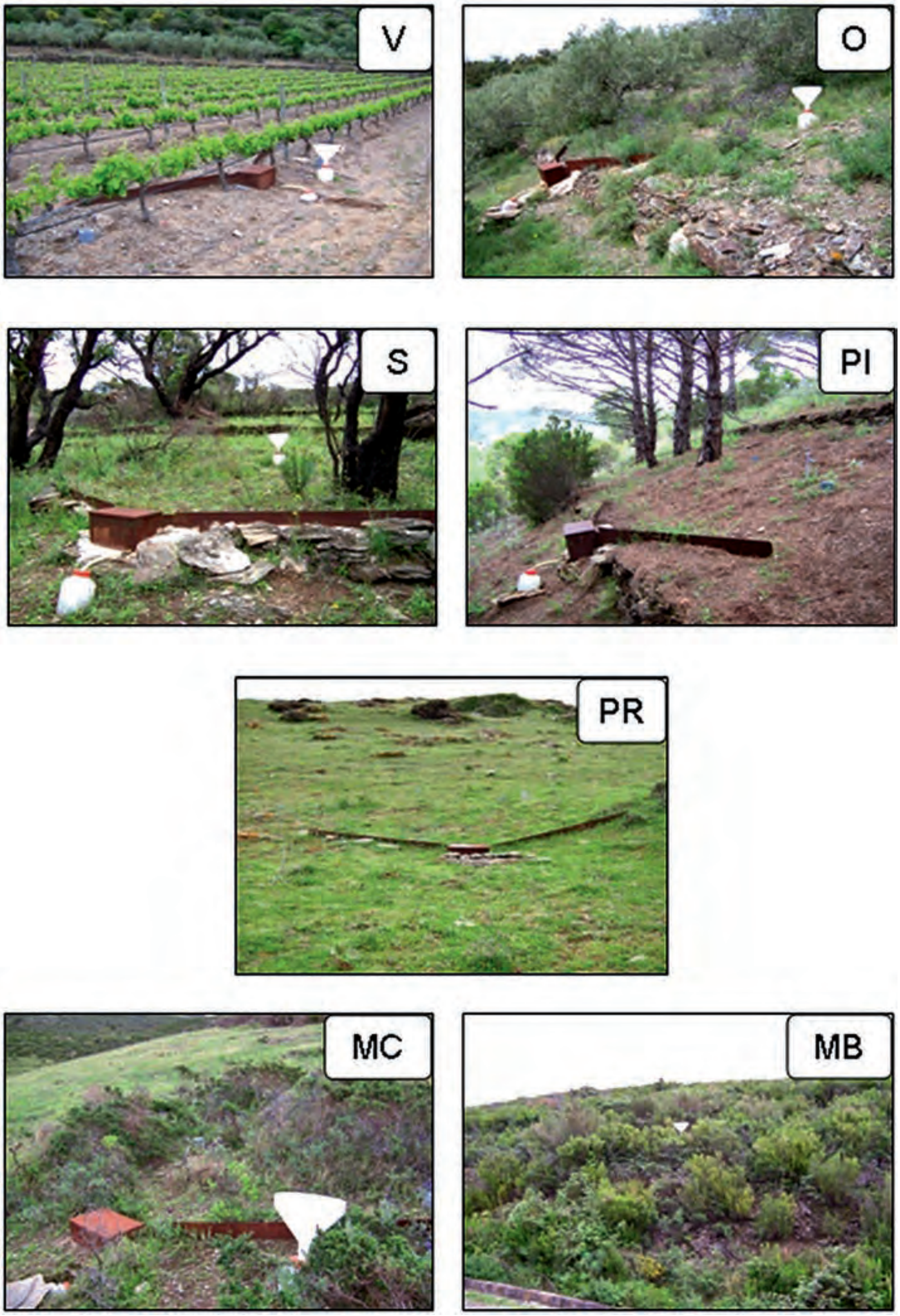


Figure 3. Examples of erosion plot installed in the different studied environments. V (vines), O (olive groves), S (stands of cork trees), PI (stand of pine trees), PR (pastureland), MC (Cistus scrub), MB (Erica scrub).

(Pardini and Gispert, 2006). Each plot was equipped with splash cups (7×5 cm) to collect the splashed materials, infiltration rings (20×10.5 cm) for infiltration rates measurements (IC). Field measurements included also soil temperature by non-contact laser thermometer, mechanic impedance (MI) with a static penetrometer, shear strength (SS) with the pocket vane tester, soil hydraulic conductivity (HC) by Mini-Disk infiltrometer (Zhang, 1997) and bulk density (BD) by using (5×5 cm) steel cylinder (Forster, 1995). All field determinations were carried out at each rainfall event or on monthly basis. The eroded soil material and runoff water collected at significant rainfall events were analyzed for total organic carbon (EOC in eroded soil, DOC in runoff water) according to Vance et al. (1987), and total nitrogen (EN in eroded soil, DN in runoff water) by Kjeldahl method (Kjeldahl, 1983).

Soil samples were collected at least three times for each season, (three replications each time) at 0-15 cm depth (organic horizon). Soil portions for biological tests were separated immediately and stored in sterile plastic bags for subsequent laboratory analysis of carbon dioxide (CO_2) production capacity (Edwards, 1982; Page *et al.,* 1982; Heinemeyer *et al.,* 1989; Alef and Nannipieri, 1995; Grogan, 1998). Quantitative determination of glomalin content (TG) in soil was carried out by solubilizing the glomalin by citrate under high temperature (Wright and Upadhyaya, 1996) and then estimating by Bradford protein assay (Bradfrod, 1976; Wright and Upadhyaya, 1998).

