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EFFECT OF LAND USE ON FOREST FLOOR AND SOIL OF A *QUERCUS SUBER* L. FOREST IN GALLURA (SARDINIA, ITALY)

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ABSTRACT

In order to determine the effect of land use on forest floor and soil, two adjacent sites with different land use were investigated in Gallura (northern Sardinia, Italy). One site is a *Quercus suber* L. forest mainly used for cork production and the other is an open *Quercus suber* L. forest where livestock is put out to graze. In each site one soil profile was studied to characterize the mineral soil, and five humus profiles were opened along a vegetation transect, were studied to characterize the forest floor. Samples of L, F and H horizons of the forest floor and of the A mineral horizons were collected and analysed for each profile. In the site mainly used for cork production well-developed ectorganic (L, F and H) horizons are always present, with a total thickness ranging from 5·2 to 9·5 cm. Humus profile is of the Moder type, while mineral soils have an A–C profile, generally 50 cm deep. Organic matter content in the forest floor ranges from 1·76–3·72 kg m^{-2} and nutrients content in the mineral soil is high. In the site used chiefly for grazing the ectorganic horizons are very poorly developed, with a total thickness ranging from 1–3 cm, except for some islands under the *Quercus suber* L. canopy where the total thickness may reach 5·3 cm. Humus profile is of the Mull type, but the used classification system seems not appropriate when the tree density is below a critical limit. Mineral soils have an A–C profile 20–25 cm deep. The organic matter content in the forest floor ranges from 0·45 to 1·84 kg m^{-2}, while nutrient content in the mineral soil maintains at high level, even higher than in the former case for C, N and Ca, probably in relation with higher supply of cattle excreta. Sheet erosion is evident in the site. It is concluded that cork production will maintain a sustainable forest floor development in cork–oak forest ecosystem, whereas cattle grazing, fires and ploughing in cork–oak forests may be considered to trigger off severe soil degradation processes. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS: forest floor; land use; *Quercus suber*; cork production; cattle grazing; Sardinia

INTRODUCTION

Cork production is important for the economy of Sardinia (Italy). Cork–oak (*Quercus suber* L.) stands cover roughly 90 000 ha (about 3·75 per cent of the island's surface), and yield over 7500 tonnes per year (Sanfilippo and Vannelli, 1992). However, production satisfies only half of the home demand which is rising steadily, especially for corking bottles of vintage wines. On the other hand, the productive areas are on the decline and cork quality is deteriorating due both to the intensification of exploitation and the lack of proper management of the cork–oak forests (Cacciarru *et al.*, 1997).

In Sardinia, the most important cork-growing areas are in the district of Gallura where, depending on prevailing land use, different forest types are present. The most stable are those with a good structural complexity, several layers of shrubby undergrowth, characterized by richness and abundance of species, and uneven aged stands with high tree density (200–250 to 400 cork–oak trees per hectare) (Cacciarru *et al.*, 1997). Land use here is limited to cork extraction, and grazing is restricted. On the other hand, the most degraded forests have rather low tree density (40–60 cork–oak trees per hectare), even aged stands, limited

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and extremely localized cork–oak renewal, and poor species diversity in the undergrowth (Cacciarru *et al.*, 1997). The main causes for the degradation are overgrazing, fires and ploughing (Aru *et al.*, 1994).

In the present study we compare the effects of different land uses on the soil, with special attention to the forest floor and the upper mineral horizon, which reflect the actual ecological conditions rather than the subsurface mineral horizons which commonly represent the result of soil forming processes active over a longer period of time.

MATERIALS AND METHODS

The study area (40°55′N, 9°15′E) is in the region of Gallura (Figure 1), in the municipal district of Calangianus (northern Sardinia). Topography is rolling (5–16 per cent slope), the elevation ranges from 470–480 m a.s.l., and the local bedrock is Hercynian unequigranular granite (Oggiano and Di Pisa, 1992). Climate is Mediterranean, with mild winters, short cold periods and hot summers. Mean annual temperature is about 14 °C; mean January (coldest month) and August (hottest month) temperatures are 6·7 °C and 23·8 °C, respectively. Mean annual precipitation is 1033 mm but annual variations of half this amount frequently occur. The rainfall distribution shows a peak in autumn and a secondary peak in spring (Sezione Autonoma per il Servizio Idrografico della Sardegna).

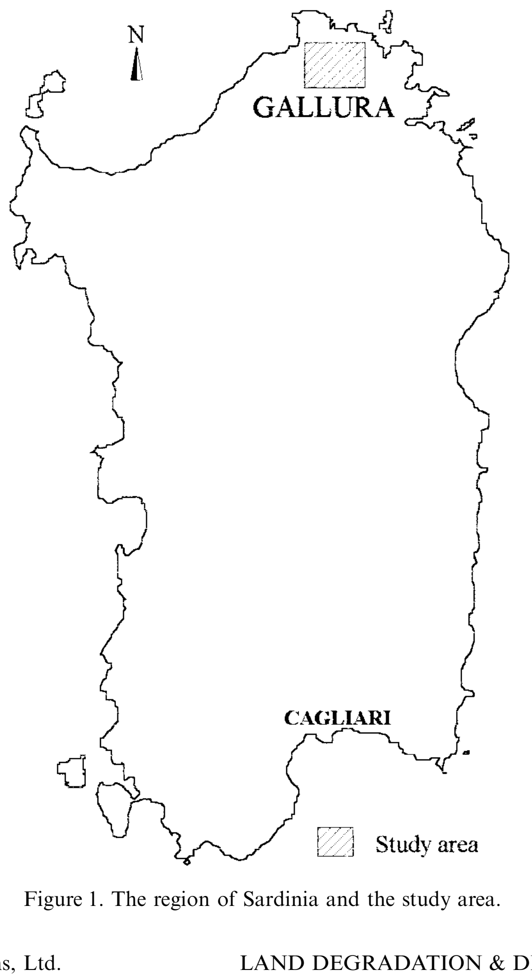

Figure 1. The region of Sardinia and the study area.

