Changes in Soil Quality and Plant Succession in the Thermophile Forest of the Canary Islands

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Résumé
Le présent travail étude les variations dans la qualité du sol produites dans les moyennes zones des Îles Canariennes à cause de la disparition de sa végétation originale, une forêt ouverte d'affinités méditerranéennes. L'étude, menée à bien dans un secteur expérimental étendu dans l'île de Tenerife, révèle comment la destruction de la végétation et sa régénération spontanée postérieure sont associée à des processus intenses de dégradation du sol, qu'elles commencent seulement à remettre après avoir produit une détérioration dramatique dans la capacité de charge de l'écosystème, dans un processus clair de désertification qui ne montre pas un retour perceptible à court et moyen terme.

Introduction

Nowadays, the Canary Islands undergo severe desertification processes, that began with the European colonization, five hundred years ago. The most damaged natural ecosystem is the so-called *thermophile forest*. This mediterranean, open sclerophyllous forest grows potentially between 300-600 m.a.s.l. on the windward (northern) slopes of the islands and 500-800 m.a.s.l. on the leeward (southern) sides. Termophile forest areas were chosen for early traditional agriculture and human settlements due to their mild climate, wood resources and deep, fertile, highly productive soils (mainly Luvisols, Cambisols and Vertisols). The aim of this paper is to study the variations in soil quality derived from human-induced degradation and natural regeneration of the plant cover in an area located at Tenerife island.

Study area

The study zone extends over 100 km^2 at the SE side of the island. The relief is rough, with a steep slope (25-30% on average). Soil parent materials include basaltic and trachybasaltic lava flows and pumiceous tuffs. The climate is characterized by a mild temperature (14-17ºC with a difference of 6-7ºC between summer and winter mean values), low rainfall rates (200-350 $mm.yr^{-1}$ with a high seasonal and interannual variability) and a high potential evapotranspiration (750-875$mm.yr^{-1}$). Soil moisture regime is typically aridic, whereas soil temperature regime oscillates between thermic and mesic.
The most common soil types in the area are poorly-developed Haplocambids and Torriorthents. The low capability of the land for agricultural practices has been overcome by local farmers by using fragmented salic pyroclastic materials, locally known as *jables,* as a surface mulching layer. They provide a base-rich, easy-to-till, hygroscopic substrate with a high water-holding capacity. Since the 1930's the *jable* system was extended to other soils in the area, using pumice as a surficial mulching layer.
The study area includes some relicts of the termophile forest that constituted its former vegetation, now restricted to the steeper, non-accessible slopes. Tree species like Canary savin (*Juniperus turbinata* ssp. *canariensis*), wild olive tree (*Olea europaea* ssp. *cerassiformis*) and mastic trees (*Pistacia atlantica* and *P. lentiscus*) are typical. The anthropic pressure has removed the thermophile forest almost completely, replacing it with a complex

of extremely diverse substitution communities. Thus, perennial and annual pastures grow on the most recently disturbed sites, to furtherly evolve to shrubs made up of species like incense (*Artemisia thuscula*), sorrel (*Rumex lunaria*), rockrose (*Cistus monspeliensis*), bitter tabaiba (*Euphorbia obtusifolia*), wild daisy (*Argyranthemum frutescens*) and thyme (*Micromeria hyssopifolia*) (Marrero-Gómez et al., 1991).

Materials and methods

Sixty field sites were studied, including non-disturbed sites as well as ancient farmlands that were given up for agriculture in different times: <20 years, 20-40 years and >40 years. In each site, a plant inventory and a soil description were carried out, and a sample of surface, plant-rooting soil layer was also collected for analysis.

A Redundancy Analysis (RDA) of soil properties as related to certain natural factors: soil parent materials (basalt, trachyte, phonolite, pumice), elevation, and slope, was made to identify the main conditioning factors affecting the natural quality of soils in the area. The vegetation was analysed using Detrended Correspondence Analysis (DCA) and k-means cluster analysis. The indicator plant species for each group and the optimal number of clusters were determined by means of *IndVal* analysis (Legendre & Legendre, 1991).

The first ordination axis seemed to be directly related to degree of disturbance, as the ordering of the sites reflected the degree of ecological maturity. Pearson and Spearman correlations between soil properties and the first DCA axis scores were therefore used to identify soil properties most closely related to the ecosystem degradation.