Soil samples prior to physical and chemical analysis were air dried at 20^{o}C and stored. From a portion of the soil, aggregates of 0.25-2.00 mm and 2.00-5.60 mm classes were obtained by sieving in order to determine the water stable aggregates (Kemper and Rosenau, 1986). Other soil was sieved at 2 mm, mixed and stored. The following parameters were analyzed: Texture by pipette method (Porta *et al.,* 1994), water holding capacity (WHC) (Forster, 1995), pH by potentiometric method (Alef and Nannipieri, 1995), electrical conductivity (EC) (Porta *et al.,* 1994), total organic carbon (SOC) (Alef and Nannipieri, 1995), total nitrogen (TN) by Kjeldahl method (Kjeldahl, 1983). The mean annual values of the analyzed parameters both in the field and laboratory, together with rainfall, runoff and related erosion rates are reported in table 2.

Table 2. Mean annual values (± standard error) of selected field and laboratory parameters in the seven investigated sites during the period Autumn 2009–Autumn 2010.

	V	**O**	**S**	**PI**	**PR**	**MC**	**MB**
Erosion parameters							
Rainfall (l m^{-2})	42.86 ±42.22	36.82 ±37.72	19.32 ±22.55	36.28 ±40.48	20.73 ±26.54	32.12 ±31.16	38.03 ±31.79
Runoff (l m^{-2})	0.12 ±0.11	0.17 ±0.19	0.05 ±0.08	0.09 ±0.10	0.13 ±0.12	0.08 ±0.07	0.06 ±0.07
Erosion (g m^{-2})	3.59 ±4.44	0.37 ±0.42	0.25 ±0.32	0.13 ±0.13	0.60 ±0.65	0.16 ±0.23	0.01 ±0.01
EOC (mg g^{-1})	86.11 ±37.32	38.31 ±34.74	59.92 ±61.39	60.24 ±69.67	71.88 ±9.61	35.77 ±40.75	12.57 35.53
DOC (mg g^{-1})	0.89 ±1.43	0.80 ±0.90	1.05 ±1.30	1.29 ±1.37	0.76 ±0.71	0.40 ±0.32	0.38 ±0.47
EN (mg g^{-1})	2.18 ±1.54	6.75 ±6.25	6.39 ±7.41	4.20 ±5.01	12.97 ±4.07	6.95 ±5.81	1.59 ±4.65
DN (mg g^{-1})	0.01 ±0.001	0.01 ±0.02	0.04 ±0.07	0.02 ±0.04	0.02 ±0.02	0.01 ±0.001	0.01 ±0.001
Field parameters							
MI (K Pa)	232.50 ±81.82	450.60 ±104.50	356.30 ±86.60	315.70 ±122.90	512.10 ±109.60	475.50 ±82.71	420.50 ±131.70
SS (K Pa)	134.90 ±39.02	313.80 ±67.03	259.50 ±65.22	193.70 ±52.57	383.30 ±150.30	353.70 ±52.96	327.10 ±155.10
IC (mm h^{-1})	1154.00 ±251.50	1817.00 ±240.90	331.24 ±92.49	654.80 ±410.90	105.70 ±55.73	345.30 ±298.10	322.10 ±155.00
HC (cm h^{-1})	5.54 ±3.06	2.20 ±3.21	7.88 ±9.15	0.88 ±0.63	1.93 ±1.88	3.34 ±5.90	3.15 ±1.71
Moisture (%)	5.13 ±1.60	8.00 ±4.94	12.03 ±6.06	9.88 ±6.51	19.27 ±14.54	14.23 ±6.98	16.20 ±8.63
BD (g cm^{-3})	1.54 ±0.09	1.35 ±0.07	1.14 ±0.08	1.22 ±0.15	1.09 ±0.14	1.17 ±0.09	0.99 ±0.12
Laboratory parameters							
Clay (%)	4.17 ±1.77	13.33 ±1.44	10.83 ±3.82	11.67 ±1.44	17.50 ±4.33	18.33 ±3.82	12.50 ±2.50
Silt (%)	10.83 ±6.61	20.00 ±1.44	27.50 ±5.20	20.83 ±2.50	20.00 ±4.33	26.67 ±2.89	23.33 ±2.89
Sand (%)	85.00 ±1.52	66.67 ±0.71	61.67 ±1.73	67.50 ±0.56	62.50 ±1.04	55.00 ±0.26	64.17 ±0.70
WHC (%)	25.11 ±3.84	46.68 ±6.45	67.76 ±11.23	59.93 ±15.89	63.97 ±15.50	66.11 ±10.05	77.77 ±10.74
WSA (0.25-2.00) (%)	48.78 ±18.16	59.12 ±21.94	82.05 ±3.89	78.61 ±9.30	85.04 ±4.35	82.91 ±4.88	85.25 ±5.14
WSA (2.00-5.69) (%)	23.22 ±11.23	70.89 ±20.55	87.15 ±0.68	74.07 ±8.37	84.68 ±8.07	89.32 ±2.64	92.76 ±0.88
pH	6.62 ±0.32	6.34 ±0.15	6.23 ±0.75	6.10 ±0.40	5.79 ±0.08	6.27 ±0.36	5.93 ±0.30
EC (dSm^{-1})	0.07 ±0.03	0.06 ±0.02	0.14 ±0.07	0.06 ±0.02	0.12 ±0.04	0.08 ±0.01	0.10 ±0.05
SOC (mg g^{-1})	3.10 ±0.84	13.99 ±2.68	29.06 ±4.68	14.81 ±6.47	35.64 ±3.53	29.40 ±5.10	32.87 ±7.69
SOM (mg g^{-1})	5.35 ±1.45	24.13 ±4.63	50.11 ±8.07	35.88 ±11.15	61.45 ±6.08	50.68 ±8.79	56.67 ±13.26
TN (mg g^{-1})	0.70 ±0.16	1.70 ±0.30	2.75 ±0.83	2.13 ±0.89	4.48 ±0.58	3.01 ±0.64	3.15 ±1.05
C/N	5.48	8.22	10.57	9.78	7.96	9.77	10.44
CO_2 (mg g^{-1})	0.35 ±0.13	0.48 ±0.17	0.74 ±0.19	0.61 ±0.24	0.84 ±0.36	0.82 ±0.29	0.83 ±0.39
CO_2/SOC	0.11	0.03	0.03	0.03	0.02	0.03	0.03
TG (mg g^{-1})	0.96 ±0.1	1.75 ±0.7	2.91 ±1.2	1.65 ±1.2	4.08 ±1.7	3.07 ±1.1	3.72 ±1.5
TG/SOC	0.31	0.13	0.10	0.12	0.10	0.11	0.10