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After a detailed survey two adjacent sites with different land use were chosen for investigation. The main characteristics of the studied sites are given in Table I.

Within each of the above described sites a representative plot was selected. Plots measured 20 × 8 m at Cuncata and 100 × 20 m at Carrulu. Plot dimension was larger at Carrulu because of the lower tree density in this site. In each plot one profile was investigated so as to characterize the mineral soil. Mineral soil profiles were described according to the standard FAO guidelines (FAO-ISRIC, 1990). Designation of mineral horizons followed the procedure described in the Soil Survey Manual (Soil Survey Division Staff, 1993). Soil colours are those of Munsell Soil Color Charts (Munsell Color Company, 1975). Lateral variability of the forest floor was observed in each plot along a vegetational transect placed in the middle of the plot in the direction of the maximum slope gradient. Five humus profiles for each plot, chosen to provide examples under the different vegetation and at different distances from the cork–oak canopy, were described according to the method used by Green *et al.* (1993). An iron frame (30 × 30 cm) was driven through the ectorganic (L, F and H) horizons into the mineral soil. Each ectorganic horizon was scraped off with a knife and sampled. On the remaining bare surface, the uppermost 25 cm of the mineral soil were also described and sampled.

Samples of ectorganic horizons were airdried, weighed and analysed for organic carbon and total nitrogen, determined by CHN elementary analyser (Perkin Elmer, USA). Roots, stones and mineral contaminants were removed by hand. Samples of mineral horizons were analysed, after air drying and sieving to <2 mm, for particle size distribution, pH, organic carbon (C), total nitrogen (N), available phosphorus (P), cation exchange capacity (CEC), exchangeable calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), exchangeable acidity (EA) and pF according to USDA (1996).

Table I. Main characteristics of the studied sites

Cuncata Mainly cork production site (stocking rate of 0·2 adult cattle/ha), not cultivated (400 trees ha^{-1})	Carrulu Heavily grazed cork–oak forest (stocking rate of about 0·8 adult cattle/ha), with cultivation, burning and clearing (40 trees ha^{-1})
Structure: complex height zones and layers Tree cover: 80%, uneven-aged Tree renewal: 12 seedlings/m^2 Shrubs: 50–60% with *Cytisus triflorus* 25–30% *Arbutus unedo* 17–22% *Juniperus communis* 4% *Erica arborea* 2% *Lavandula stoechas* 2%	Structure: few height zones and layers Tree cover: 15%, even-aged, senescent Tree renewal: <1 seedling/m^2 Shrubs: 90% with *Cistus monspeliensis* 70% *Calycotome spinosa* 6% *Juniperus communis* 5% *Arbutus unedo* 4% *Phyllirea angustifolia* 1% *Phyllirea latifolia* 1% *Erica arborea* 1% *Lavandula stoechas* <1% *Cystus salvifolius* <1% *Myrtus communis* <1%
Selected plot: 20 × 8 m Ectorganic layer: 5·2–9·5 cm A horizon: 50 cm, with felty A1 No sheet erosion	Selected plot: 100 × 20 m Ectorganic layer: <3 cm, rarely 5·3 cm under trees A horizon: 25 cm, without A1 Sheet erosion
Mineral soil: loamy, mixed, mesic Lithic Xerumbrepts loamy, mixed, mesic Dystric Lithic Xerochrepts Humus form: Moder	Mineral soil: loamy, mixed, mesic Dystric Lithic Xerochrepts loamy, mixed, mesic Lithic Ultic Haploxerolls loamy, mixed, mesic Lithic Xerumbrepts Humus form: Mull

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Humus form was classified according to Green *et al.* (1993). All the soils were classified according to the Keys to Soil Taxonomy (Soil Survey Staff, 1997).

RESULTS AND DISCUSSION

Soil profile descriptions for Cuncata and Carrulu are summarized in Tables II and III, where Ln is the organic horizon composed of newly accreted and essentially unfragmented plant residues, Lv is the organic horizon exhibiting initial decay and strong discoloration, Fz is the organic horizon comprised of partly decomposed plant residues with active populations of soil meso- and microfauna, and Hh is the organic horizon predominated by fine substances with very few if any recognizable plant residues (Green *et al.*, 1993). Analytical soil data are shown in Tables IV and V.

