Soil Quality and Plant Succession in Forest Andosols

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Abstract : Soil quality is closely related to processes of ecological succession. The degradation of an ecosystem causes a decrease in soil quality and a simultaneous regression in plant succession. The aim of this work is to study regeneration processes of the vegetation on forest andosols in an area within the Garajonay National Park (island of La Gomera, Canary Islands) and determine the variations in the soil quality associated with plant succession. The results obtained show that the plant formations with a lesser degree of regeneration are associated with processes of leptosolization, erosion, compactation and mineralization of organic matter, while the communities closer to the climax present important improvements in soil quality, tending towards andosolization.
Keywords: andosols, soil quality, plant succession, Canary Islands, laurel forest

1 Introduction

The term succession is applied to the sequential change in the abundance of the different species in an ecosystem over time. In forests, the succession finally leads to a stable arboreous vegetation, in equilibrium with the environmental conditions. The soils that develop underneath the mature or climax vegetation are of a high quality, since they are also active, stable systems in equilibrium (R.F. Fisher & D. Binkley, 2000; J.W. Doran *et al*., 1996). Plant succession is a progressive-regressive dynamic process associated with variations in soil properties. Thus, the evolution of a degraded ecosystem returning towards the climax necessarily goes through a process of recovery of soil quality (A. Rodríguez Rodríguez *et al*., 2000, 2001b).

Forest Andosols in the Canary Islands are of great value because of their high environmental quality and because they provide vital support for the Canarian laurel forest. The Canarian laurel forest is a highly unique forest and the habitat of rare and endangered species. The most diverse and extensive manifestation of this forest is to be found in the Garajonay National Park (La Gomera, Canary Islands), included since 1986 by UNESCO in the list of World Heritage Natural Sites.

The objective of the present work is to study the variations in soil quality associated with the regeneration of the vegetation in an area of the laurel forest deeply degraded by anthropic interventions over several centuries.

2 Study area

The study zone has an area of 525 hectares (13% of the surface are of the Garajonay National Park) and is situated in the southeast of the Park, at altitudes between 1100 and 1435 m. This area is located on the southern flanks of the island, on the leeward side, protected from the predominating winds but under the influence of overflowing fog (M.E. Arozena Concepción, 1990). The soil climate of the zone is udic with a tendency to ustic. The predominating soils are haplic Andosols, humic Umbrisols and andic Cambisols, with nuclei of leptic Andosols and Leptosols (C.C. Jiménez Mendoza *et al*., 1990, A. Rodríguez Rodríguez *et al*., 2001a).

The area has been submitted for centuries to a strong anthropic pressure. Intense livestock-breeding and timber exploitation caused the substitution of the original forest by heather scrub and leguminosae. Starting in the 1960s, conifer reafforestation was begun for the timber industry. Forest-fires are also frequent in the area. In recent years, the Park authorities have implemented a plan for the selective removal of the conifer plantations and the progressive restoration of the original forest (M.J. del Arco *et al*., 1990; A.B. Fernández López, 1990).

3 Material and methods

Sampling was carried out in a total of 73 plots, integrated in a network of plots under the Program for the Ecological Monitoring of the Garajonay National Park, distributed at regular intervals of 250m throughout the study area. A complete description of the soil and terrain was made in each case and a soil sample was taken to a depth of the first 30cm—35cm, the most sensitive to variations in soil quality.

Diverse physico-chemical properties were analysed in the laboratory, related to the capacity of the soil to sustain plant production, the functioning of its water system and its andic nature: water content at different depths, bulk density, granulometric composition, water retention, aggregate stability, pH in water, KCl and NaF, electrical conductivity, exchangeable cations, assimilable phosphorus, micronutrients, phosphorus retention, Fe, Al and Si extractable with oxalic acid-ammonium oxalate and with sodium pyrophosphate, total organic carbon and extractable with sodium pyrophosphate, humic and fulvic acids, melanic index and total nitrogen. Many of these properties are widely acknowledged as quality indicators in forest soils (S. H. Schoenholtz *et al*., 2000).

In order to delimit the main plant formations present in the area, an abundance matrix was developed by plots of the different native plant species. This matrix was analysed by multivariant statistical techniques: a divisive hierarchical classification using the TWINSPAN method (M. O. Hill, 1979) and an ordering by way of a Detrended Correspondence Analysis—DCA— (M. O. Hill, & H. G. Gauch, 1980). Once the main plant formations were established, the soil properties characteristic of each community were analysed by means of the ANOVA and Tukey tests on the parametric variables, and the Kruskal-Wallis and Mann-Whitney U test on the non-parametric variables. The relationship was also studied between the floristic composition and soil properties by means of a Canonic Correspondence Analysis–CCA— (C. J. Ter Braak, 1986).