Results

The RDA points to the occurrence of pumiceous tuffs as the only environmental factor affecting soil properties significantly. Over such parent material, the soils are yellowish and more brilliant in colour, coarser in texture, show a less-aggregated crumb structure, have higher available water holding capacity, lower stoniness and higher contents of exchangeable Na^+ and K^+ than other soils over basaltic or phonolitic parent materials.

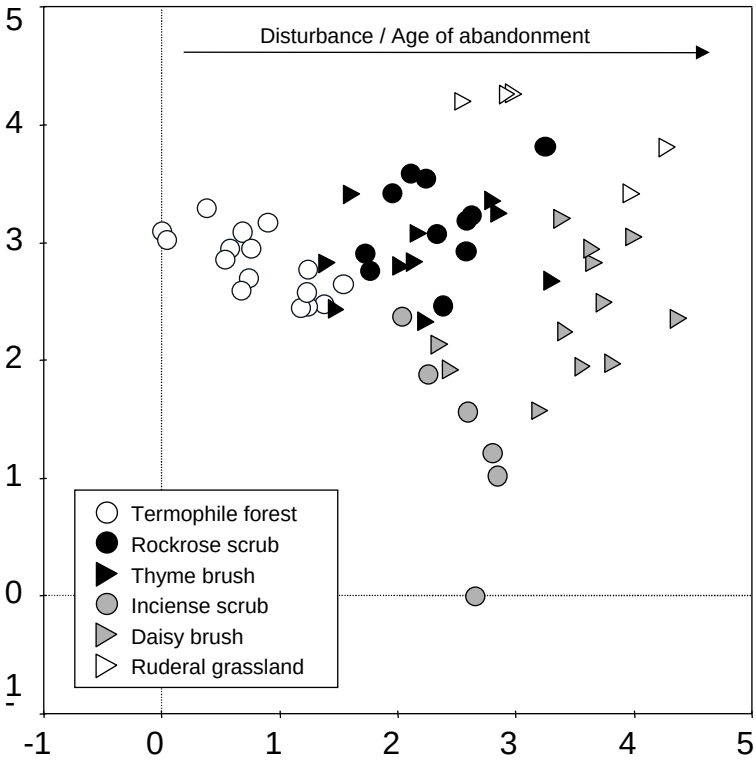

Figure 1

The results of cluster analysis and DCA are shown in Figure 1. DCA places termophile forest sites at the lowest values of the first axis, being replaced along it by shrubs (Rockrose scrub, Incense scrub, Thyme brush) and eventually by grasses (Daisy brush and Ruderal grassland). This sequence relates directly to the degree of anthropic disturbance: scarcely disturbed and anciently disturbed sites show lower scores for the first axis than those sites affected by a recent land use (ρ_s=0.658, p=0.000).

The first DCA axis reflects a transition between a wild, close-to-climax tree vegetation to substitution communities as the degree of anthropic disturbance increases. Site scores along this axis are a measure of ecosystem maturity and can be used as a disturbance index. Correlation with this index allows to identify those soil properties that undergo a variation along degradation or natural ecosystem regeneration, and thus are indicators of the natural quality of soils in the area. According to the obtained results (Table 1), the main processes related to transformation of the plant landscape in the area are:

Table 1.- Some soil properties significantly correlated to first DCA axis ($p \leq 0,05$)

	Correlation coeff.		p
ΔpH	r	0,299	0,020
Total oxidizable C	r	-0,450	0,000
pF 33 KPa	r	0,309	0,016
pF 1500 KPa	r	0,322	0,012
P-Olsen	r	0,383	0,003
Exchangeable Na^+	r	0,447	0,000
Exchangeable K^+	r	0,300	0,020
E.S.P.	r	0,494	0,000
Bioavailable Zn^{+2}	r	0,267	0,039
Surface gravel coverage	ρ_s	0,504	0,000
Surface stone coverage	ρ_s	-0,648	0,000
Rocky outcrops	ρ_s	-0,717	0,000
Sheet erosion	ρ_s	-0,264	0,042
Rill erosion	ρ_s	-0,399	0,002
Soil depth	ρ_s	0,459	0,000
Munsell colour hue	ρ_s	0,289	0,025
Munsell colour value	ρ_s	0,368	0,004
Munsell colour chroma	ρ_s	-0,271	0,036
Structure	ρ_s	-0,392	0,002
Gravel content	ρ_s	0,356	0,005
Stone content	ρ_s	-0,445	0,000
Plant root size	ρ_s	-0,563	0,000
Plant root vitality	ρ_s	0,432	0,001