Comparison of morphological and chemical properties of the soils at Cuncata with those at Carrulu indicates clear differences for the two sites. At Cuncata, where the forest ecosystem is more luxuriant, a well-developed ectorganic layer is always present, with total thickness ranging from 5·2 to 9·5 cm (with the exception of profile Cun2 under cattle trampling) (Figure 2). At Carrulu the ectorganic layer is very poorly developed, and total thickness of more than 3 cm is only observed under the *Quercus suber* canopy (profile Car3), where it reaches 5·3 cm (Figure 3). The upper mineral horizons of the studied profiles also exhibit significant differences. At Cuncata the A horizon is generally 50 cm deep, while the maximum depth at Carrulu is 25 cm. Moreover, at Cuncata the A horizon may be composed of two subhorizons, with a felty A1. It is well known that the development of humus profiles is basically controlled by the input of litter and the decomposition of the organic matter (Swift *et al.*, 1979; Green *et al.*, 1993). Here the differences between Cuncata and Carrulu are the result of the different vegetation quality and density in the two sites, caused by dissimilar land use, which produces a greater input of litter at Cuncata where the litterfall production per

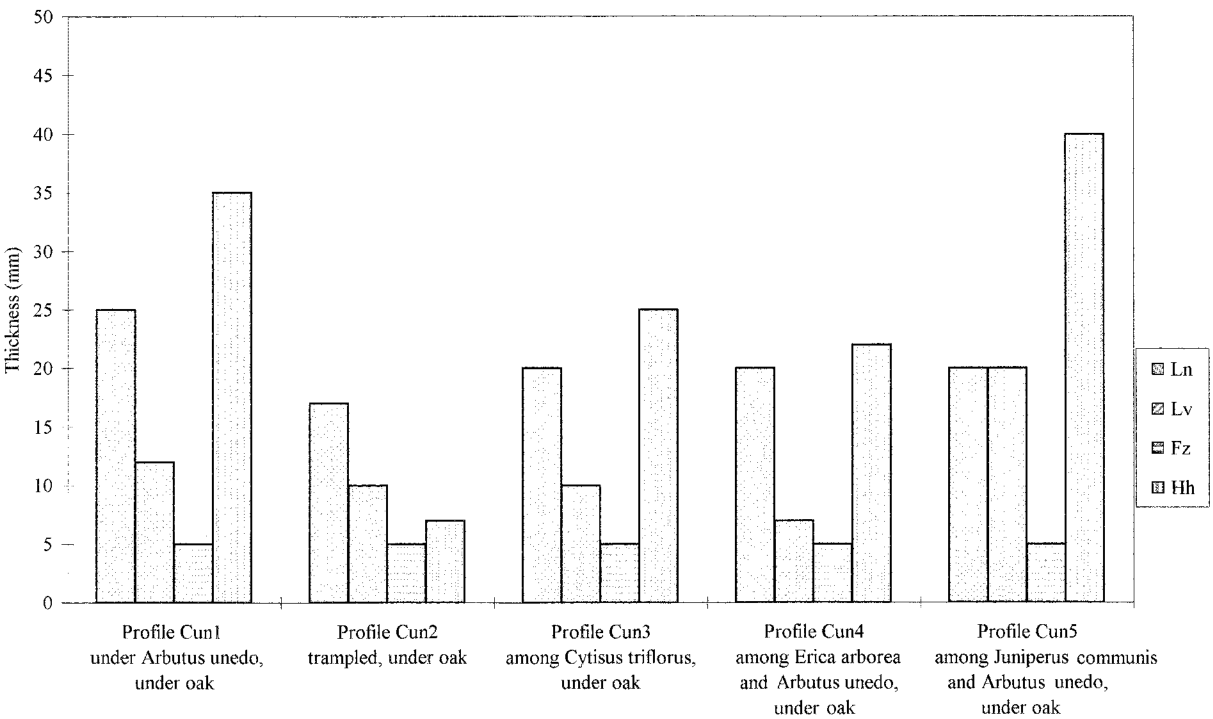

Figure 2. Thickness of organic horizons at Cuncata (dense cork-oak forest).

unit basal area is certainly higher than that of Carrulu. These results are in agreement with those of Read and Mitchell (1983), who reported that in the Mediterranean shrublands the organic matter accumulation in ectorganic horizons is generally insignificant because there is limited litter input, and that which does occur is frequently destroyed by fires. Moreover, during the survey at Carrulu it was observed that the soil tends to accumulate in the upslope part of the oak trunks whereas in the downslope part of the trunks the soil has been transported away, and that the soil surface is covered with numerous well-cleaned, shiny quartz grains. These signs are evidence of sheet erosion at Carrulu, affecting both organic horizons and surface mineral horizons. Ecologically these differences are important, because nutrient uptake in forest ecosystems is at the forest floor chiefly (Tamm and Petterson, 1969; Lefevre and Klemmedson, 1980; Krause *et al.*, 1980; Green *et al.*, 1993). Moreover, it protects the underlying soil and regulates the movement of air and water therein (Lefevre and Klemmedson, 1980; Green *et al.*, 1993).

C and N concentration in the forest floor horizons at Cuncata and Carrulu show significant differences only for the Lv horizon (Table VI). This is due to the fact that at Carrulu the Lv and F horizons were described and sampled together, because they were intimately associated in a layer never thicker than 1 cm. It must be pointed out that profiles Car2 and Car5 are not considered in the statistical analysis due to the same fact that Ln, Lv, and F horizons were described and sampled together because of their very limited thickness (cumulatively less than 1 cm), and consequently, due to the low number of samples, the statistical error is high. Considering the total thickness of the ectorganic layer, organic matter content is higher at Cuncata where, in the forest floor, it ranges from 1·76 to 3·72 kg m^{-2}, while at Carrulu it only ranges from 0·45 to 1·84 kg m^{-2}. The only significant differences found between Cuncata and Carrulu in the selected soil properties of the A horizon (Table VII) are those concerning the C, N, and Ca content (higher at Carrulu), which is also affecting CEC, together with C, and base saturation. These results may be related to the higher stocking rate at Carrulu, and the consequent higher supply of cattle excreta.

