EVOLUTIVE AN REGRESSIVE SOIL SEQUENCES FOR ASSESSMENT OF SOIL DEGRADATION IN DESERTIFIED AREAS OF CANARY ISLANDS (SPAIN)

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ABSTRACT

The assessment of soil degradation in natural ecosystems must necessarily be performed from a non-conventional perspective, focused on agricultural productivity. Thus, the assessment of soil degradation in natural ecosystems requires the definition of standards with which to compare other soils and thus evaluate their quality. In order to define these standards and manage appropriately the processes involved in the degradation and variation of soil quality, it is necessary to understand and establish in detail the genetic processes that have taken place in that area and have led to the formation of a mature soil, which would be considered to be standard, as a non-degraded soil. In accordance with these ideas, we present in this work the evolutive and regressive succession of the soils and examples of the utilization of this methodology to evaluate soil degradation in arid zones and those in high desertification risk in the Canary Islands.

INTRODUCTION

Soil is a non-renewable natural resource that constitutes the functional basis of all the terrestrial ecosystems, so that the life all over the planet is linked, to a great extent, to an appropriate fulfillment of their productive and environmental functions (biomass production, either agricultural or not, fluid-regulator filter, regulation of the biogechemical cycling of elements, etc.) (Blum, 1998; Nortcliff, 2002).

The capacity of a soil to adequately accomplish all these functions is known as soil quality (Doran *et al*, 1994; Doran and Jones, 1996; Karlen *et al*., 1997; Karlen and Andrews, 2000; Singer and Ewing, 2000; Blum, 2002; Sposito and Zabel, 2003).

Therefore, soil degradation can be conceived as the set of processes that lead to a loss of soil quality, which means that soil no longer fulfills some of these functions properly

(Elmholt *et al*., 2000). It is worth pointing out in this sense that soil degradation invariably leads to a loss of soil quality (Lal, 1998), whereby degraded soils show poor quality, even though this can happen naturally, under certain environmental conditions and several genetic processes that have taken place during the soil formation. These soils cannot be considered as degraded ones, due to the lack of external influences (Nortcliff, 2002).

The relevance of soil as a natural resource is therefore obvious, and the degradation processes have been recognized during the last decades as an major environmental issue, since they constitute one of the processes of (and the main factor for) desertification.

However, it is necessary to establish the concept of soil degradation from a realistic point of view, and to distinguish clearly between these processes from those genetic ones that, as stated above, occur under certain environmental conditions and lead to low-quality soils.

The establishment of a methodology to evaluate soil degradation is also a complex issue, as they are the soil in itself and their functions (Diodato and Ceccarelli, 2004). Traditionally, soil degradation induced by anthropic activities has been evaluated from the acting processes at a given moment: water and wind erosion, excessive saline levels, chemical degradation, physical degradation, and biological degradation, or evaluating the negative changes in several soil parameters that are regarded as indicators of soil quality for a given soil function, that may lead to unclear results, provided the difficulty in distinguishing those changes produced by strict soil degradation from those other effects due to natural soil evolution.

Soil is an essential component of all the terrestrial ecosystems and, simultaneously, a self-organised system in both space and time (Phillips, 1999; García-Alvarez *et al*., 2003), so that from different scientific circles an ecosystem approach to soil degradation has been raised, to specifically consider soil as a natural ecosystem in an specifical pedobioclimatic context, and having a considerable dynamism and complexity (de Kimpe and Warkentin, 1998; Lal, 1998).

From our point of view, and in order to manage the processes involved in the soil degradation of a given environmentally homogeneous area in a proper way, it is necessary to understand and establish in detail the genetic processes that have taken place in that area and that have led to the formation of a mature soil, with certain properties and mechanisms of functioning, under a climax vegetation and under those environmental conditions, which would be considered to be standard. The result of all this, would be a non-degraded soil with the highest quality in that environment, that would constitute a metastable state with very low free energy.

