# Mechanisms of Soil Erosion in Andic Soils of the Canary Islands*

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**Abstract**: The aim of this paper is to assess the mechanisms of water erosion in andic soils, by two tests, which in a certain way simulate the two principal mechanisms of aggregate destruction in the process of water erosion: water dispersion and raindrops impact and compare it with the aggregation observed in material dettached by interrill erosion (sediments) in experimental plots with natural rain. In accordance with the obtained results, the erosive process in these soils seems to come about through a picking off of surface material of larger aggregates, due to the impact of raindrops. The intensity of pull off and fragment size from larger aggregates, depends on the cinetic energy of the drops (rain intensity), but the size generally ranges between 0.2 and 0.5 mm. Therefore interrill erosion initially proceeds by a washing down of smaller aggregates (<0.5 mm) (of less bulk density than larger aggregates 0.4 $MgM^{-3}$ against 0.9 $MgM^{-3}$), enrichening the soil in larger sized aggregates that on being fragmented by picking off of raindrops, supply new material for washing down by interrill erosion.

**Keywords**: Andosols, aggregates breakdown, soil erodibility, Canary Islands

## 1 Introduction

The unusual mineralogical composition of andic soils is responsible for the existence of certain physical and mechanical properties characteristic of these soils. (*E.Fernández-C ld s et l.*,1975, *B.P. W rkentin et .l*,1980, *R.T. Meurisse*, 1985, *P.Qu ntin*, 1994). Thus, their low apparent density, high porosity and capacity of water retention and high limits of plasticity are closely related to the presence of allophanes, imogolite and other minerals with short-range ordination and having a particular manner of associating among one another and with organic compounds, generating structures with a high degree of aggregation and stability, which are ultimately responsible for those properties.

All these characteristics, in turn, are in close relationship with the erodibility characteristics of andic soils, hence the fact that erosive processes in soils in which short-range ordination minerals predominate in the fine fraction also present differential features with respect to soils with a mineralogy dominated by crystalline clays (*T. Y m moto et l.*, 1967, *S. El-Sw ify et l.*, 1977, *T. Kubot et l.*, 1990, *I. Plá*, 1992).

## 2 Soil erosion in andic soils. What is the problem?

It is generally admitted that, under normal conditions, the degree of water erosion in andic soils is low. Indeed, a high vegetation cover, the low erosivity of the rainfall in the areas in which they are found and a very low erodibility, in accord with all the indexes traditionally used, would seem to point to this.

However, in many cases, particularly when changes occur in the use and management of these soils, important erosive processes are triggered that can affect the totality of the soil, leaving outcrops of the material of origin at the surface.

This apparent controversy seems to be due to the fact that the indexes normally used to assess soil erodibility are not applicable to andic soils, very low values of erodibility being obtained for these soils which do not correspond to those observed in reality, mainly because of their characteristic physical

* This work has been supported through the Agreement: “Spanish Contribution to UN Convention to Combat Desertification. I.-Network of Experimental Stations for the Tracking and Evaluation of Erosion and Desertification (RESEL)” Ministerio de Medio Ambiente and Universidad de La Laguna

properties for which the process of erosion must take place in these soils in a manner different from that established for other non-andic soils.

We can conclude definitively that andisols and andic soils where short-range ordination minerals predominate in the fine fraction present differentiated characteristics of erodibility and of water erosion mechanisms with regard to other soils, which can be summarised as follows:

- A characteristic mineralogy that conditions the genesis of an aggregation model that is also characteristic and which is responsible for physical properties that are differentiated from those of soils with crystalline clays: very low apparent density, high structural stability, high microporosity and capacity of water retention, high hydraulic conductivity and rate of infiltration, even with high volumes of water, high limits (liquid and plastic) of plasticity, etc..
- Under these conditions, indexes of erodibility such as the K factor of the USLE, based on parameters such as the granulometric composition (giving excessive weight to the silt and very fine sand fractions), the content in organic matter and numerical codes of structure and permeability do not take into account the true susceptibility of the soil to the separation and transfer of particles due to water, generally underestimating the degree of erosionability.
- The morphological features of erosion observed at times in these soils correlate better with environmental variables and use of the soils than with the intrinsic properties of same and in particular with the erodibility (K) estimated from the nomograph of Wischmeier (*W.H. Wischmeier et l.,* 1971, 1978). Factors such as slope angles of over 30%, vegetation that does not form a cover in many cases, high erosivity of the strongly seasonal rains and other anthropic factors of use and management determine to a greater extent the degree and intensity of the erosive morphology than the erodibility itself.
- The hypothesis has been put forward and several authors have suggested that water erosion in andisols and andic soils takes place by way of two main mechanisms that in no case involve particle dispersion prior to being displaced by rainwash since the mobilization of particles takes place in the form of aggregates that are highly stable in water or by means of the downslope sliding of the total mass of water-saturated soil upon exceeding its liquid limit.

## 3 Study methodology

In order to know the true rate of soil loss and the rate of generation of runoff in andic soils, as well as other parameters related to erodibility and the erosion process in these soils, a study was performed in experimental erosion plots.