The mineral soils at Cuncata are classified as loamy, mixed, mesic Lithic Xerumbrepts, with the exception of profile Cun1 which is classified as loamy, mixed, mesic Dystric Lithic Xerochrept. At Carrulu the mineral

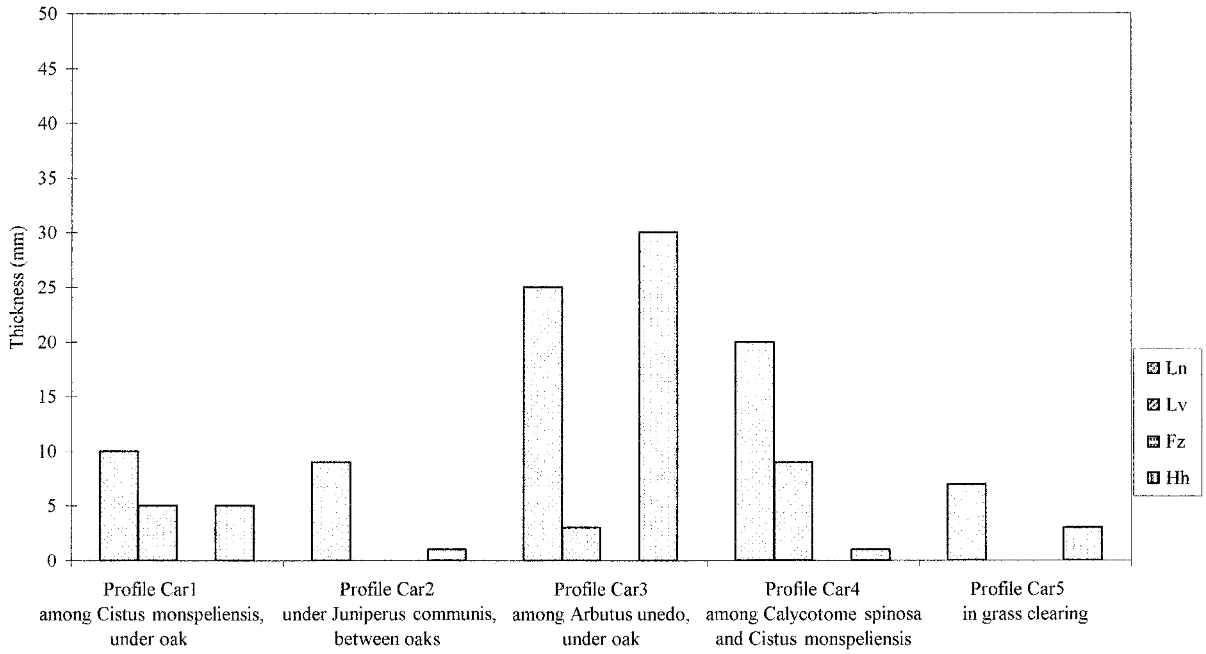

Figure 3. Thickness of organic horizons at Carrulu (open, degraded cork-oak stands).

Table II. Soil profiles in Cuncata (dense cork–oak forest)

General information on the site		Altitude: 470–475 m; slope: 7–16%; well drained; surface stoniness: 0–3%; no rock outcrop; no erosion.
Representative mineral soil profile		
Profile A		
A1	0–10 cm	Dry; 10 YR 2/2 moist; 10 YR 4·5/2 dry; sandy loam; moderate, fine, subangular blocky; non-sticky, slightly plastic, very friable, slightly hard; many fine, medium, and coarse inped and exped pores; abundant fine, medium, and coarse oblique, vertical, and horizontal roots; high biological activity; clear, wavy boundary.
A2	10–50 cm	Dry; 10 YR 3/2, 10 YR 3/3, and 10 YR 4/4 moist; 10 YR 4·5/2, 10 YR 5/3, and 10 YR 5/4 dry; sandy loam; moderate, fine and medium, subangular blocky; slightly sticky, slightly plastic, friable, hard; many fine, medium, and coarse inped and exped pores; abundant fine, medium, and coarse oblique and horizontal roots; high biological activity; abrupt, smooth boundary.
C	> 50 cm	Weathered unequigranular granite.
Representative humus profiles		
Profile Cun1. Under *Arbutus unedo* in the middle of *Quercus suber* and *Juniperus communis*		
Ln	9/6·5–6/4·5 cm	Leaves and plant residues of *Quercus suber* and *Arbutus unedo*, acorns; dry; single particle; loose; leafy and ligneous; no roots; common ants and spiders.
Lv	6/4·5–4·5/3·5 cm	Leaves and plant residues of *Arbutus unedo*, *Quercus suber*, and *Juniperus communis*, flowers of *Quercus suber*, acorns; dry; single particle; loose; leafy and ligneous; no roots; common ants and spiders.
Fz	4·5/3·5–4/3 cm	Dry; massive; friable; felty; no roots; common spiders and ants; few clustered droppings.
Hh	4/3–0 cm	Dry; massive; friable; felty; common very fine and fine roots, few medium roots; common spiders and ants; common clustered droppings; few clustered fungal mycelia.
A1	0–1·5 cm	Dry; 10 YR 3/2 moist; 10 YR 5/2 dry; sandy loam; felty; non sticky, non plastic, friable, slightly hard; many fine, medium, and coarse inped and exped pores; abundant fine and medium oblique and horizontal roots; high biological activity; abrupt, smooth boundary.
A2	1·5–18 cm	Dry; 10 YR 3/3 moist; 10 YR 4/3 dry; sandy loam; moderate, fine and medium, subangular blocky; slightly sticky, slightly plastic, very friable, soft; many fine, medium, and coarse inped and exped pores; common fine, medium, and coarse oblique and horizontal roots; high biological activity; abrupt, smooth boundary.
C	> 18 cm	Weathered unequigranular granite.
Profile Cun2. Cow trampling under *Quercus suber* canopy		
Ln	4·5/3·5–2·5/2 cm	Leaves and plant residues of *Quercus suber* and *Arbutus unedo*, acorns; dry; single particle; loose; leafy and ligneous; no roots; few ants and spiders.
Lv	2·5/2–1·5/1 cm	Leaves and plant residues of *Quercus suber* and *Arbutus unedo*, flowers of *Quercus suber*, acorns; dry; single particle; loose; leafy and ligneous; no roots; few ants and spiders.
Fz	1·5/1–1/0·5 cm	Dry; single particle; friable; gritty, leafy, and ligneous; few very fine roots; few spiders and ants; few clustered droppings; few clustered fungal mycelia.
Hh	1/0·5–0 cm	Dry; weak, medium, granular; friable; gritty; few very fine and fine roots; few spiders and ants; few clustered droppings; few clustered fungal mycelia.
A1	0–1·5 cm	Dry; 10 YR 2/2 moist; 10 YR 5/2 dry; sandy loam; felty; non-sticky, non plastic, friable, soft; many very fine, fine, medium, and coarse inped and exped pores; abundant fine and medium oblique and horizontal roots; high biological activity; abrupt, smooth boundary.
A2	1·5–25 cm	Dry; 10 YR 2/2 moist; 10 YR 4/3 dry; sandy loam; moderate, very fine and fine, subangular blocky; slightly sticky, slightly plastic, friable, slightly hard; many very fine, fine, and medium inped and exped pores; abundant fine, medium, and coarse oblique and horizontal roots; high biological activity.