3. Results and discussion

3.1. Characteristics of the studied soil environments

Physiographical characteristics of the selected soil environments are shown in table 1. A relevant peculiarity of the soils is the general shallowness of the soil profiles that is generally lower than 30-40 cm. The areas representatively monitored in each selected environment covers approximately 1.5 hectares, the surface slope ranges from 15% to 21%, and the plant cover is different according to land use-cover change. Soils were monitored along autumn 2009 to autumn 2010 in order to record their response to water erosion by analyzing field and laboratory parameters. Among the physical surface parameters measured along the experiments, mean soil moisture, surface impedance and shear strength values increased in the studied soil sequence. However decrease in mean bulk density, soil infiltration and hydraulic conductivity values were also recorded (table 2) probably accounting for a gradual soil structure improvement from V environment to MB environment. According to erosion and both field and laboratory related parameters it must be pointed out that a high variability was found along the measurements (table 2). The highest annual mean value of runoff was found in the soil under pasture (0.13 l m^{-2}) whereas the mean annual value of eroded soil (3.59 g m^{-2}) was recorded in the soil under cultivated vines (table 2).

3.2. Water erosion

Despite the variability of rainfall events recorded in each environment, their effect on runoff erosion was evaluated. Linear functions between cumulative runoff and cumulative rainfall are showed in fig. 4A. The differences in runoff production between the soils under a same rainfall amounts may be given mainly by the diverse plant cover. In the rainfall/runoff relationships the soil under pasture (PR) showed the highest runoff followed by the soil under olive groves (O), stands of cork trees (S), cultivated vines (V), stands of pine trees (PI), Cistus scrub (MC). The lower quantity of runoff was recorded in the abandoned soil under Erica scrub (MB) probably accounting for a more efficient plant cover protection. Moreover, the infiltration rate and hydraulic conductivity were moderately low as to assume higher water use efficiency in this environment also corroborated by the yearly mean moisture (table 2). Conversely, the linear functions between cumulative erosion (g m^{-2}) and cumulative runoff (l m^{-2}) showed that soil under vines revealed a high susceptibility to erosion, featuring physical and chemical properties decline with such current management (fig. 4B). The erosion rate in vines is approximately 7.4 times that of the soil under pasture, which had shown the highest runoff under the same rainfall effect. However, absolute values of erosion were low when compared to other areas of Spain (Castillo *et al.,* 2000; Calvo Casas *et al.,* 2003). By extrapolating the amount of eroded soil (g m^{-2}) per l m^{-2} runoff, the higher value was found in soil under cultivated vines (34.52 g m^{-2}). For the same runoff, the erosion under pasture was 4.66 g m^{-2}, under corks 3.16 g m^{-2}, under olives 2.57 g m^{-2}, under Cistus scrubs 1.59 g m^{-2}, under pines 1.10 g m^{-2}. Yet, the lower erosion was recorded in the soil under Erica scrubs 0.19 g m^{-2}. Despite the low erosion amounts, values may be