This would therefore be an ecosystemic approach to soil degradation, which as a component of the ecosystem is subjected to an evolutive process. It is a method to evaluate soil quality in natural ecosystems, based on the fact that soil formation under certain environmental conditions constitutes a process of evolutive ecological succession with a decrease in free energy until a metastable state is reached, while soil degradation, due to the introduction of new forms of energy into the system (climatic changes, land-use changes, etc.) gives raise to a regressive ecological succession that gets away from the metastable state as the free energy of the system increases.

The mature soil as a final stage of the evolutive succession in a certain environmental setting (edaphoenvironmental unit) constitutes the standard, as already stated, and the knowledge of its properties and mechanisms of functioning, makes it possible, by comparison with those of the remaining soils in the area, to establish its state of evolution or degradation and thus its quality.

It would be therefore possible to readily distinguish degraded soils from immature ones in a given evolutive sequence, as well as from low quality soils formed by genetic processes under particular environmental conditions (e.g. leptosolisation).

MATERIALS AND METHODS

This approach has been used to evaluate the quality and state of degradation of the soils of the islands of Gran Canaria and Tenerife (Rodríguez Rodríguez *et al*., 2000), accord to the following methodological process:

a) Zonification of the land in environmentally homogeneous areas, with regard to the environmental factors responsible for the genesis of the soils: parent material (type and age), relief, vegetation, climate, uses and anthropic activities.

b) These homogeneous areas or land units are grouped in units of a greater range or morphodynamic environments, defined by their bioclimatic characteristics, that vary as a function of altitude and are characterized by differences in soil processes and the distribution of the vegetation and uses of the soil.

c) In each morphodynamic environment and based on the existence of lands units on different geological materials, the evolutive and regressive succession of the soils, the dominant edaphogenetic processes and the characteristics of the mature or standard soil in that environmental setting are established for each lithology.

d) Once the standard has been established for each land unit, the different occurring soil types are placed in the genetic sequence and their degree of maturity and ecological value are determined with regard to the standard established for that unit. This will allow us to know, by a quantitative comparison of its properties, the quality of a soil and whether this quality is due to a state of immaturity within the natural succession or to a regressive evolution caused by human-related impacts or changes in climatic conditions (degradation).

An example of this methodology in Gran Canaria island, in the morphodynamic environment named as *Northern Coastal Desertic* over basalts is presented below.

The ecological characteristics of this area placed between 0 and 300 m.a.s.l. are shown in Table 1.

Table 1. Ecological characteristics of the morphodynamic environment "Northern Coastal Desertic "

Bioclimate	Arid, desertic, inframediterranean
Soil moisture regime	Aridic
Soils	Calcisols, Cambisols, Leptosols, Gypsisols and Solonchaks
Soil degradation processes	Water and wind erosion, Salinization, Sodification
Climacic plant communities	-Frankenio capitatae-Zygophylletum fontanesii -Astidamio-Euphorbietum aphyllae -Euphorbietum balsamiferae-Astydamietum latifoliae
Parent material	Miocene basalts (12-14 My) Pliocene basalts (2-8 My) Pleistocene basalts (0.5-0.7 My)