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Profile Cun3. Among *Cytisus triflorus* under *Quercus suber* canopy		
Ln	6–4 cm	Leaves and plant residues of *Quercus suber* and *Arbutus unedo*, acorns, flowers of *Quercus suber*; dry; single particle; loose; leafy and ligneous; no roots; common ants.
Lv	4–3 cm	Leaves and plant residues of *Quercus suber* and *Arbutus unedo*, flowers of *Quercus suber*, acorns; dry; single particle; loose; leafy and ligneous; no roots; common ants.
Fz	3–2·5 cm	Dry; single particle; loose; gritty, leafy, and ligneous; very few very fine roots; common ants; few clustered droppings.
Hh	2·5–0 cm	Dry; massive tending to weak, fine, granular; friable; gritty and felty; common very fine and few fine roots; common ants; common random droppings; few clustered fungal mycelia.
A	0–25 cm	Dry; 10 YR 2/2 moist; 10 YR 4/2 dry; sandy loam; strong, fine and medium, subangular blocky; non sticky, non plastic, friable, slightly hard; many fine, medium, and coarse inped and exped pores; common fine and medium oblique and horizontal roots; high biological activity.
Profile Cun4. Among *Erica arborea* and *Arbutus unedo* under *Quercus suber* canopy.		
Ln	5·7/5·2–3·7/ 3·2 cm	Leaves and plant residues of *Quercus suber* and *Arbutus unedo*, flowers of *Quercus suber*; dry; single particle; loose; leafy and ligneous; no roots; common spiders and ants.
Lv	3·7/3·2–3/2·5 cm	Leaves and plant residues of *Quercus suber*, *Arbutus unedo*, and *Erica arborea*, flowers of *Quercus suber*, acorns; dry; single particle; loose; leafy and ligneous; no roots; common spiders and ants.
Fz	3/2·5–2·5/2 cm	Dry; massive tending to single particle; friable; felty; very few very fine roots; common spiders and ants; few clustered droppings.
Hh	2·5/2–0 cm	Dry; massive tending to weak, fine, granular; friable; felty; common very fine and few fine roots; common spiders and ants; common random droppings; few clustered fungal mycelia.
A	0–25 cm	Dry; 10 YR 2/2 moist; 10 YR 4/3 dry; sandy loam; strong, fine and medium subangular blocky; non sticky, non plastic, friable, slightly hard; many fine, medium, and coarse inped and exped pores; abundant fine and medium oblique and horizontal roots; high biological activity.
Profile Cun5. Among *Juniperus communis* and *Arbutus unedo* under *Quercus suber* canopy.		
Ln	9·5/7·5–7·5/ 5·5 cm	Leaves and plant residues of *Arbutus unedo* and *Quercus suber*, flowers of *Quercus suber*; dry; single particle; loose; leafy and ligneous; no roots; few spiders and ants.
Lv	7·5/5·5–5·5/ 3·5 cm	Leaves and plant residues of *Arbutus unedo* and *Quercus suber*, needles and plant residues of *Juniperus communis*, flowers of *Quercus suber*; dry; single particle; loose; leafy and ligneous; no roots; few spiders and ants.
Fz	5·5/3·5–5/3 cm	Dry; massive tending to single particle; friable; felty; very few very fine roots; common spiders and ants; few random droppings.
Hh	5/3–0 cm	Dry; massive tending to weak, fine, granular; friable; felty; common very fine and fine roots; common spiders and ants; common random droppings; common clustered fungal mycelia.
A	0–25 cm	Dry; 10 YR 3/3 moist; 10 YR 4/3 dry; sandy loam; strong, fine and medium, subangular blocky; non sticky, non plastic, friable, slightly hard; many fine, medium, and coarse inped and exped pores; common fine, medium, and coarse oblique and horizontal roots; high biological activity.

