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Distribution Patterns of Soil Properties in a Rural Mediterranean Area in Northeastern Spain

Soil properties on the Cap de Creus Peninsula, NE Spain depend primarily on scarce agricultural practices and early abandonment. In the study area, 90% of which is mainly covered by Cistus *shrubs, 8 environments representing variations in land use/land cover and soil properties at different depths were identified. In each environment variously vegetated areas were selected and sampled. The soils, collected at different depths, were classified as Lithic Xerorthents according to the United States Department of Agriculture system of soil classification (USDA-NRCS 1975). Differences in soil properties were largely found according to the evolution of the plant canopy and the land use history. To identify underlying patterns in soil properties related to environmental evolution, factor analysis was performed and factor scores were used to determine how the factor patterns varied between soil variables, soil depths and selected environments. The three-factor model always accounted for 80% of the total variation in the data at the different soil depths. Organic matter was the more relevant soil property at 0–2 cm depth, whereas active minerals (silt and clay) were found to be the most relevant soil parameters controlling soil dynamics at the other depths investigated. Results showed that vineyards and olive tree soils are poorly developed and present worse conditions for mineral and organic compounds. Analysis of factor scores allowed independent assessment of soils, depth and plant cover and demonstrated that soils present the best physicochemical characteristics under* Erica arborea *and meadows. In contrast, soils under* Cistus monspeliensis *were less nutrient rich and less well structured.*

Keywords: *Abandoned fields; soil properties; shrubland; pastureland; vineyards; olive trees; factor analysis; Spain.*

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Introduction

Mid-mountain rural abandonment in northeast Spain has produced changes in soil properties; moreover, landscape has changed from an ordered mosaic to a continuous, disorganized *garrigue* (Lasanta 1988), often devastated by fire. Many authors have studied the distribution patterns of soil properties under extensive shrub canopies compared with adjacent cultivated or open grass areas (Charley and West 1975; Martinez-Fernandez et al 1995; Bochet et al 1998; Ross et al 1999). Increased fire recurrence with detrimental effects on plants and soils has also been extensively studied (Andreu et al 1996; Inbar et al 1997; Thomas et al 1999; Gimeno-García et al 2000).

The evolution of soil properties after land abandonment has been found to depend on 1) the condition of the soil at agricultural release; 2) the subsequent evolution of fire-dependent vegetation cover; and 3) the capability of the soil itself to counteract erosion and degradation processes (García-Ruiz et al 1991; Pardini et al 1991; Ruiz-Flaño et al 1992). Soil degradation on abandoned and still cultivated terraced soils may be consistent in terms of organic matter and nutrient depletion, and lack of appropriate management. The impacts of land use and land use change are often disregarded at the soil level, affecting soil quality (Seybold et al 1999). Soil properties (variables) measured in different existing environments may give indications of the state of degradation or recovery of given environments undergoing different kinds of perturbation. Factor analysis, for example, makes it possible to simplify the study of complex data systems by identifying a relatively small number of factors that can be used to represent the relationships among sets of many interrelated discrete variables and observations (environments) without important loss of information (Brejda 1998). The aim of the present study is to assess the relationships between soil variables at different depths in selected environments by identifying factor patterns and factor scores, in order to determine how cultivation practices and relevant abandoned environments influence soil properties.

FIGURE 1 Vineyard patches surrounded by abandoned fields (Serra de Rodes catchment, spring 2002). (Photo by Giovanni Pardini)

FIGURE 2 Measurements made in a recently recovered olive tree plantation. (Photo by Giovanni Pardini)

Methods and materials

The study area is located in the Serra de Rodes catchment, Cap de Creus Peninsula, Girona Province, in the Pyrenees, northeast Spain (Table 1). The region has a Mediterranean xerothermic climate, with hot summers and mild winters, an annual average temperature of 16°C and a mean annual rainfall of 450 mm. The area has been thoroughly cultivated with olive trees and vines since ancient times. As a consequence of the *Phylloxera vastatrix* devastation in 1865 and the extreme cold during the winter of 1956, vineyards and olive trees were decimated and a large part of the territory was almost completely abandoned. The forthcoming "green revolution" shifted agricultural production to the best plots in the plains, and additional socioeconomic factors forced rural abandonment. Some patches of cork trees (*Quercus suber*) were later established for cork production, but were successively abandoned. Today, 90% of the territory is covered by dense brushland, most of it *Cistus monspeliensis*-dominated, with 10% divided into vineyards (Figure 1) and olive plantations (Figure 2) that are still cultivated, meadows for pasture, and small pine and cork tree forest patches. The vegetated area, either brushland or forest, does not receive any management.