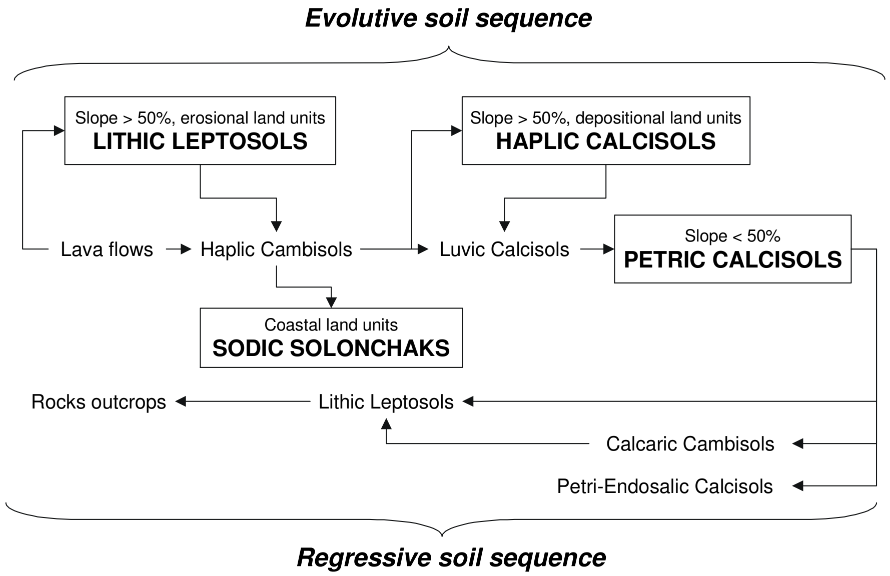
We have selected sixteen soil profiles developed from basaltic lavas, with ages comprised between Miocene to Pleistocene, and placed on topographical setting with varied slope degree, so that the entire soil diversity at this morphodynamic environment is covered.

The standard morphoanalytical properties used as indicators of non-degraded soils for each of the mature soils considered are determined by means of a cluster analysis, so as to obtain a representative profile (European Soil Bureau, 1999), that basically consists of constructing a centroid profile from the sampled and analysed profiles of each type and assigning to each horizon of this *virtual* profile the average values of those properties determined for the true profiles.

This *virtual* profile represents the soil body considered to have the highest environmental quality in the study area. Thus, the remaining profiles representative of the different soil bodies found in the morphodynamic environment can be compared with it, and with its relative position in the genetic sequence, so that it can be established with a high certainty whether its lower quality is due to degradation processes or to an evolutive immaturity.

RESULTS AND DISCUSSION

On these basaltic consolidated materials, and in accordance with the observations carried out in the different land units, the evolutive sequence can be established as follows:



On this parent material, in this morphodynamic environment, the dominant genetic processes of soil formation have been: weathering of lava flows, leptosolisation in units with slopes steeper than 50%, rubefaction and clay illuviation, in a more humid and contrasted climatic period than the current one (Torres *et al*., 1992), and secondary carbonatation, forming petrocalcic horizons, which is the main pedogenic process taking place at the present time, with *per ascensum* recarbonatation of the argic horizons, together with natural salinisation in coastal areas.

Thus, the mature and non-degraded soils of the highest environmental quality in this morphodynamic environment are:

***Lithic Leptosols**:* Developed over slopes steeper than 50%, where the dominant genetic process, determined by the relief, is leptosolisation. These soils have an AC, AB-C or AR type-profile, are less than 10 cm thick, with sandy or sandy-loam texture, and poor in organic matter (<20 g.kg^{-1}) (Tables 2 and 3). This type of soils constitutes the standard in these situations and is therefore that of the greatest environmental quality, being unaffected by any degradation process. The characteristic plant community in these soils is Astidamio-Euphorbietum aphyllae.

Haplic Calcisols*:* Also in steep slope units (>50%) but in areas of already stabilised colluvial deposit materials. The dominant genetic process nowadays is carbonatation, giving rise to soils with an $AB_{ca}C$ or $A(BC)_{ca}$ profile, relatively deep (40-50 cms), with clayey or loam-clayey texture and 20-40 $g.kg^{-1}$ organic matter content (Tables 2 and 3). This type of soils are the climacic soils of the highest environmental quality on old scree deposits and are therefore the standard with which to compare the quality of the remainder of the soils in these areas. The characteristic plant community is Astidamio-Euphorbietum aphyllae.