Organic horizons nomenclature according to Green *et al.* (1993); mineral horizons nomenclature according to Soil Survey Division Staff (1993).

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Table III. Soil profiles in Carrulu (open, degraded cork–oak stands)

General information on the site		Altitude: 470–480 m; slope: 5–14%; well drained; surface stoniness: 2–10%; no rock outcrop; strong sheet erosion.
Representative mineral soil profile		
Profile B		
A	0–20 cm	Dry; 10 YR 2/2 moist; 10 YR 4·5/2 dry; sandy loam; weak, fine, subangular blocky; slightly sticky, slightly plastic, friable, slightly hard; common fine and medium inped and exped pores; common fine and medium oblique and horizontal roots; high biological activity; abrupt, smooth boundary.
C	> 20 cm	Weathered unequigranular granite.
Representative humus profiles		
Profile Car1. Among *Cistus monspeliensis* under *Quercus suber* canopy.		
Ln	2–1 cm	Leaves of *Quercus suber*, plant residues of *Quercus suber* and *Cistus monspeliensis*, cork fragments; dry; single particle; loose; leafy and ligneous; no roots; few ants and spiders.
Lv&F	1–0·5 cm	Leaves and plant residues of *Cistus monspeliensis* and *Quercus suber*; dry; single particle; loose; leafy; no roots; few ants and spiders.
Hh	0·5–0 cm	Dry; weak, fine, granular; friable; gritty; few very fine roots; common ants and spiders; few clustered fungal mycelia.
A	0–3/4 cm	Dry; 10 YR 2/2 moist; 10 YR 4/3 dry; sandy loam; moderate, fine, subangular blocky; non sticky, non plastic, friable, slightly hard; many very fine, fine, and medium inped and exped pores; abundant fine vertical and horizontal roots; high biological activity; abrupt, wavy boundary.
Bw	3/4–25 cm	Dry; 10 YR 3/3 moist; 10 YR 5/3 dry; sandy loam; strong, medium and coarse, subangular blocky; non sticky, non plastic, friable, slightly hard; common very fine, fine, and medium inped and exped pores; abundant fine, medium, and coarse oblique roots; low biological activity.
Profile Car2. Beneath *Juniperus communis* between two *Quercus suber* trees		
Ln&Lv&F	1–0·1 cm	Leaves of *Quercus suber*, *Juniperus communis*, and *Cistus monspeliensis*, plant residues of *Cistus monspeliensis*; dry; single particle; loose; leafy and ligneous; no roots; no biota.
Hh	0·1–0 cm	Dry; single particle; loose; gritty; very few very fine roots; no biota.
A	0–25 cm	Dry; 10 YR 2/2 moist; 10 YR 4/3 dry; sandy loam; strong, fine and medium, subangular blocky; non sticky, non plastic, very friable, slightly soft; common very fine, fine, and medium inped and exped pores; common fine, medium, and coarse oblique and horizontal roots; high biological activity.

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Profile Car3. Among *Arbutus unedo* under *Quercus suber* canopy		
Ln	5·3/4·3–2·3 cm	Leaves and plant residues of *Quercus suber* and *Arbutus unedo*, cork fragments; dry; single particle; loose; leafy and ligneous; no roots; common ants and spiders.
Lv&F	2·3–2 cm	Leaves and plant residues of *Quercus suber* and *Arbutus unedo*, cork fragments; dry; single particle; loose; leafy and ligneous; no roots; common ants and spiders.
Hh	2–0 cm	Dry; weak, fine, granular; friable; gritty; few very fine roots; common ants and spiders; few clustered droppings.
A	0–20 cm	Dry; 10 YR 3/3 moist; 10 YR 4/3 dry; sandy loam; moderate, fine and medium, subangular blocky; non sticky, non plastic, very friable, soft; many very fine, fine, and medium inped and exped pores; common fine and medium oblique and vertical roots; high biological activity; abrupt, irregular boundary.
C	> 20 cm	Weathered unequigranular granite.
Profile Car4. Among *Calycotome spinosa* and *Cistus monspeliensis*		
Ln	3–1 cm	Leaves and plant residues of *Quercus suber*, *Cistus monspeliensis*, and *Calycotome spinosa*; dry; single particle; loose; leafy, ligneous, and mossy; no roots; no biota.
Lv&F	1–0·1 cm	Leaves and plant residues of *Quercus suber*, *Cistus monspeliensis*, and *Calycotome spinosa*; dry; single particle; loose; leafy and ligneous; no roots; no biota.
Hh	0·1–0 cm	Dry; single particle; loose; gritty; very few very fine roots; few ants.
A	0–25 cm	Dry; 10 YR 2/2 moist; 10 YR 4/2 dry; sandy loam; strong, fine and medium, subangular blocky; non sticky, non plastic, very friable, slightly hard; common fine, medium, and coarse inped and exped pores; abundant fine, medium, and coarse oblique roots; high biological activity.
Profile Car5. Grass clearing		
Ln&Lv&F	1–0·3 cm	Leaves and plant residues of *Quercus suber* and *Cistus monspeliensis*, death grasses; dry; single particle; loose; leafy and ligneous; no roots; few ants.
Hh	0·3–0 cm	Dry; single particle; loose; gritty; very few very fine and fine roots; few ants.
A	0–25 cm	Dry; 10 YR 2/2 moist; 10 YR 4/3 dry; sandy loam; strong, fine and medium, subangular blocky; non sticky, slightly plastic, very friable, slightly hard; common fine and medium inped and exped pores; abundant fine and medium oblique and horizontal roots; high biological activity.