In the study area, 8 different environments were selected in order to analyze the distribution of soil properties at different depths. The following areas (approximately 1.5 ha) were identified and are described in Table 1:

- V: 7-year-old cultivated vines with *Vitis vinifera*;
- O: 30-year-old (recently recovered) cultivated olive trees with *Olea europea*;
- ES: 25-year-old shrubland vegetated with *Erica arborea*;
- CS: 10-year-old shrubland vegetated with *Cistus monspeliensis*;
- BS: Recently burned (2001) shrubland with mainly *Cistus monspeliensis* resprouts;
- M: 15-year-old meadows mainly vegetated with *Brachipodium retusum*;
- P: 50-year-old pine tree forest with *Pinus halepensis*; and
- BP: Recently burned (2001) pine tree forest with a current cover of *Cistus monspeliensis* resprouts.

The cultivated areas are under very low agricultural management (no addition of organic matter, no fertilizers), whereas meadow areas are being progressively invaded by *Cistus monspeliensis* (Figure 3). The pine tree area (P) is an example of 20th century pine afforestation policy, although many pine forests have been completely destroyed by wildfires and progressively replaced by *Cistus monspeliensis* shrubland.

TABLE 1 Physiographical and pedological characteristics of the selected environments. V: Vineyards; O: Olive trees; ES: *Erica* shrub; CS: *Cistus* shrub; BS: Recently burned shrub; M: Meadows; P: Pine tree forest; BP: Recently burned pine forest.

Characteristic	Environments							
	V	O	ES	CS	BS	M	P	BP
Lithology	Schist	Schist	Schist	Schist	Schist	Schist	Schist	Schist
Soil group	Entisol	Entisol	Entisol	Entisol	Entisol	Entisol	Entisol	Entisol
Location	42°18′N 3°12′E	42°18′N 3°13′E	42°18′N 3°13′E	42°18′N 3°11′E	42°17′N 3°15′E	42°18′N 3°14′E	42°20′N 3°06′E	42°16′N 3°15′E
Slope (%)	15%	18%	18%	18%	18%	15%	18%	20%
Orientation	SE	SE	SE	SE	SE	SE	SE	SE
Altitude (m)	60	200	240	254	150	248	235	165
Surface (ha)	1.8	1.2	1.6	1.4	1.4	1.9	1.5	1.8
Main vegetation	*Vitis vinifera*	*Olea europea*	*Erica arborea*	*Cistus monspel.*	*Cistus* resprouts	*Brachi-podium r.*	*Pinus halep.*	*Cistus* resprouts
Last fire (year)	1986	1986	1986	1986	2000	1986	1986	2000

Soil samples were collected at 0–2, 2–10, 10–30, and 30–50 cm depths at 3 different sites in each representative area in each environment. Horizon development was O, Ap, C/R for all the abandoned soil environments and Ap, C/R for cultivated vines and olive tree soils. The shallow and poorly developed soils (0–50 cm maximum depth) were classified as Lithic Xerorthents according to USDA-NRCS (1975). The O horizon corresponds to a depth of 0–2 cm, while the Ap horizon corresponds to 0–30 cm and the C/R horizon to 30–50 cm. A total of 12 samples (3 sampling points, 4 soil depths) at each area were collected, and a total of 96 soil samples were obtained. Analytical determinations based on conventional methods were carried out for: moisture (M), bulk density (Bd), sand, silt and clay (Sa, Si, Cl), water holding capacity (Wh), pH, electric conductivity (Ec), exchangeable Ca, Mg, K, and Na, cation exchange capacity (EC), organic matter (Om), total nitrogen (N), available phosphorus (P), and soil respiration and carbon dioxide emission (CO_2).