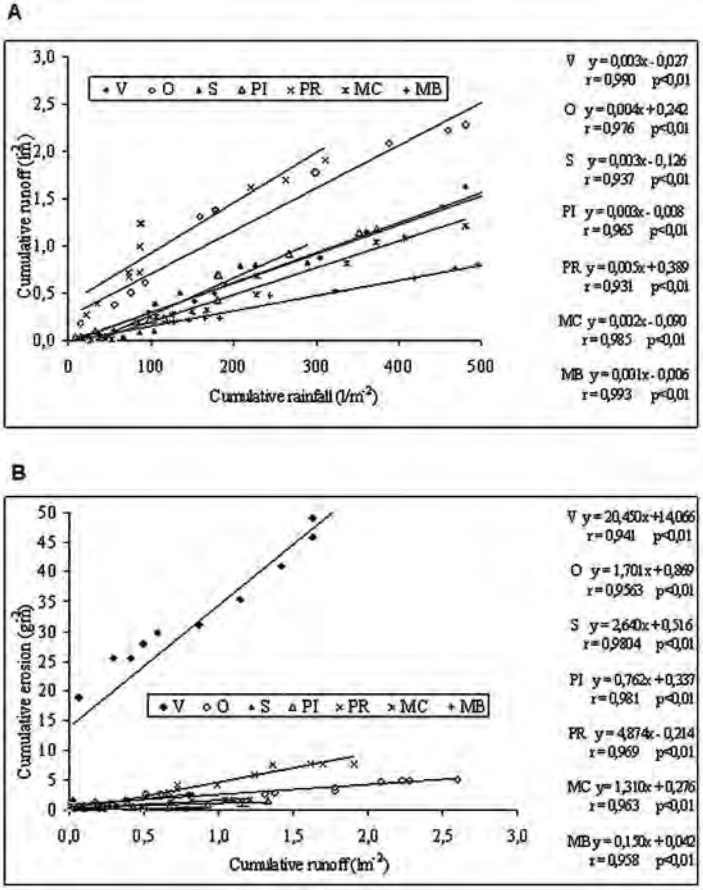


Figure 4. A) Trend in cumulative runoff vs. cumulative rainfall along the period of study for all the selected environments. B) Trend in cumulative erosion vs. cumulative runoff along the period of study for all the selected environments.

consistent for environment degradation because of the very shallow nature of these soils, though, according to Albaladejo Montoro and Stocking (1989), they will fall in the very low or no erosion category (0-3 T/Ha year). DOC and DN as well as EOC and EN were analyzed in runoff water and eroded soil respectively along the observed period. The percentage of DOC to eroded soil was 0.08, 0.08, 0.10, 0.13, 0.09, 0.03, 0.02% for V, O, S, PI, PR, MC, MB environments respectively, whereas the percentage of EOC to eroded soil was 8.52, 3.84, 6.05, 6.11, 7.13, 3.63, 1.39% for V, O, S, PI, PR, MC, MB environments respectively. These data were in agreement with previous findings of De Nobili and Maggioni (1993) reporting that EOC amount may reach mean values of 5-10% of eroded soil and indicating that some environments may release in the eroded material several times the organic carbon content of the soil itself. This trend may be particularly of concern in these shallow soils with a 10-15 cm deep A horizon. In fact, the mean SOC value of the soil under vines was 0.31%, whilst the mean EOC value of the eroded material from vines was 8.52% probably accounting for a stronger carbon loss from this environment. By contrast, the mean SOC value of the soil under Erica scrub was 3.29% against a mean EOC value of the eroded material from Erica scrub of 1.39%, indicating that the organic compounds in this soil environment may be more stable and difficult to be removed by surface erosion. The ratio EOC/SOC corroborate these considerations being 27, 10, 3, 2, 4, 2, 1, 0,4 for V, O, S, PI, PR, MC, MB respectively. Although the comparison between the SOC in soil and the EOC in eroded soil may be somewhat unrealistic, data may broadly outline the carbon dynamics along the period observed.

3.3. Relationships between soil carbon, glomalin and carbon dioxide

Soil organic carbon (SOC), soil respiration capacity (CO_2) and glomalin content (TG) were measured in the investigated environments along the observed period and the mean annual values are reported in table 2. Glomalin content showed the highest value in soils under pasture with respect to other soil environments. The same trend was observed in CO_2 measurements. However when the ratio of carbon dioxide to soil organic carbon (CO_2/SOC) as well as the ratio of glomalin to soil organic carbon (TG/SOC) were checked for each environment, it was observed that cultivated soils showed the highest value with respect to other soils (table 2). The content and type of organic carbon was assumed to be related to this trend. Soils under vines showed the lesser amount of organic carbon which was approximately 12 times lower than all other soil environments. However, soils under olive groves and stands of pine trees also showed lesser amounts of SOC with respect to soils under stands of cork trees, scrubs and pasture. The results may indicate that the organic matter decline in unmanaged still cultivated soils and soils under pines may be due to the presence of both labile organic compounds and hardly mineralizable organic compounds respectively, probably related to a highest sensitivity to degradation processes by opposite mechanisms, an easier consumption of much easily mineralizable organic compounds in the former, a scarce contribution to humification of decaying organic debris in the latter. The lowest ratio CO_2/SOC (0.02) was found in the soil under pasture stressing the role of this environment in preserving the organic carbon pool. The soils under vines produced 0.96 mg/g of total glomalin and the TG/SOC ratio of 0.31 also indicated that part of glomalin produced in V environment may be easily mineralized. The ratio decreased in the order O, PI, PR, MB, MC, S and was 0.13, 0.12, 0.10, 0.10, 0.11, 0.10 accounting for a small but indicative difference in carbon storage capacity in more ancient environments. It was assumed that both lower CO_2/SOC and TG/SOC ratios indicated a twofold positive effect both in soil structure formation and organic carbon storage (table 2).