4 Results

Analysis of the vegetation by means of TWINSPAN and DCA differentiates in the study area at least four natural plant communities (Figure 1):

- Humid Erica-Myrica heath: characterised by the presence of arboreous species (Erica arborea, Myrica faya, Laurus azorica) and by plants with a preference for humid and shaded sites (Viola riviniana).
- Xeric Erica-Myrica heath: in this case the characteristic arboreous species (E. arborea, M. faya, L. azorica) are accompanied by undergrowth characteristic of dry and sunny sites (Chamaecytisus proliferus)
- Humid brush: a community of small height, in which abound the characteristic species of humid environments such as *P. aquilinum*.
- Xeric brush: bush formation characterised by the presence of photophyllic species such as *Ch. proliferus*.

The CCA analysis indicates which are the most relevant properties of the soil and terrain in order to explain the vegetation of the plots (Figure 2).

The results of the comparison of the soil properties among the different plant communities are shown in Table 1. The *xeric* formations, on the basis of their floristic composition, present significant differences with respect to the *humid* formations in the humidity content at different depths, in several andic properties and in phosphorus availability. The arboreous formations have developed over deeper and less stony soils, and show significantly higher values, with respect to the scrub, of total and humified organic matter, metals bonded to organic amorphous compounds, water retention capacity, phosphorus retention and fine-grain fraction.

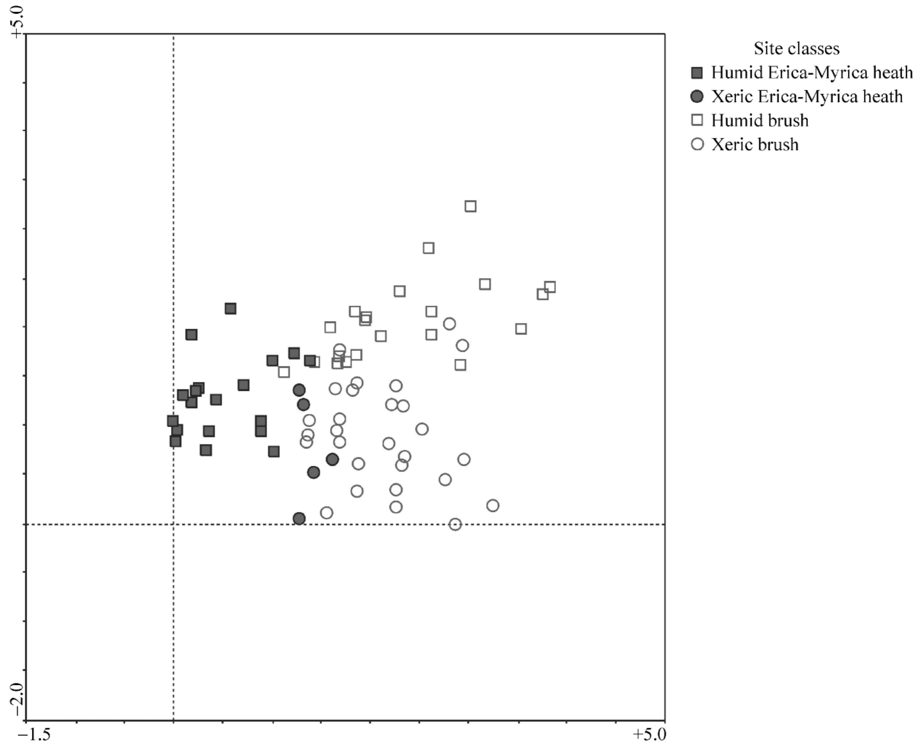

Fig.1 Analysis of the present vegetation by means of TWINSPAN and D.C.A.
D.C.A. values: *Total inertia*= 6.137, *Eigenvalues*=0.538, 0.313, *Cumulative variance* (%)=8.8, 13.9