Statistics

In order to obtain statistical evidence from analytical data at different depths and in different environments, differences between means were tested using one-way ANOVA (test F). This simple exploratory statistical procedure establishes whether groups of independent variables mark significant differences between the analyzed (dependent) variables. In factor analysis, factors were extracted by principal component analysis (PCA) and only factors with eigenvalues >1 were selected, using the Kaiser criterion, stating that a factor must extract at least as much as the equivalent of one original variable. Varimax rotation was subsequently carried out according to the varimax rotation method (Statsoft Inc. 2002). Factor score helped in the interpretation of the relationships between soil variables and factors by giving actual values (negative or positive) for the factors in individual cases (environments) and explaining which environments contribute more to soil health or to degradation.

Results and discussion

Soils were mainly characterized by a sandy loam texture (USDA classification) at any depth. Soils under olive

FIGURE 3 Meadows with *Cistus* shrub colonization. (Photo by Giovanni Pardini)

tree cultivation showed a sandy texture at a depth of 30–50 cm, whereas soils under *Erica arborea* shrub showed a loamy sand texture at each analyzed depth.

Results from ANOVA are displayed in Table 2. It can be observed that significant differences were found in moisture content, clay, water holding capacity, exchangeable potassium, soil organic matter, total nitrogen, available phosphorus and CO_2 production capacity. These are the soil properties largely related to land use and land cover change (Harden 1996). Moreover, no significant differences were found either in sand and silt content or in bulk density and pH, which were mostly associated with parent material composition. Evidence of nutrient enrichment was found in recently burned environments, although ash wash-out may be consistent after fire and cause further soil impoverishment (Andreu et al 1996).

Abandoned terraced soils colonized with *Erica arborea* shrub (ES) showed the highest organic matter content, followed by soils under meadows (M) and soils under *Cistus monspeliensis* shrub (CS). Still cultivated soils with vines (V) and soils under pine forest (P) showed the lowest organic matter content. Similarly, the low soil respiration of soils under *Erica arborea* indicated that accumulation of organic carbon occurs in these environments, enhancing aggregation and structural stability. Soils under *Cistus monspeliensis* showed comparatively worse physical conditions with frequent crust formation and low infiltration capacity, which may lead to increased erosion phenomena (Lasanta et al 2001). Conversely, when *Erica arborea* prevails, representing the natural evolution of the abandoned environments without fire perturbation, the development of a nutrient-rich, well-structured soil may be expected. Evidence has shown that *Cistus monspeliensis* is continuously replacing *Erica arborea*, owing to high frequency of fires and the greater germination capacity of this species after the occurrence of fire (Trabaud and Oustric 1989). This evidence suggests the need for proper management of abandoned areas in order to limit ongoing land degradation (Molinillo et al 1997).

Factor analysis was carried out by running the soil variables of all environments studied simultaneously at each depth, in order to understand how different land use and land cover contribute to the development of soil properties at any depth, based on factor structure

Dependent variable	Mean	Standard deviation	F	P
Moisture	11.23	6.15	3.63	**0.0390**
Bulk density	1.34	0.08	0.13	0.8743
Sand	74.62	7.35	0.22	0.7998
Silt	17.19	5.48	0.47	0.6313
Clay	8.21	4.38	4.11	**0.0187**
Water holding capacity	38.65	11.05	3.47	**0.0443**
pH	6.01	0.64	2.16	0.1331
Electric conductivity	0.11	0.08	2.31	0.1165
Exchangeable Ca	4.49	2.57	2.46	0.1023
Exchangeable Mg	2.34	1.64	0.68	0.5136
Exchangeable K	0.46	0.31	16.47	**0.0002**
Exchangeable Na	3.54	1.61	0.12	0.8845
Cation exchange capacity	8.92	4.14	3.53	**0.0423**
Soil organic matter	1.85	1.79	8.52	**0.0012**
Total nitrogen	0.11	0.09	16.05	**0.0002**
Available phosphorus	29.81	12.56	3.63	**0.0389**
Soil respiration	0.71	0.92	15.51	**0.0000**

TABLE 2 Results from ANOVA test used to establish differences between measured soil parameters (N=96), taking as independent variables the different environments and the sampling depth. In bold font: significant differences at $p < 0.05$.