- Accelerated erosion: water erosion is enhanced by the removal of the plant coverage for cropping, and especially after crop abandonment, when management practices for soil conservation (agroforestry, maintenance of terraces) are given up. Water erosion prompts a progressive thinning of soils, removing the surficial layers and causing the outcropping of stony subsurficial layers and rocks, as shown by and increase of the stone and rock surface coverages. The incidence of water erosion can also be detected by a progressive occurrence of rill and sheet erosion evidences. The evolution of erosive morphologies differs from that reported in other similar ecosystems of the mediterranean area, where sheet erosion evidences gradually decrease as the succession proceeds. In this sense, termophile forest ecosystem seems to have a lower recolonizating efficience with regard to other mediterranean ecosystems.
- Biological soil degradation: the anthropic transformation in the study area relates to a marked decrease in the organic matter content, due to soil erosion processes, a lower development of plant roots, a fertilizer-prompted mineralization of soil carbon, and an addition of fresh pumice materials (*jable*). The organic matter content gradually recovers and soil colour chroma decreases after the abandonment of cropping practices.
- Changes in water dynamics: the establishment and the further abandonment of farming are related to changes in soil porosity and structure, as seen by variations in soil water retention capacities. Moisture retention at 33KPa and 1500KPa initially increase in soils abandoned 20-40 years ago, to furtherly decrease, reaching minimum values as the ecosystem approaches to maturity. The transitory initial increase seems to derive from the tillage itself that, as widely known, improves soil structure and porosity, whereas the further decrease could be due to an increasing degradation of physical properties. This behaviour is opposed to that described in other mediterranean zones, where water holding capacity gradually

increases as natural vegetation is re-established, which again evidences the lesser resilence of soils under thermophile forest related to other mediterranean formations.
- Weathering of *jable* materials: *jable* layers are quickly weathered because of its high porosity and glass content, decreasing their favourable properties and forcing the addition of new fresh pumiceous materials at short time intervals, to keep crop productivity. Once farming is abandoned, the weathering of *jable* is enhanced by the dense root systems of natural vegetation, which release abundant acid exudates and CO_2 that accelerate the process. The variation of some soil properties along plant recolonization of abandoned fields can be related to this process: soil darkening, diminution of gravel content, etc. Also, the weathering of pumices release alkali cations that reach maximum concentrations in fields with an intermediate age of abandonment (20-40 years), to decrease later due to leaching.
- Increase of soil nutrient contents.- The disturbance of ecosystems in the study area coincides with a significant increase in contents of bioavailable phosphorus and zinc. These nutrients are added in great amounts to soils as fertilizers, especially in *jable* fields, and their levels turn back to its original natural values as time and succession progress.

Discussion and conclusions

Natural environmental factors in the area strongly affect natural soil quality. The low rainfall and the steepness of the slopes make local factors like soil parent material particularly important and influent on soil properties. In these environments, farming is only possible by artificial means, i.e., terracement, tephra mulching (subjected to periodical care and renewal) and irrigation with groundwater. Once farming is abandoned, all of this added energy is released and soils evolve backward to a more thermodynamically stable situation. Although the end of the process is a mature, evolved soil, in equilibrium with its forming factors, the consequence at short- and intermediate-terms of such evolution is a severe loss of biological potential, both in the soil and in the whole ecosystem.
According to the obtained results, human activities in the study area have given rise to an important soil degradation in termophile forests along the last five centuries. Soils have been exposed to erosive agents, responsible for reducing its thickness and water holding capacity by the removal of the plant cover and the further abandonment of agriculture. Erosion has affected water dynamics, inducing an intense aridification of soil climate, thus prompting the expansion of transgressor plant communities from the coastal ecosystem, such as succulent *Euphorbia* scrubs.
Thermophile forest seems to be less resilient to degradation processes than other Mediterranean ecosystems, that favour a fast establishment of a substitutive plant cover that softens the incidence of erosion processes. In this case, the degradation only decays once soil properties have been seriously damaged. This desertification process shows no perceptible reversion at the time scale of this study, and its severity might increase in the next decades, because of the accelerated change of soil use and land abandonment. An eventual plan to fight desertification in these areas must be based on the quick establishment and long-term maintenance of a plant coverage, crucial to mitigate effects of erosive action.

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