3.4. Water stable aggregates and glomalin

The structural stability of aggregates analysis was established in two classes of aggregates (0.25-2.00 mm, and 2.00-5.6 mm). The average annual values of water stable aggregates (WSA) are reported in table 2. Yet, higher values of WSA were found in soils under S, PR, MC, and MB environments indicating a better structure. Moreover, WSA values of these soils in the 0.25-2.00 class were rather similar, scarcely reaching 3%

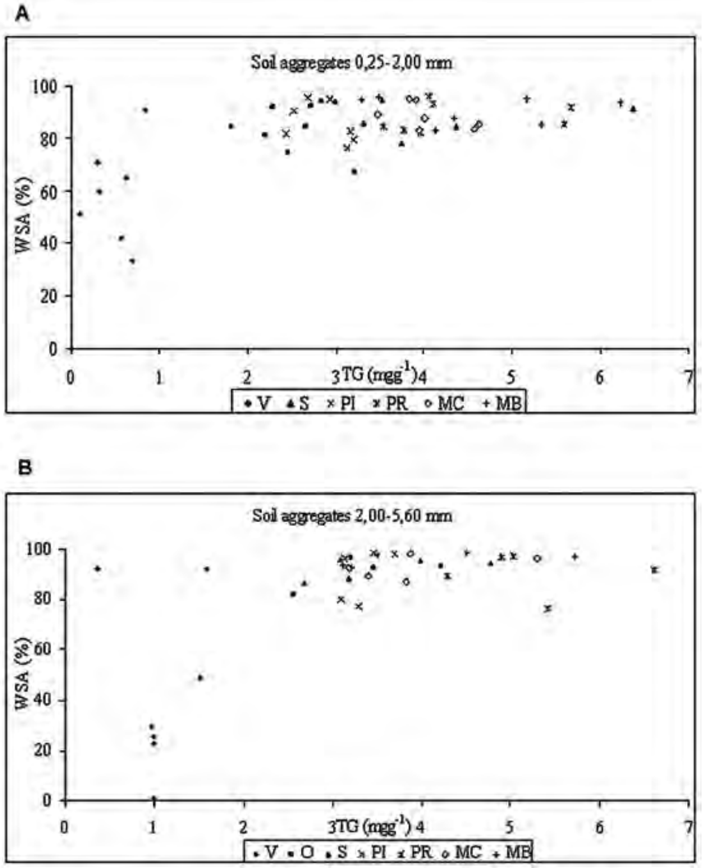


Figure 5. Patterns in water stability of aggregates for the 0.25-2.00 mm class (A) and the 2.00-5.60 mm class (B), when plotted against the total glomalin content. The scattered points for each environment indicate a rather high variability during the measurements along the observed periods.

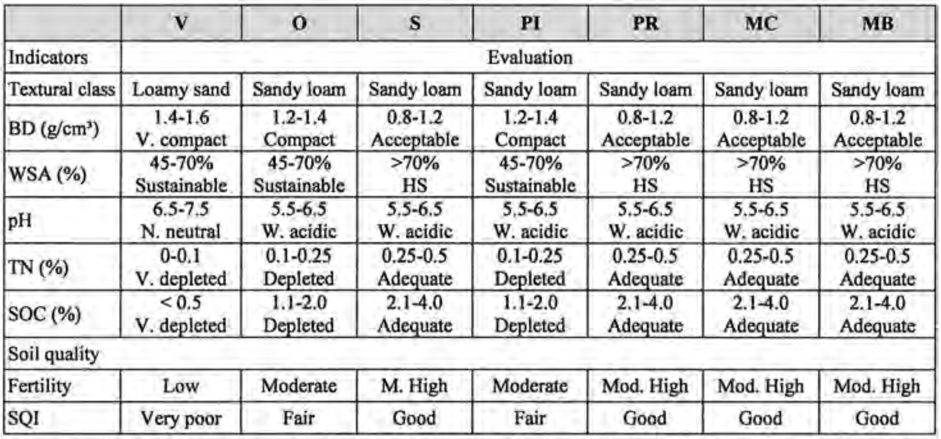
difference one another. Similarly higher WSA values were found in the 2.00-5.60 aggregate class in the same S, PR, MC, and MB soils which had a mean difference of 6% one another. Also in this class, the aggregate stability resulted 13% lower in soil under pines (PI) and 87% lower in soils under V and O environments when compared with the above mentioned well structured soils. These findings are in agreement with Cammeraat and Imeson (1998), suggesting that larger aggregates are likely to occur to a larger extent in mature soils, with a suitable plant cover which, in turn, may positively influence soil structure conditions through the production of stable organic compounds. As elsewhere mentioned, when improvement of aggregate stability occurs from smaller to larger aggregates a more stable soil environment with best structural conditions is expected.

The previous consideration may also suggest that organic material is more important in binding soil particle than clay (Oades and Waters, 1991). This would be especially true in our environments under study classified as sandy or sandy loam due to low clay fraction (table 2). The maintenance of stable organic compounds is therefore a primary conditions in abandoned environments often subjected to wildfire devastation. At this regard, the water stable aggregate (WSA) was plotted against total glomalin (TG) with the aim to establish the relationships between the two soil attributes (fig. 5). Despite the variability of data showed by the scatter of points of each environment, significant correlations were found with the following equations: WSA=5.524TG+65.407, $r=0.614$, $p<0.01$ for the 0.25-2.00 mm aggregate class (fig. 5A) and WSA=8.709TG+55.219, $r=0.601$, $p<0.01$ for the 2.00-5.60 mm aggregate class (fig. 5B). Glomalin seems therefore to be more active in terms of structural stability of aggregates in more mature abandoned soils.