TABLE 3 Eigenvalues and proportion of variance for the three-factor model in the 4 soil depths analyzed for this study.

Soil depth	Factor 1	Factor 2	Factor 3
0–2 cm	(Organic matter factor)	(Nutrient factor)	(Active minerals factor)
Eigenvalue	8.04	4.20	2.35
Proportion of variance	47.31	24.71	13.84
2–10 cm	(Active minerals factor)	(Nutrient factor)	(Organic matter factor)
Eigenvalue	7.06	3.46	2.63
Proportion of variance	41.58	20.39	15.48
10–30 cm	(Active minerals factor)	(Nutrient factor)	(Organic matter factor)
Eigenvalue	7.16	3.87	2.79
Proportion of variance	42.14	22.77	16.44
30–50 cm	(Active minerals factor)	(Nutrient factor)	(Organic matter factor)
Eigenvalue	7.45	3.70	2.84
Proportion of variance	43.84	21.79	16.74

and its changes along the soil profiles. Eigenvalues for the first 3 factors were always >1 (Table 3). For 0–2 cm, the 3 extracted factors accounted for 85.86% of the total variation in the soil variables.

The first factor, accounting for 47.31% of the total variation in soil variables, had high positive loadings for organic matter, moisture, water holding capacity, soil respiration and total nitrogen, and was designated as the organic matter factor. Decaying vegetal debris, either deposited over the soil surface or incorporated as dead roots into the soil, are of paramount importance at this depth for subsequent development of the soil profile. The second factor, accounting for 24.71% of the total variation in the soil variables, had high positive loadings for electric conductivity, bicarbonate-extractable P, pH, and exchangeable Ca, and was termed the nutrient factor. The third factor, accounting for the 13.84% of the total variation in the soil variables, had high positive loadings for exchange capacity, silt and clay, and high negative loadings for sand and bulk density, and was termed the active minerals factor. The highest negative correlation found for sand (−0.929) with the third factor may indicate that the predominance of coarser texture at this soil depth hampers clay and organic matter interaction, lowering exchange capacity (Quiroga et al 1996).

Factor scores (positive or negative) at a depth of 0–2 cm are shown in Table 4. Scores refer to the contribution of each environment (land use/land cover) to soil properties and their distribution. Generally, the higher the score (either positive or negative), the greater the contribution (either positive or negative) of that factor and associated variables in any given environment. Organic matter factor scores (factor 1, 0–2 cm; Table 4) had the largest negative score values for the soil under vines (V), followed by soils under burned shrub (BS), pine trees (P) and olive trees (O). This indicates either scarce or insufficient contribution of these land use/land cover types to proper soil organic compound intake and maintenance. At the same depth, the largest positive factor score was recorded for *Erica arborea* shrub (ES), followed by meadows (M) and *Cistus monspeliensis* (CS), reflecting the importance of the kind of vegetation that favors litter accumulation and surface organic layer formation.

Nutrient factor scores (factor 2, 0–2 cm; Table 4) had the highest positive value for recently burned pine forest (BP), followed by a very low positive value for burned shrub (BS), indicating that burned environments may contribute to temporary changes in pH and electric conductivity with calcium and phosphorus enrichment, as reported by several authors (Gimeno-García et al 2000). Active minerals factor scores (factor 3, 0–2 cm; Table 4) were positive for *Erica* shrub (ES), burned shrub (BS), and pine tree forest (P), whereas *Cistus* shrub (CS), olive trees (O) and vines (V) showed negative values. This indicates that these latter environments make a smaller contribution to exchange properties and structure at 0–2 cm. Both soils under vines and *Cistus* shrub showed the lowest cation exchange capacity at any depth among the selected environments.