The study area consisted of three experimental plots, each measuring 200 m$^2$ (25 × 8 m). In the 1$^{st}$ one the soil is kept bare and ploughed (with a slope of 24%), the 2$^{nd}$ one features pine with a density greater than 60% and a slope of 13%. The 3$^{rd}$ plot features substitution vegetation and repopulated species with a slope of 24%.

The soils were classified as Haplic Andosols (WRB,1998) or Typic Hapludands (USDA,1999). This type of soil is frequently found in the forest areas of the islands. The parent material of the surroundings are basic and intermediate lava flows of the “Series III” (Upper Pleistocene), with insertions of pyroclastic materials of the same Series. The surface horizon is very deep (up to 70 cm), and very dark brown to brownish-black in colour. In this horizon, two subhorizons can be differentiated (A11 and A12), the lower having a more massive structure. Below 70 cm a weathering horizon was found (Bw), that was yellowish brown, silty clayish and with a massive structure. The NaF reaction was fast and weak throughout the entire profile The selected physical and chemical properties of these soils are represented in Table 1. The classification as regards the Andisols Order was verified by means of: (1) content of Alo + 1/2 Feo higher than 2%; (2) bulk density lower than 2%, and (3) phosphate retention higher than 85%.

In order to assess the mechanisms of water erosion in andic soils, soil samples were selected from the top layer (0 cm—5 cm) on the bare soil since this is the layer directly affected by raindrops and where splash and interrill erosion processes take place. In soil samples a distribution analysis of aggregates was carried out by dry sieving, according to size range >8 mm, 7.1mm—8mm, 6.3 mm—7.1mm, 5mm—6.3mm, 4mm—5mm, 3.2mm—4mm, 2mm—3.2mm, 1mm—2mm, 0.5mm—1mm, 0.1mm—0.5mm,

<0.5mm. Aggregate distribution in the sediments was carried out by wet sieving and according to size range >6.3mm, 6.3cm—4cm, 4.0cm—3.2cm, 3.2cm—2.0cm, 2.0cm—1.0cm, 1.0cm—0.5cm, 0.5cm—0.1mm, in sediments collected during 15 erosive episodes in 1977—1999, establishing the mean values for each fraction.

**Table 1  Selected properties of soils**

| Horizon | $O+A_{11}$ (0cm—25 cm) | $A_{12}$ (25cm—70 cm) | Bw (70cm—130 cm) |
|---|---|---|---|
| Water content (%) (dry) | | | |
| 1/3 atm | 69.1 | 62.6 | 56.3 |
| 15 atm | 40.3 | 42.0 | 40.4 |
| Water content (%) (wet) | | | |
| 1/3 atm | 76.3 | 69.1 | 82,2 |
| 15 atm | 47.6 | 44.2 | 66.6 |
| Bulk density ($Mg\cdot M^{-3}$) | 0.4 | 0.5 | 0.5 |
| Saturated hydraulic conductivity ($mm\cdot h^{-1}$) | 167.6 | 43.0 | 133.1 |
| Coarse fragments (>2 mm) ($g\cdot kg^{-1}$)* | 61 | 58 | 65 |
| Clay ($g\cdot kg^{-1}$)* | 190 | 380 | 564 |
| Silt ($g\cdot kg^{-1}$)* | 714 | 496 | 389 |
| Fine sand ($g\cdot k^{-1}$)* | 41 | 34 | 32 |
| Coarse sand ($g\cdot kg^{-1}$)* | 22 | 63 | 16 |
| pH ($H_2O$,1:2,5) | 6.0 | 5.8 | 5.8 |
| pH (KCl,1:2,5) | 4.9 | 4.9 | 5.5 |
| Organic matter ($g\cdot kg^{-1}$) | 250 | 118 | 35 |
| P-retention (%)** | 95.4 | 96.0 | 94.4 |
| CEC ($cmol_c kg^{-1}$)*** | 57.2 | 53.9 | 42.3 |
| Alo+1/2Feo | 4.5 | 5.8 | 7.6 |
| Mineralogy of clay fraction | Hematite,Vermiculite, Illite | Hematite,Gibbsite, Vermiculite, Illite | Hematite,Vermiculite, Illite |

* Soil texture: Na-resin method (*B rtoli et l.*,1991). ** *Bl kemore et l.*,1981. *** *Mehr et l.*,1960

In each aggregate fraction obtained from the soil sample, two aggregate stability tests were applied:

(1) Disaggregation test (*B rtoli et l.*,1991), as a measure of structure dispersion due to aggregate humectation. Nine brass sieves (mesh size 0.2mm) were immersed for 2cm—3cm in 200ml distilled water contained in a plastic can. Oscillations were sinusoidal, with an amplitude of 2 cm and frequency of 98 oscillations/min. The dissaggregation kinetics of the soil studied (in accord with previous works) indicated that 6 hours was an appropriate time of disaggregation in water.