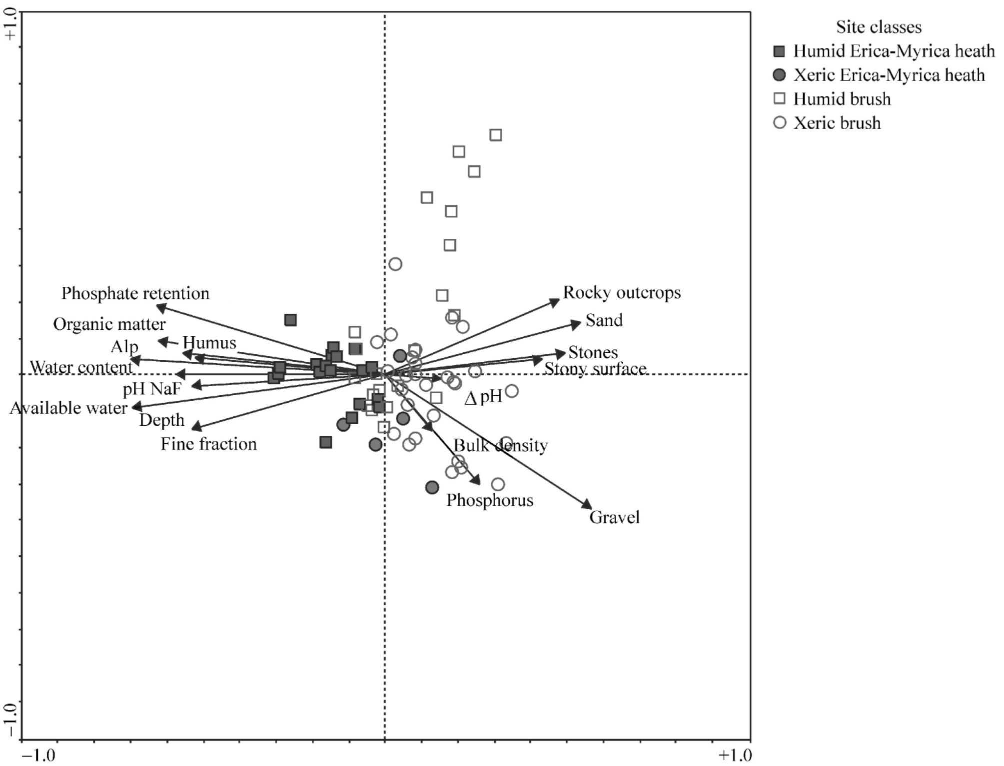

Fig.2 Analysis of soil and vegetation by means of C.C.A.*C.C.A. values: Total inertia*=6.137, *Eigenvalues*=0.438, 0.301, *Cumulative variance* (%)=16.9, 28.4

Table 1 Soil properties that exhibit significant differences (p<0.05). Groups with the same character do not exhibit signicant differences