3.5. Soil quality evaluation

Selected soil physical and chemical indicators of soil quality were used according to the soil quality evaluation of the USA National Research Council-NARC (1993) and Shukla *et al*. (2006). The soil quality evaluation of the environment under study is reported in table 3. Doran and Parkin (1994) and Larson and Pierce (1994) suggested a similar number of soil parameter (minimum data set) to carry out soil quality evaluation based mainly on soil related functions.

Table 3. Soil quality evaluation in the selected environments.



	V	**O**	**S**	**PI**	**PR**	**MC**	**MB**
Indicators	Evaluation						
Textural class	Loamy sand	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam
BD (g/cm³)	1.4-1.6 V. compact	1.2-1.4 Compact	0.8-1.2 Acceptable	1.2-1.4 Compact	0.8-1.2 Acceptable	0.8-1.2 Acceptable	0.8-1.2 Acceptable
WSA (%)	45-70% Sustainable	45-70% Sustainable	>70% HS	45-70% Sustainable	>70% HS	>70% HS	>70% HS
pH	6.5-7.5 N. neutral	5.5-6.5 W. acidic	5.5-6.5 W. acidic	5.5-6.5 W. acidic	5.5-6.5 W. acidic	5.5-6.5 W. acidic	5.5-6.5 W. acidic
TN (%)	0-0.1 V. depleted	0.1-0.25 Depleted	0.25-0.5 Adequate	0.1-0.25 Depleted	0.25-0.5 Adequate	0.25-0.5 Adequate	0.25-0.5 Adequate
SOC (%)	< 0.5 V. depleted	1.1-2.0 Depleted	2.1-4.0 Adequate	1.1-2.0 Depleted	2.1-4.0 Adequate	2.1-4.0 Adequate	2.1-4.0 Adequate
Soil quality							
Fertility	Low	Moderate	M. High	Moderate	Mod. High	Mod. High	Mod. High
SQI	Very poor	Fair	Good	Fair	Good	Good	Good

SQI=soil quality index; V. compact=very compact; HS =highly sustainable; N. neutral =nearly neutral; W. acidic= weakly acidic; V. depleted= very depleted; M. High: Moderately High.

Textural class, bulk density (BD), water stable aggregates (WSA), pH, total nitrogen (TN) and soil organic carbon (SOC) were used. Results show that the soil environment under vines (V) presents the worse situation of soil quality with a low fertility and very poor quality index (SQI). Soils under olives (O) and pines (PI) may be considered as intermediate with a moderate fertility and a fair SQI. Other soils are confirmed as depicting the best conditions both from a physical and chemical point of view (table 3). The rather good performance of the soil under MC environment was rather surprising as worse conditions were expected due to frequent fire occurrence in this area.

3.6. Factor analysis

Factor analysis was performed by using the statistical program Statistics 7.1 of Statsoft Inc. (2005). The analyzed parameters of all the environments were run simultaneously. Three types of factor structures were tried in order to find statistical evidence of the natural dynamics occurred in the area of study.

A first three factor structure was carried out for soil properties, a second three factor structure processing erosion related parameters and a third three factor structure taking into account soil parameters related with biological activity. Factors were explained as indexes of global soil dynamics. A conceptual name was given to each factor as to identify the relevance of the variables included (Paniagua *et al.,* 1999). The factor analysis was used to rank the soil attributes and calculate the related communality values. The communality value is the variance explained by each variable to the three factors jointly (Paniagua *et al.,* 1999). The loadings of varimax rotated factor analysis and percentages of the explained absolute and cumulative variance by the three components in each factor structure are reported in tables 4, 5 and 6.

The factor analysis of soil properties is showed in table 4. The total variance is concentrated in the first three factors with a 91% of the significant variables. The three principal factors were identified and variables grouped as following: the factor 1 explained the 71% of the total variance and was named the organic reserve factor. High positive loadings were found for total nitrogen (+0.772), soil organic carbon (+0.746), electrical conductivity (+0.840), and moisture (+0.79) whereas negative loadings were found for soil infiltration capacity (-0.880), pH (-0.727), and bulk density (-0.685). Factor 2 explained 13% of the total variance and showed high positive loadings for mechanic impedance (+0.706), shear strength (+0.621) and negative for soil hydraulic conductivity (-0.898). This factor was named surface hydraulics. The third factor named texture and structural stability explained only 8% of the total variance with positive loadings for silt content (+0.957), (+0.823) for water stable (0.25-2.00 mm) aggregates (+0.767) for water stable (2.00-5.60 mm) aggregates, water holding capacity (+0.743), clay content (+0.611) and negative loadings for sand content (-0.880).

The communality for a given variable can be interpreted as the proportion of variation in that variable explained by the three factors jointly. Communalities are computed by using the sum of the squared loadings for that given variable. The soil organic carbon is the most important variable in this factor structure as it shows a communality of 0.997 obtained from $(0.746)^2+(0.294)^2+(0.595)^2$. The sum of all the communalities values divided by the number of variables gives the proportion of total variance explained by the three factors i.e. 14.604/16=0.9128=91.28%. In general, this factor structure explains clearly that among the studied soil environments the organic matter content has a primary role, even though contrasted by bulk density and infiltration rate which may be associated to soil environments with poorer conditions. In fact the factor score the first factor categorized with positive values the soil PR (+1.480), soil MB (+0.671), soil S (+0.642) and soil MC (+0.353) whilst attributed negative values to soils V (-1.521), O (-0.520) and PI (-0.378).