The three-factor model for depths of 2–10 cm presented a different arrangement of the variables/factors correlation structure. In this run, factor 1, accounting for 41.58% of the total variation in the soil variables, was characterized by high positive loadings for silt, water holding capacity, exchange capacity, moisture and clay, and negative loadings for sand and bulk density, and was termed the active minerals factor (Table 3). The fact that these parameters appeared on the third factor in the run for 0–2 cm, explaining only 13.84% of the total variation in soil variables, may indicate their relevance to soil exchange capacity and water retention below the first soil layer, where the role of organic matter content is relevant. This variation in factor position points out the great differences in soil properties at a scale of a few centimeters in depth, as also reported by ANOVA results, displayed for all the variables and at any depth (Table 2).

Factor 2, 20.39% of the total variation in the soil variables, exhibited positive loadings for pH, electric conductivity, exchangeable Ca and exchangeable Mg, and was still termed the nutrient factor. Conversely, the third factor, accounting for 15.48% of the total explained variance in the soil variables and showing high positive loadings for organic matter, total nitrogen, soil respiration, and exchangeable potassium, was termed the organic matter factor. As stated elsewhere in the present article, this factor accounted for 47.31% of the total variation in soil variables in the run at 0–2 cm, now accounting for only 15.48% in the factor model at 2–10 cm. The change depicts the diversity and general impoverishment of organic compound distribution below 2 cm, and an extended poorer horizon development, reflecting a certain fragility of these shallow soils, especially after abandonment.

Active minerals factor scores (Factor 1, 2–10 cm; Table 4) were very negative for vines and olive trees, accounting for the scarce contribution of these environments to fine particle enrichment and exchange capacity. By contrast, there were high positive scores for *Erica* shrub environment (ES) and also for burned shrub environment (BS), which showed clay enrichment and higher cation exchange capacity. As at the previously analyzed depth, nutrient factor scores (Factor 2, 2–10 cm; Table 4) had high positive values for burned pine forest environment (BP) where temporary post-fire beneficial effects (ashes causing an increase in pH and nutrient availability) may have occurred.

The negative scores for pine forest environment (P) seem to corroborate this assumption, as this environment showed the lowest pH (5.78) at this depth. The organic matter factor score (Factor 3, 2–10 cm; Table 4) was high and positive for meadows, followed by *Erica* shrub and *Cistus* shrub, indicating that among the environments studied at this depth the most important contribution of organic matter and related soil properties comes largely from meadows. Scores for burned shrub, pine trees and vineyards were high and negative, in agreement with the minimal contribution of these environments to organic matter content.

Factor position and distribution of variables at both 10–30 cm and 30–50 cm were similar. The three extracted factors explained 81.36% and 82.37% of the total variation in the soil variables for depths of 10–30 and 30–50 cm, respectively (Table 3). The distribution of the variables among the 3 factors was rather similar to that at a depth of 2–10 cm, corroborating that organic compounds are randomly distributed through the soil profiles and among the different environments, and depend mainly on the type of vegetation that colonizes abandoned fields. Factor scores (Factor 1, 10–30 cm; Table 4) showed a high positive value for *Erica* shrub (ES), followed by pine tree forest (P). By contrast, high negative scores were found for olive trees (O), followed by vines (V).

Factor 2 scores (10–30 cm; Table 4) continued to be positive for burned pine forest (BP), indicating the persistence of cation enrichment into the soil profile after fire, and highly negative for olive trees (O). Factor 3 scores (10–30 cm, Table 4) were high and positive for meadows, indicating that penetration and persistence of organic matter and related properties in the soil profile are mainly associated with meadow (M) environments. Scores for factor 1 at 30–50 cm (Table 4) were negative for vines (V) and olive trees (O) and positive

TABLE 4 Factor score from factor analysis for the different sites studied (environments) and the respective soil depths. Legend: 0–2 cm depth: factor 1, organic matter; factor 2, nutrient; factor 3, active minerals. 2–10, 10–30, and 30–50 cm depth: factor 1, active minerals; factor 2, nutrient; factor 3, organic matter. Legend for sites: see Table 1.