	Statistic	Humid *Erica-Myrica* heath			Xeric *Erica-Myrica* heath			Humid brush			Xeric brush		
		Mean	Median	Group	Mean	Median	Group	Mean	Median	Group	Mean	Median	Group
Water content -*surface* (%)	ANOVA, Tukey	18.9	15.6	A	12.2	11.2	a	12.1	11.7	b	9.8	9.4	b
Water content -*30cm depth* (%)	Kruskal-Wallis, U	25.2	22.4	A	18.4	14.9	bc	19.0	16.8	b	14.0	14.7	c
Bulk density (g/cm^3)	ANOVA, Tukey	0.47	0.5	A	0.42	0.4	a	0.60	0.7	ab	0.63	0.6	b
Silt (%)	Kruskal-Wallis, U	50.5	51.1	A	49.3	51.7	ab	43.0	42.0	bc	42.3	42.9	c
Fine fraction (%)	ANOVA, Tukey	67.5	67.0	A	61.8	63.7	ab	61.5	57.6	ab	56.9	56.1	b
Fine sand (%)	Kruskal-Wallis, U	13.1	13.5	A	15.6	14.3	ab	15.6	14.4	ab	16.6	15.8	b
Coarse sand (%)	ANOVA, Tukey	20.1	19.9	A	22.6	24.0	ab	22.9	21.6	ab	26.5	27.2	b
Sand (%)	ANOVA, Tukey	33.1	32.1	A	38.2	36.3	ab	38.5	37.7	ab	43.1	43.8	b
Water retention pF1/3 (%)	Kruskal-Wallis, U	53.9	53.1	A	50.4	50.4	ab	46.6	42.3	b	43.9	42.7	b
Water retention pF15 (%)	ANOVA, Tukey	34.6	34.4	A	31.5	31.8	ab	30.6	30.5	ab	29.0	28.9	b
Available water (%)	Kruskal-Wallis, U	19.3	19.4	A	18.8	18.4	ab	16.0	13.8	b	14.9	13.6	b
P-*Olsen* (mg/kg)	ANOVA, Tukey	11.6	10.4	Ab	21.4	20.4	a	10.8	9.9	b	16.8	14.9	a
Total organic matter (%)	ANOVA, Tukey	18.9	17.7	A	18.0	19.0	ab	12.7	12.2	b	13.6	13.2	ab
Humified organic matter (%)	ANOVA, Tukey	6.5	3.9	A	6.7	4.1	ab	4.6	2.9	b	5.0	2.9	ab
Humic acids (%)	ANOVA, Tukey	2.1	2.1	A	2.3	2.5	ab	1.4	1.4	b	1.6	1.6	ab
Oxidizable C-$Na_4P_2O_7$ (%)	Kruskal-Wallis, U	4.1	3.9	A	3.8	3.9	ab	2.9	2.6	bc	2.7	2.5	c
Al-$Na_4P_2O_7$ (mg/kg)	Kruskal-Wallis, U	1.05	1.1	A	0.77	0.8	ab	0.96	0.8	b	0.61	0.6	b
Fe-$Na_4P_2O_7$ (mg/kg)	Kruskal-Wallis, U	0.31	0.3	A	0.22	0.2	ab	0.28	0.2	a	0.17	0.1	b
Si- $Na_4P_2O_7$ (mg/kg)	Kruskal-Wallis, U	0.28	0.3	A	0.18	0.2	bc	0.32	0.2	ab	0.19	0.2	c
pH (NaF, *2'*)	Kruskal-Wallis, U	10.6	10.7	A	10.5	10.4	ab	10.2	10.6	ab	10.0	10.1	b
Phosphate retention (%)	Kruskal-Wallis, U	84	91	A	80	75	ab	76	85	b	72	68	b
Zn -*EDTA* (mg/kg)	Kruskal-Wallis, U	1.18	0.9	A	1.17	1.1	a	1.01	0.5	b	0.97	0.8	a
Co -*EDTA* (mg/kg)	Kruskal-Wallis, U	0.19	0.0	A	0.65	0.0	ab	1.86	0.9	b	1.31	1.5	b
B (mg/kg)	Kruskal-Wallis, U	1.20	1.0	A	1.00	1.1	ab	0.78	0.6	b	0.98	0.8	ab
Depth (cm)	Kruskal-Wallis, U	110	125	A	105	125	ab	70	75	bc	65	75	c
Stony surface (%)	Kruskal-Wallis, U	4	2	A	35	10	bc	8	10	ab	9	10	c
Rocky outcrops	Kruskal-Wallis, U	5	1	A	15	6	ab	14	6	b	9	6	b
Bare soil (%)	Kruskal-Wallis, U	2	0	A	0	0	a	8	1	b	18	1	ab
Gravel (%)	Kruskal-Wallis, U	23	25	A	34	25	ab	32	2	a	45	48	b
Stones (%)	Kruskal-Wallis, U	23	25	A	43	48	b	39	25	ab	36	25	b