Table 4. Variable's loadings in the factor analysis by using mainly soil parameters of all studied environments simultaneously. Values below 0.60 omitted.

Variables	**Factor analysis**			**Communalities**
	Organic reserve	**Surface hydraulics**	**Texture and structural stability**	
Clay (%)	0.270	0.483	**0.611**	0.914
Silt (%)	0.277	-0.035	**0.957**	0.995
Sand (%)	-0.302	-0.324	**-0.880**	0.971
WHC (%)	0.573	0.185	**0.743**	0.916
WSA (0.25-2.00) (%)	0.301	0.403	**0.823**	0.931
WSA (2.00-5.60) (%)	0.556	0.126	**0.767**	0.915
BD (g cm^{-3})	**-0.685**	-0.264	-0.518	0.923
MI (kPa)	0.278	**0.706**	0.515	0.842
SS (kPa)	0.372	**0.621**	0.541	0.817
HC (cm h^{-1})	0.156	**-0.898**	0.050	0.833
IC (mm h^{-1})	**-0.880**	0.028	-0.268	0.847
Moisture (%)	**0.789**	0.491	0.333	0.975
pH	**-0.727**	-0.540	-0.269	0.893
EC (dSm^{-1})	**0.840**	-0.255	0.266	0.842
SOC (mg g^{-1})	**0.746**	0.294	0.595	**0.997**
TN(mg g^{-1})	**0.772**	0.467	0.412	0.985
Explained Variance (%)				
Absolute	70.732	12.977	7.560	
Cumulative	70.732	83.709	91.275	91.275

The factor structure related to erosion dynamics is reported in table 5. This three factor structure explained 87.70% of the total variance into the analyzed variables. The three factors allowed to group the variables as following: The factor 1 named erosion factor explained the 60.54% of the total variance with positive loadings for soil organic carbon (+0.801), water stable (2.00-5.60 mm) aggregates (+0.965), water holding capacity (+0.934), silt content (+0.909), water stable (0.25-2.00 mm) aggregates (+0.802) and negative loadings for bulk density (-0.862), surface erosion (-0.809), water run off (-0.788) and sand content (-0.790). The second factor named eroded nitrogen factor related to rainfall and the nature of soil surface explained 15.34% of total variables with positive loadings for dissolved nitrogen by water runoff (+0.834), nitrogen in eroded soil (+0.780), mechanic impedance (+0.757), clay content (+0.720), soil moisture (+0.687), and negative loadings related with the effect of rainfall amount (-0.681) on soil surface and the pool of removed nitrogen from soil. The third factor named eroded carbon explained the 11.80% of the total variance with only negative loadings for eroded organic carbon and dissolved organic carbon, (-0.943 and -0.907 respectively). The proportion of the total variation explained by the three factors is 14.901/17 variables = 0.8766 this mean 87.70% of variation explained through these factors as total communalities. Yet soil organic carbon result as an important variable in this factor structure with communality of 0.92. Nevertheless, there are three variables with communalities values higher than soil organic carbon indicating that structural stability, surface compaction, and water holding capacity have important role in contrasting erosion processes. The factor score of the first factor categorized with negative values the soil V (-1.705), soil O (-0.881), soil PR (-0.280) whilst attributed positive values to soils S (+0.951), MB (+0.890) MC (+0.630) and PI (+0.382). The soil under cultivated vines is the environment with the highest contribution to erosion in the studied area. Despite that, the factor score for the second factor named eroded nitrogen, attributed positive value to soil PR (+1.855) probably related to the highest nitrogen loss by runoff erosion due to cattle manure at soil surface. Moreover, the factor score for the third factor (eroded carbon) attributed a negative value (-1.460) that the soil MB indicating a stronger resistance to carbon removal.

Table 5. Variable's loadings in the factor analysis by using the erosion related parameters of all studied environments simultaneously. Values below 0.60 omitted.

Variables	**Factor analysis**			**Communalities**
	Erosion	**Eroded nitrogen**	**Eroded carbon**	
Rainfall (l m^{-2})	-0.455	**-0.681**	0.306	0.766
Runoff (l m^{-2})	**-0.788**	0.437	0.107	0.824
Erosion (g m^{-2})	**-0.809**	-0.374	-0.099	0.805
EOC (mg g^{-1})	-0.088	0.017	**-0.943**	0.898
DOC (mg g^{-1})	-0.233	0.092	**-0.907**	0.885
EN (mg g^{-1})	0.362	**0.780**	-0.361	0.870
DN (mg g^{-1})	-0.007	**0.834**	-0.136	0.715
Clay (%)	0.490	**0.720**	0.344	0.877
Silt (%)	**0.909**	0.217	0.026	0.875
Sand (%)	**-0.790**	-0.493	-0.189	0.904
WHC (%)	**0.934**	0.230	0.216	**0.972**
WSA (0.25-2.00) (%)	**0.802**	0.474	0.123	0.885
WSA (2.00-5.60) (%)	**0.965**	0.202	0.116	**0.987**
BD (g cm^{-3})	**-0.862**	-0.314	-0.256	0.909
SOC (mg g^{-1})	**0.801**	0.476	0.236	**0.924**
MI (kPa)	0.341	**0.757**	0.532	**0.972**
Moisture (%)	0.537	**0.687**	0.257	0.826
Explained Variance (%)				
Absolute	60.540	15.338	11.778	
Cumulative	60.540	75.879	87.657	87.657

Table 6. Variable's loadings in the factor analysis by using parameters related with soil biological activity of all studied environments simultaneously. Values below 0.60 omitted.