Site	0–2 cm soil depth			2–10 cm soil depth			10–30 cm soil depth			30–50 cm soil depth		
Factor	1	2	3	1	2	3	1	2	3	1	2	3
V	–1.42	–0.25	–0.62	–1.00	–0.58	–0.76	–0.84	–0.89	–0.60	–0.94	–1.01	–0.01
O	–0.51	–0.20	–1.13	–1.46	0.23	–0.33	–1.52	–1.74	–0.40	–1.80	0.04	–0.46
ES	1.22	–0.60	1.07	1.55	–0.27	0.80	1.59	–0.21	0.62	0.70	–0.04	2.00
CS	0.77	–0.43	–1.21	–0.12	–0.40	0.73	0.36	–0.16	0.21	–0.08	–0.56	0.57
BS	–0.82	0.11	1.54	0.89	0.52	–1.00	0.01	–0.53	–0.35	0.79	–0.51	–1.06
M	1.18	–0.33	–0.14	–0.55	–0.10	1.76	–0.63	0.32	2.14	0.08	0.11	0.26
P	–0.67	–0.68	0.54	0.52	–1.41	–0.96	0.93	–0.64	–0.81	1.29	–0.31	–1.08
BP	0.26	2.39	–0.04	0.16	2.02	–0.24	0.09	2.30	–0.80	–0.04	2.29	–0.22

FIGURE 4 Dense shrubland with a water reservoir to extinguish the frequent fires that occur on this abandoned land. (Photo by Giovanni Pardini)

for pine trees (P), accounting for increased clay contribution at this depth from pine tree forest. Factor 2 score values (30–50 cm; Table 4) were positive for burned pine forest, as above, and only vines (V) showed a negative factor score. *Erica* shrub environment (ES) seems to perform a relevant role in organic matter content at this depth (30–50 cm; Table 4), whereas meadows (M) show very low scores due to shallowness with respect to *Erica arborea* soils and the consequent sharp decrease in organic matter content.

Conclusions

The first conclusion to be drawn is that *Cistus monspeliensis* shrub appears not to contribute to the development of nutrient-rich, well-structured soils. Nor do fields cultivated with vines and olive trees, due to scarce agricultural maintenance. Nevertheless, they should be preserved as open, clean agricultural areas, to increase their efficiency in limiting fire propagation (Figure 4). Improvement of soil properties should be achieved in these environments through correct agricultural practices. Factor analysis helped to clarify the correlation structure present in the data set containing 17 correlated variables, distributed among 8 environments at 4 soil depths, by reducing unwieldy and intercorrelated soil variables to only 3 principal factors that always explained up to 80% of the total variation in the soil variables analyzed.

Factors were also named in order to identify 3 main features: organic matter content, nutrients and active minerals components. It was also postulated that this interpretation might be in line with field reality, as the change in factor distribution from 2–10 cm in depth was logical according to field observations and analyzed parameters. By means of attributed factor scores, factor analysis has also shown which environments help to maintain good soil properties in the study area and which do not. These indications are useful for land management practices and agroforestry work.

Moreover, factor scores made it possible to distinguish the role of each environment at any soil depth analyzed, with the result that the *Erica arborea* shrub environment was shown to be the most efficient, both in terms of organic matter content and active mineral dynamics. By contrast, meadows covered essentially with *Brachipodium retusum* were shown to be very important in controlling organic matter content, at least to a depth of 30 cm. In terms of the potential recovery of landscape heterogeneity and the state of soil properties, meadows should be recovered, as they are in transition to *Cistus* shrub. The latter is apparently replacing meadow, probably with a worsening effect on current soil properties.

It is important to underline that in the overall soil variables–environments architecture, the three-factor model indicated that organic matter content is the most important soil property at 0–2 cm, whereas from 2 to 50 cm (maximum soil depth), active mineral soil components such as clay and silt, whose presence is necessary to ensure a good profile development, are more relevant. The nutrient factor (second factor at any depth) was always associated with burned pine forest, indicating that despite devastation of pine trees by fire (Figure 5), a considerable amount of nutrients may be recycled into the soil.

FIGURE 5 Recently burned pine forest, completely destroyed. Though fires need to be controlled because of production losses incurred, soils can profit from occasional fires. (Photo by Giovanni Pardini)

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