Petric Calcisols*:* The greater part of the land units described in this morphodynamic environment on Miocene-Pliocene parent materials are placed on slopes below 50% in steepness. The dominant genetic process in these areas is recarbonatation of argic horizons of the Luvic Calcisols, by capillar rising of carbonates under conditions of wide seasonal contrast, both in terms of soil temperature and moisture. The most typical soils show an AB_{cam}, $AB_{ca}C_{cam}$ or $A(BC)_{cam}$ profile, with a petrocalcic horizon up to 80 cm in thickness, that rises as a mycelium through the argic horizon. These soils are deep (>80 cm), with a clay loam texture and a low organic matter content (<20 $g.kg^{-1}$) (Tables 2 and 3) and are covered by the climacic Euphorbietum balsamiferae-Astydamietum latifoliae plant community.

Sodic Solonchaks*:* These are the climacic soils in the coastal areas, characterised by the Frankenio capitatae-Zygophylletum fontanesii plant community. In these situation, the dominant genetic process is the accumulation of salts as a consequence of the continual influence of the sea spray that saturates the soils in salts and sodium, so that they quickly acquire the morphology and characteristics typical of salt-affected soils. The depth of these soils is variable and they generally show a clay loam texture and a intermediate content in organic matter (20-40 $g.kg^{-1}$) and values de $EC_{es} > 20\ dSm^{-1}$ and $ESP > 15\%$ (Tables 2 and 3).

These soils constitute the mature, non-degraded standard, and result from the pedogenetic processes acting on basaltic lava flows on this morphodynamic environment. Other soil types, as Haplic Cambisols and Luvic Calcisols that can be found over Pleistocene basalts have low environmental quality, since they are scantly evolved soils that tend to evolve towards Petric Calcisols in slightly sloping areas, by means of a genetic process of secondary carbonatation, or towards Sodic Solonchaks in coastal land units, by salinisation.

Conversely, the Calcaric Cambisols are formed by water erosion from those Petric Calcisols that loss the surface horizon, with decarbonation of the remainders of the calcic horizons that give rise to a cambic horizon with abundant limestone crust fragments (calcaric character), and with a lower clay content and soil moisture retention capacity (Tables 2 and 4). The Petri-Endosalic Calcisols have been degraded by salinisation of Petric Calcisols in agricultural areas subjected to irrigation with low-quality water, with leads to a remarkable increase of the EC_{es} in the B_{wca2} horizon. These soils can be morphologically distinguished from genetic saline soils (Sodic Solonchaks) by the occurrence of anthropogenic and petrocalcic horizons, and from the chemical point of view, by higher pH values and Ca content, as well as a lesser amount of sodium.

Lithic Leptosols formed by water erosion are also different from those non-degraded soils of the same type, and have been origined by a genetic leptosolisation process: they are shallower, poorer in clay, organic matter and basic cations, cation-exchange capacity and soil moisture retention capacity.

CONCLUSIONS

The methodology used here allows to evaluate soil degradation in certain environmental conditions. The occurrence of basaltic rocks of diverse age leads to *pedotaxa* having different evolución and/or degradation degree, from which several hypotheses on their possible evolutive or regressive directions may rise, and makes it possible to determine the ideal soil in equilibrium with all the environmental components: the mature or *climax* soil, which is considered as a reference to use in each local condition, based upon the fact that soils that develop undisturbed reach an equilibrium that leads to long-term stability in natural ecosistems.

In addition, this methodology has allowed us to distinguish the soils degraded by water erosion and by salinization in the morphodynamic environment studied, from those immature o scarcely evolved soils on the one hand, and from those whose low quality is due to determined pedogenic processes on the other hand: leptosolisation or natural salinization. It therefore consists on an approach to the evaluation of soil degradation based on purely ecosystemic and pedogenetic criteria.