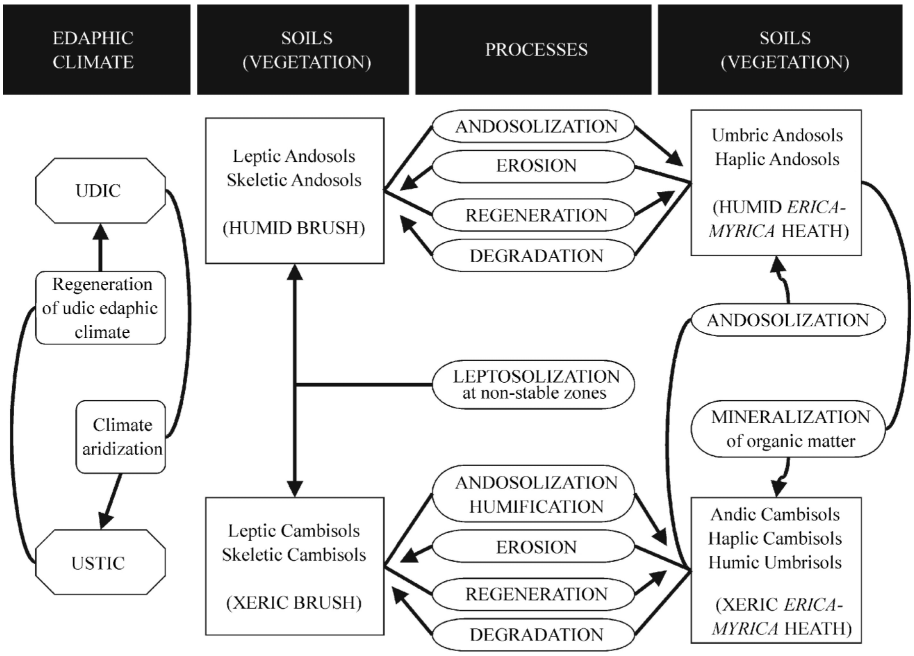

Fig.3 Genetic proceses in the soils of the area studied

Table 2 Mean values of some diagnostic soil properties

	Humid *Erica-Myrica* heath	Xeric *Erica-Myrica* heath	Humid brush	Xeric brush
Bulk density (g/cm^3)	0.47 ± 0.16	0.42 ± 0.13	0.60 ± 0.19	0.63 ± 0.15
Clay (%)	16.4 ± 5.6	12.5 ± 2.1	18.6 ± 9.9	14.5 ± 6.1
Al_{ox}+ 1/2 Fe_{ox} (%)	2.2 ± 0.7	1.8 ± 0.5	2.0 ± 1.5	1.8 ± 1.1
Phosphate retention (%)	84 ± 12	80 ± 12	76 ±16	72 ± 15
Organic carbon (%)	11.0 ± 4.8	10.4 ± 1.8	7.4 ± 4.9	7.9 ± 3.7
Melanic index	1.88 ± 0.10	1.85 ± 0.08	1.96 ± 0.16	1.89 ± 0.12
Coarse fragments (%)	Many (35–60%)	Very many (>60%)	Many (35%—60%)	Very many (>60%)
Depth (cm)	110	105	70	65
Structure	Blocky	Crumb	Blocky	Blocky
Hardness	Soft	Soft	Soft	Soft
Munsell color value	2.9	3.4	3.5	3.9
Munsell color chroma	2.5	2.4	3.3	3.5

5 Discussion

The analysis performed shows that the regeneration of the natural vegetation in this degraded area is determined in the first instance by the edafoclimate and the associated soils. The arboreous and scrub formations with a *humid*-type floristic composition appear in the most umbrous zones, with a udic edafoclimate and andic-type soils (Andosols). The floristically more *xeric* formations (woods or scrub) are associated with more thermal areas, with an edafoclimate tending to ustic and over Cambisols.

The greater or lesser degree of regeneration of the vegetation (arboreous or scrub heath) appears to be related to certain soil characteristics. Thus, the scrub develops at the present time on shallow stony soils that are sandy and compacted, while the tree formations develop on deeper soils with a greater content in coarse elements and a higher fine-fraction proportion.

The analytical data show that the regeneration of the vegetation is associated with an improvement in soil quality in conjunction with a process of andosolisation:

— Greater humification of the organic matter
— Greater porosity, better structure and a larger water retention capacity
— Progressive metal complexation and greater phosphorus retention

Contrarily, the scrub formations, with a lower degree of regeneration, are associated with low quality soils dominated by processes of leptosolisation (in zones of abrupt topography) or soils degraded by erosion, compactation and other structure degradation processes, enhanced by the characteristics of the vegetation (Figure 3).

These genetic processes give place presently to soils of different typology and with different values in the indicators of soil quality parameters (Table 2). The soils that present more favourable values are the umbric Andosols and haplic Andosols sustaining the humid *Erica-Myrica* heath, and the andic Cambisols, haplic Cambisols and humic Umbrisols with zeric *Erica-Myrica* heath. The scrub are associated leptic Andosols and leptic and skeletal Cambisols of very low natural quality or affected by degradation processes.

The umbric and haplic Andosols with humid *Erica-Myrica* heath constitute the most mature ecosystems of the area. It is therefore important to promote the implantation of an arboreous plant cover in the scrub zones to retard erosion, contribute to restore the udic edafoclimate and promote andosolisation, in order to achieve a faster evolution of the ecosystem, leaving the scrub on Cambisols and leptic-skeletic Andosols in those areas where leptosolisation is the dominant process and where it is therefore of less interest to force the regeneration of the ecosystem beyond its present state.

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