Variables	**Factor analysis**			**Communalities**
	Soil biophysical dynamics	**Soil acidity**	**Soil surface compaction**	
Clay (%)	0.483	0.243	**0.823**	0.971
Silt (%)	**0.845**	-0.323	0.395	0.973
Sand (%)	**-0.748**	0.067	**-0.652**	0.989
WHC (%)	**0.938**	0.281	0.181	0.993
WSA (0.25-2.00) (%)	**0.857**	0.034	0.422	0.914
pH	-0.082	**-0.883**	-0.169	0.816
MI (kPa)	0.166	0.404	**0.876**	0.959
Moisture (%)	**0.881**	0.295	0.273	0.938
BD (g cm^{-3})	**-0.972**	-0.089	-0.023	0.953
SOC (mg g^{-1})	**0.882**	0.365	0.286	**0.993**
TN (mg g^{-1})	**0.698**	0.580	0.401	0.986
CO_2 (mg g^{-1})	**0.910**	0.226	0.267	0.951
TG (mg g^{-1})	**0.766**	0.529	0.296	0.955
Explained Variance (%)				
Absolute	69.893	15.869	7.160	
Cumulative	69.893	85.763	92.923	92.923

The factor structure related to biological parameters explained the 92.92% of the total variance in the variables. The three factors identified and associated variables gave allowed the following observations: The first factor explains 69.69% of the variance from the total variables, with high positive loadings on water holding capacity (+0.938), CO_2 production (+0.910), soil organic matter (+0.882), soil moisture (+0.881), water stable (0.25-2.00) aggregates (+0.857), silt content (+0.845), glomalin content (+0.766), total nitrogen (+0.698), and high negative loadings on bulk density (-0.972), and sand content (-0.748). This factor was referred as the soil biophysical dynamics factor related to organic reserve, soil biological activity, and structural stability. The second factor was named the soil acidity factor. This factor explained 15.87% of the total variance in the analyzed variables and showed high negative load on soil pH (-0.883) probably indicating that the soil reaction in the environments under study may have some role in the overall soil functions. The third factor explaining 7.16% of the total variance in the variables had positive loads on clay content (+0.822) and mechanic impedance (+0.876) and negative loads on sand content (-0.652). This factor was named soil surface compaction suggesting a relatively low effect of the sealed surface on parameters related to soil biological functions. The proportion of the total variation explained by the three factors was 13.938/15 variables = 0.929, that means 92.92% of variation explained through these factors as total communalities. Soil organic matter had the highest communality value (0.993) in this factor structure which highlighted its highest contribution in improving soil biological functions. The factor score of the first factor categorized with positive values the soil MB (+1.243), soil S (+0.871), soil PR (+0.880), soil MC (+0.407), soil PI (+0.03), whilst attributed negative values to soils V (-1.615) and O (-0.970). The factor score for the second factor, named acidity, attributed a high positive value to soil PR (+2.015) as the environment that prevalently shows very acid reaction. The factor score for the third factor attributed a positive value (+1.226) to the soil MB probably indicating a residual effect of fire on the soil surface.

4. Conclusion

The overall analysis aimed at understanding the relevance of different parameters in the evaluation of soil quality along the environments under study and the period observed. Soil quality is an assessment of soil functions evaluated by the integration of soil physical, chemical, and biological parameters correlated with natural processes in the ecosystem. Many external factors play relevant roles in soil quality assessment such as vegetation cover and species, land use change and management, the age of land abandonment, and periodical natural or induced perturbations like wildfire.

The interrelationships of these factors, which absolute effect on soil quality is rather difficult to quantify, may lead to soil degradation especially in soil not properly managed. Some of our results demonstrated that abandonment is generally contributing to soil regeneration even without a proper management of the abandoned land. For example, the soils under stands of cork trees, *Erica arborea* scrubs, pasture and even *Cistus monspeliensis* scrub, often fire affected, showed satisfactory soil properties, in front of still cultivated soils or soils under stands of pine trees (this latter including also the issue of plant species used for reforestation.). A special attention should be therefore deserved especially when the abandoned land is located in a very vulnerable territory, with very shallow soils and dense extension of scrubland. Even though with time the soil ecosystem is generally recovering a steady state, reiterated wildfire occurrence may affect the main physical properties such as water holding capacity and soil aggregation, chemical properties such as soil reaction, and the soil biological crumb, controlling soil organic compounds together with nutrients availability which also influence the installation and persistence of wider number of plant species. Thus, soil conditions favoring soil organic matter increase and storage may also increase glomalin production, hence soil structure stability. Opposite trends leading to nutrient depletion, structure instability, carbon loss through CO_2 production and increased erosion rates should be avoided by appropriate soil care against soil mismanagement.

The statistical analysis used gave the possibility to analyze all the data simultaneously in three different sets of soil parameters, each set with a three factor structure made up of soil properties, soil erosion and soil biological dynamics. All three factor structures indicated the importance of organic matter content in soil. Soil organic matter represents therefore the most important parameter driving physical and chemical soil properties evolution through suitable biological activity, that should be enough efficient to produce both nutrients and humic compounds in soil, in turn improving soil structure which in turn may entrap organic carbon in the pore space so as to preserve soil quality.

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