Table 2. Some physical properties of non-degraded soils

Soil Type	Hor.	Depth (cm)	Clay	Silt	Sand	Water retention 33kPa	Water retention 1500kPa
			g kg^{-1}				
LITHIC LEPTOSOLS (Centroid for 4 analized soil profiles)	**AB**	0-10	267.5±15.3	449.1±18.0	300.3±11.8	395.6±13.7	141.1±9.9
	R	>10	-	-	-	-	-
HAPLIC CALCISOLS (Centroid for 3 analyzed soil profiles)	**AB**	0-5	348.6±17.1	400.7±12.2	283.5±9.7	379.0±13.3	215.8±11.0
	Bw	5-30	384.9±15.9	511.0±11.8	154.7±10.0	307.3±15.9	207.1±10.4
	Bwca	30-40	520.0±15.0	348.0±15.1	134.9±8.8	357.2±15.5	227.2±10.9
	Cca	>40	338.3±14.7	414.0±14.4	255.8±8.9	305.9±14.2	177.1±9.8
PETRIC CALCISOLS (Centroid for 6 analyzed soil profiles)	**AB**	0-10	-	-	-	-	-
	Bwca1	10-18	214.1±11.7	546.3±17.0	239.6±12.2	389.1±11.7	109.7±11.0
	Bwca2	18-40	497.0±18.9	412.2±14.6	91.0±10.0	396.1±13.9	192.8±12.1
	Ccam	40-76	544.0±17.9	364.5±13.2	91.5±9.3	398.7±12.5	193.2±12.2
SODIC SOLONCHAKS (Centroid for 2 analyzed soil profiles)	**Bw1**	10-18	231.5±9.6	609.2±12.8	137.9±5.9	301.7±10.5	107.2±8.9
	Bw2	18-40	500.7±12.2	465.1±12.0	60.7±3.9	468.9±10.7	188.9±9.6
	BCca	40-76	316.3±11.8	581.4±12.4	149.0±3.8	407.4±9.9	148.2±7.7

Table 3. Some chemical properties of non-degraded soils

Soil Type	Hor.	pH (H_2O)	Org C (g kg^{-1})	EC_{es} (dS m^{-1})	Ca	Mg	K	Na	CEC	S/CEC (%)
					cmol$_c$ kg^{-1}					
LITHIC LEPTOSOLS (Centroid for 4 analized soil profiles)	**AB**	7.4±0.6	15.3±2.5	1.5±0.1	7.7±1.9	5.0±1.4	2.3±0.9	3.3±0.8	17.6±2.8	100
	R	-	-	-	-	-	-	-	-	-
HAPLIC CALCISOLS (Centroid for 3 analyzed soil profiles)	**AB**	7.8±0.4	16.4±2.9	3.3±1.1	6.3±2.0	10.3±2.8	2.4±1.0	2.1±0.4	30.1±5.2	70,1
	Bw	7.0±0.4	2.5±1.2	1.7±0.6	19.3±4.7	11.2±2.5	1.2±0.6	8.0±1.1	24.6±3.6	100
	Bwca	8.0±0.5	3.2±1.0	2.1±0.7	30.2±4.9	13.6±2.9	0.3±0.1	8.7±1.5	25.5±3.3	100
	Cca	8.3±0.8	2.8±0.9	1.6±0.2	15.4±3.3	12.7±2.0	0.3±0.2	8.6±1.3	18.7±2.8	100
PETRIC CALCISOLS (Centroid for 6 analyzed soil profiles)	**AB**	8.8±0.4	6.4±1.3	1.3±0.3	16.3±2.2	-	-	-	-	-
	Bwca1	9.6±0.3	4.5±1.2	2.4±0.3	39.8±4.3	5.1±1.0	3.4±0.5	4.0±0.6	21.8±5.7	100
	Bwca2	8.7±0.5	2.8±1.4	35.9±4.5	39.3±4.4	6.5±1.1	1.8±0.4	23.6±6.5	23.1±5.8	100
	Ccam	8.7±0.6	2.5±0.7	24.9±5.0	42.5±4.7	8.0±2.0	0.6±0.0	6.3±1.4	21.4±4.9	100
SODIC SOLONCHAKS (Centroid for 2 analyzed soil profiles)	**Bw1**	9.8±0.8	5.4±0.7	6.4±1.1	7.9±1.0	5.2±0.3	2.8±0.3	4.0±0.7	14.8±1.9	100
	Bw2	7.9±0.9	6.0±0.8	60.9±12.8	6.0±0.6	7.4±0.3	3.4±0.7	13.6±1.9	22.7±2.0	100
	BCca	8.4±0.9	5.7±0.7	42.1±11.0	9.7±0.7	6.1±0.2	2.2±0.5	4.8±0.9	20.6±2.1	100