Organic horizons nomenclature according to Green *et al*. (1993); mineral horizons nomenclature according to Soil Survey Division Staff (1993).

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Table IV. Analytical soil data for Cuncata (dense cork–oak forest)

Horizon	Sand	Silt	Clay	pH	C	O.M.	N	C/N	P_2O_5	CEC	Ca	Mg	K	Na	EA	Base sat.	pF 4·2	pF 2·5
	(g kg^{-1})				(g kg^{-1})				(mg kg^{-1})	(cmol(+)kg^{-1})						(%)		
Profile A																		
A1	696	191	113	6·0	56	96	3	19	4	18·0	3·28	1·76	0·43	0·26	7·86	31·9	4·0	12·5
A2	662	236	102	4·9	18	31	1	18	2	18·2	0·37	0·86	0·24	0·25	13·55	9·4	3·0	13·4
Profile Cun1																		
Ln					439	756	7	63										
Lv					415	713	10	41										
Fz					322	554	12	26										
Hh					221	380	12	18										
A1	696	182	122	5·1	62	107	2	31	11	26·7	8·09	4·52	0·93	0·40	11·56	52·2	11·5	19·8
A2	717	191	92	5·3	26	45	1	26	7	18·3	3·07	1·90	0·37	0·20	8·58	30·2	6·0	14·8
Profile Cun2																		
Ln					454	780	8	57										
Lv					435	748	12	36										
Fz					339	583	17	20										
Hh					251	432	16	16										
A1	727	160	113	4·8	109	187	6	18	25	42·5	10·23	4·86	1·18	0·78	24·44	40·1	31·0	33·9
A2	754	157	89	5·9	116	200	7	17	6	18·6	4·58	1·56	0·53	0·21	9·00	37·1	7·7	14·6
Profile Cun3																		
Ln					464	798	9	52										
Lv					448	770	12	37										
Fz					396	681	17	23										
Hh					238	409	14	17										
A	661	228	111	6·4	25	44	1	25	6	20·5	6·98	20·18	0·66	0·23	6·93	48·1	8·6	16·9
Profile Cun4																		
Ln					474	816	7	68										
Lv					452	777	12	13										
Fz					401	689	16	25										
Hh					245	421	10	24										
A	723	180	97	4·9	25	43	1	25	6	18·3	1·88	1·26	0·19	0·34	13·54	20·0	7·0	15·8
Profile Cun5																		
Ln					464	798	6	77										
Lv					419	721	10	42										
Fz					305	524	13	23										
Hh					230	395	12	19										
A	695	196	109	5·2	18	31	1	18	7	17·6	1·53	0·90	0·32	0·15	10·96	16·5	6·2	14·6

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Table V. Analytical soil data for Carrulu (open, degraded cork–oak stands)

Horizon	Sand	Silt	Clay	pH	C	O.M.	N	C/N	P_2O_5	CEC	Ca	Mg	K	Na	EA	Base sat.	pF 4·2	pF 2·5
	($g\,kg^{-1}$)				($g\,kg^{-1}$)				($mg\,kg^{-1}$)	($cmol(+)kg^{-1}$)						(%)		
Profile B																		
A	671	221	108	5·6	29	50	2	14	4	19·1	4·24	1·17	0·29	0·14	11·60	30·5	8·6	15·7
Profile Car1																		
Ln					455	782	6	76										
Lv&F					320	552	7	46										
Hh					301	517	14	21										
A	764	157	79	5·1	58	100	3	19	15	27·6	5·92	4·18	0·64	0·72	11·60	41·4	14·4	18·5
Bw	664	197	139	5·4	20	34	1	20	7	17·0	1·17	1·74	0·37	0·34	10·76	21·2	7·0	14·0
Profile Car2																		
Ln&Lv&F					313	532	8	39										
Hh					n.d.	n.d.	n.d.	n.d.										
A	756	176	68	5·8	40	69	2	20	7	21·5	7·92	2·06	0·49	0·28	8·75	50·0	5·4	18·3
Profile Car3																		
Ln					463	797	7	66										
Lv&F					322	554	10	32										
Hh					164	279	7	23										
A	713	193	94	5·9	32	55	2	16	7	19·9	5·74	3·48	0·51	0·59	8·48	51·8	7·3	15·0
Profile Car4																		
Ln					326	560	9	36										
Lv&F					266	458	9	30										
Hh					130	224	6	22										
A	708	180	116	5·7	34	58	2	17	5	20·5	6·07	1·46	0·46	0·20	9·26	40·0	8·9	17·3
Profile Car5																		
Ln&Lv&F					385	662	7	59										
Hh					n.d.	n.d.	n.d.	n.d.										
A	687	180	133	5·7	42	72	2	21	6	23·3	8·72	2·12	0·61	0·28	10·08	50·3	3·3	17·2

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Table VI. Comparison of C and N concentrations (mean ± s.e.) in the forest floor horizons at Cuncata and Carrulu sites, with pooled estimate of variance

Nutrients	Forest floor horizons	Cuncata	Carrulu	p†
C (g kg^{-1})	Ln	459 ± 5·91	414·6 ± 44·39	n.s.
	Lv	433·8 ± 7·4	302·6 ± 18·3	***
	Hh	237 ± 5·3	198·3 ± 52·2	n.s.
N (g kg^{-1})	Ln	7·4 ± 0·5	7·3 ± 0·88	n.s.
	Lv	11·2 ± 0·48	8·6 ± 0·88	*
	Hh	12·8 ± 1·01	9 ± 2·51	n.s.