Table 4. Some physical properties of degraded soils

Soil Type	Hor.	Depth (cm)	Clay	Silt	Sand	Water retention 33kPa	Water retention 1500kPa
			g kg^{-1}				
LITHIC LEPTOSOLS-Eroded (Centroid for 3 analized soil profiles)	**AB**	0-8	159.2±9.6	410.0±16.8	433.3±10.5	275.4±8.8	83.1±7.0
	R	>8	-	-	-	-	-
CALCARIC CAMBISOLS-Eroded (Centroid for 3 analyzed soil profiles)	**Bw**	0-16	299.5±14.3	512.2±12.3	194.7±10.0	227.3±15.0	118.6±12.3
	Cca	>16	225.7±13.0	415.9±14.0	360.4±9.8	205.4±10.1	97.6±6.8
PETRI-ENDOSALIC CALCISOLS-Salinized (Centroid for 2 analyzed soil profiles)	**Ap**	0-15	126.7±15.3	468.1±17.3	410.2±15.7	199.4±6.6	100.2±9.3
	Bwca1	15-25	186.9±9.7	565.8±15.1	251.1±11.0	369.9±1047	91.4±6.4
	Bwca2	25-40	488.7±15.9	489.0±14.6	31.3±6.9	399.9±13.0	197.5±11.1
	Ccam	>40	402.7±10.4	457.5±12.0	141.8±9.0	378.6±11.8	167.3±10.7

Table 5. Some chemical properties of degraded soils

Soil Type	Hor.	pH (H_2O)	Org C (g kg^{-1})	EC_{es} (dS m^{-1})	Ca	Mg	K	Na	CEC	S/CEC (%)
					cmol$_c$ kg^{-1}					
LITHIC LEPTOSOLS-Eroded (Centroid for 3 analized soil profiles)	**AB**	6.9±0.2	4.2±0.8	0.8±0.0	6.5±0.7	5.1±0.8	2.0±0.3	2.9±0.4	12.7±1.7	100
	R	-	-	-	-	-	-	-	-	-
CALCARIC CAMBISOLS-Eroded (Centroid for 3 analyzed soil profiles)	**Bw**	7.7±0.4	4.4±0.9	1.0±0.1	3.3±1.0	10.3±2.8	1.3±0.4	1.1±0.4	20.0±4.4	80.0
	Cca	8.0±0.7	1.5±0.6	1.9±0.6	28.9±5.1	11.2±2.5	1.5±0.4	7.5±1.3	20.6±3.0	100
PETRI-ENDOSALIC CALCISOLS-Salinized (Centroid for 2 analyzed soil profiles)	**Ap**	8.1±0.5	9.8±1.5	1.1±0.3	6.2±1.2	-	-	-	-	-
	Bwca1	8.6±0.5	4.8±1.1	1.5±0.4	37.8±3.9	5.1±1.0	3.3±0.6	4.8±0.6	20.2±5.5	100
	Bwca2	9.7±0.8	2.2±1.0	74.8±5.6	41.3±4.8	6.5±1.1	4.8±1.4	6.9±5.5	23.7±4.4	100
	Ccam	8.8±0.6	2.3±0.5	14.7±5.5	49.5±5.0	8.0±2.0	0.7±0.1	5.1±1.0	21.1±4.5	100

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