***$p < 0{\cdot}001$; **$p < 0{\cdot}01$; *$p < 0{\cdot}05$; n.s. = not significant. †t test of hypothesis $H_0: \mu_{Cuncata} = \mu_{Carrulu}$ with pooled estimate of variance, $n = 5$ for Cuncata and $n = 3$ for Carrulu.

Table VII. Comparison of soil properties (mean ± s.e.) in the A horizon at Cuncata and Carrulu sites, with pooled estimate of variance

Property	Cuncata		Carrulu		p†
	n	Mean ± s.e.	n	Mean ± s.e.	
pH	5	5·54 ± 0·26	5	5·64 ± 0·14	n.s.
C (g kg^{-1})	4	23·5 ± 1·84	5	41·2 ± 4·58	*
N (g kg^{-1})	4	1 ± 0	5	2·2 ± 0·2	**
P_2O_5 (mg kg^{-1})	5	6·4 ± 0·24	4	6·25 ± 0·47	n.s.
Ca (cmol kg^{-1})	5	3·6 ± 0·99	5	6·87 ± 0·6	*
Mg (cmol kg^{-1})	4	1·4 ± 0·21	5	2·66 ± 0·5	n.s.
K (cmol kg^{-1})	5	0·41 ± 0·08	5	0·54 ± 0·03	n.s.
Na (cmol kg^{-1})	5	0·22 ± 0·03	5	0·41 ± 0·1	n.s.
EA (cmol kg^{-1})	5	9·8 ± 1·13	5	9·6 ± 0·56	n.s.
CEC (cmol kg^{-1})	5	18·6 ± 0·48	5	22·56 ± 1·38	*
Base sat. (%)	5	30·4 ± 5·7	5	46·7 ± 2·5	*
AWC (%)	5	8·2 ± 0·35	5	10·9 ± 1·22	n.s.

***$p < 0{\cdot}001$; **$p < 0{\cdot}01$; *$p < 0{\cdot}05$; n.s. = not significant. †t test of hypothesis $H_0: \mu_{Cuncata} = \mu_{Carrulu}$ with pooled estimate of variance.

soils are classified as loamy, mixed, mesic Dystric Lithic Xerochrepts (profiles B and Car1), loamy, mixed, mesic Lithic Ultic Haploxerolls (profiles Car2, Car3, and Car5), and loamy, mixed, mesic Lithic Xerumbrept (profile Car4).

Although variation in the thickness and development of the organic horizons occurs, the morphology of the humus form profile is rather invariable within each of the two sites. Two main types of humus form (Green *et al*., 1993) could be distinguished, being basically Moder at Cuncata and Mull at Carrulu. Mulls represent the most biologically active humus forms, with high decomposition rates that result in organic matter being intimately incorporated into the upper mineral soil layer instead of accumulating on its surface. Moders represent an intergrade between Mors (the least biologically active humus forms) and Mulls (the most biologically active humus forms), and are characterized by the presence of the diagnostic Fz (z: zoogenous) or Fa (a: amphimorphic) horizon (Green *et al*., 1993). In this way, Green's classification stresses the importance of biological activity in the F horizon. However, the field experience indicates that it is very difficult to discriminate humus forms with dominant fungal activity (Fa) from those within which fungal activity is balanced by faunal activity (Fz), particularly when F is very thin. Calabrese *et al*. (1996) reported the same difficulty for F horizons only 1–2 cm thick, and Fons and Klinka (1998) recognized that the identification of Fa horizons according to the proposed morphological characteristics has been ambiguous. At Cuncata, the F horizon seems to be more of the Fz type, likewise in similar forest types in Sardinia

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(Aru *et al.*, 1998a and b), while at Carrulu it was impossible to distinguish the type of F horizon because of its very small thickness. Moreover, at Carrulu the application of Green's classification seems to be forced, because the thin accumulation of organic layers on the mineral soil surface is due to low input of litter rather than high decomposition rates. In this case, the humus form at Carrulu is more likely a degraded type of humus form at Cuncata, but the Green's classification does not highlight this and seems not applicable when the tree density is below a critical value.

CONCLUSIONS

The results obtained indicate that land use of cork–oak forest has a major impact on forest floor and soil characteristics. Exploitation for cork production with restricted grazing (stocking rate about 0·2 adult cattle per hectare) has resulted in well-developed ectorganic layers and moderately deep soils. Organic carbon content in the forest floor and nutrients content in the mineral soil are high. These are very favourable conditions for the forest ecosystem. On the other hand, grazing, combined with extensive cultivation in the past and recurrent burning to clear the land, has led to very poorly developed ectorganic layers and shallow soils. Organic carbon in the forest floor is lower than in the closed forest, while nutrient content of P, N and Ca in the mineral soil is equal or even higher than in the closed forest. The very poorly developed ectorganic layers, the shallow soils, the low organic carbon content in the forest floor, and the presence of sheet erosion exert a negative impact on the open forest ecosystem. Grazing in cork–oak forests may thus be considered to trigger off severe soil degradation.

As cork is an important contributor to the Sardinian economy and the exploitation of *Quercus suber* forests for cork production is compatible with environmental conservation, this type of land use should be given priority over alternative uses.

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