(2) Water-drop test (*Imeson et l.*,1984), as a measure of structure dispersion due to raindrop impact. In the device used by us, a water supply system with a constant head was fitted to a burette, and water drops 0.1g in weight (5.8mm diameter) were obtained. The water drops were allowed to fall from a height of 1 m onto aggregates placed in a metal sieve. The time interval between drops was 1 s. (total 20 drops).

The test was carried out in two stages: in the first, 10—20 aggregates of each fraction were placed in a sieve with a diameter similar to the inferior of the fraction interval to which it corresponds. In the second, 10—20 aggregates of each fraction were situated in a 0.2 mm sieve.

In each case, aggregates were weighed before and after treatment: all weights refer to constant weighing at 105ºC.

## 4 Results and discussion

It can be said that erosivity in this area due to rain is high, with frequent, high-intensity events (up to 242 mm· $h^{-1}$) (Table 2), although a high intensity in the incidence of erosive processes is not observed at present, due to the dense plant cover supporting the soils, which decreases the generation of runoff and diminishes the impact of the raindrops.

However, the greatest productions of sediments do not present a clear relationship with the most intense rains or with the peaks of generation of runoff ($r$ = 0.70, $p$ =0.005, between sediments production and Imax).

The runoff generated in these soils is relatively low, with mean values of 14.5% (89.4 $Lm^{-2}$) and 0.2%—0.3% (1—2$Lm^{-2}$) (Table 3) when a vegetation cover is present, never exceeding 45% even with the most abundant and intense rainfall, which manifests the high capacity of infiltration of Andisols, at least in the surficial horizons, that logically increases when a plant cover exists on the soil.

This leads to a relatively small loss of soil due to sheet erosion (a mean value of 10 $Tmha^{-1}$· $year^{-1}$) (Table 3), although significant losses of soil (up to 30 $Tmha^{-1}$) can take place during certain events, which do not necessarily involve the greatest or the most intense rainfall.

**Table 2 Annual Report: Rainfall, Erosion and Runoff**

| Rainfall | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|---|---|
| P (mm) | 870 | 443 | 511 | 667 | 811 | 403.2 | 889 | 627.4 |
| Imax(mm· $h^{-1}$) | 60 | 31 | 242 | 84 | 45 | 51.68 | 81.6 | 43.2 |
| I 30 (mm· $h^{-1}$) | 15.5 | 15.7 | 11.6 | 14.8 | 17.9 | 14 | 41.2 | 32.4 |
| R ($MjHa^1mm$· $h^{-1}$) | 828 | 398 | 342 | 497 | 958.7 | 434.65 | 1220.4 | 886.38 |
| Sediments yield ($Tmha^{-1}$· $year^{-1}$) | | | | | | | | |
| Bare soil | 28.9 | 8.7 | 5.6 | 17.4 | 14.9 | 3.0 | 9.5 | 0.82 |
| Natural vegetation | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Reforested pine | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Runoff (%) | | | | | | | | |
| Bare soil | 10.9 | 18.2 | 30.5 | 23.4 | 13.0 | 19.8 | 8.7 | 3.6 |
| Natural vegetation | 0.6 | 0.3 | 0.1 | 0.3 | 0.2 | 0.2 | 0.14 | 0.3 |
| Reforested pine | 0.4 | 0.1 | 0.1 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 |

**Table 3 Global results (Years 1993—2000)**

| Plot | P | Runoff | Infiltration | Erosion | Imax | $I_{30}$ | R |
|---|---|---|---|---|---|---|---|
| | (mm) | (%) | (%) | $Tmha^{-1}$· $year^{-1}$ | (mm· $h^{-1}$) | (mm· $h^{-1}$) | (Mj· $ha^{-1}$· mm· $h^{-1}$) |
| Bare soil | 616.8 | 14.5 | 85.5 | 9.9 | 242 | 41.2 | 640 |
| Natural vegetation | 616.8 | 0.25 | 99.75 | 0.0 | 242 | 41.2 | 640 |
| Reforested pine | 616.8 | 0.26 | 99.74 | 0.0 | 242 | 41.2 | 640 |

The characteristics of the sediments (sampled during 65 erosive events) are similar to those presented by the surficial horizons of the andisols, with the exception of the clay content, which is clearly greater than in the sediments (Table 4), pointing to the fact that the clay fraction is the most easily eroded granulometric fraction, although not in a disperse state, but rather as small, highly stable, crumble and granular aggregates, such that over 50% of the sediments (527 g· $kg^{-1}$) are made up of aggregates with a particle size ranging between 0.1mm and 1.0 mm (Table 4).

The distribution of aggregates in the soil surface horizon (dry-sieving) showed a similar tendency although a slight predomination of larger fractions was observed (Table 5).

All aggregates were very stable to dispersion in water, particularly those larger than 2 mm since after 6 hours of shaking they remained stable and more than 96% of the aggregate total mass preserved its original form. In aggregates smaller than 2 mm stability was lower and about 65% of the total mass of the aggregate dispersed into particles of less than 0.2 mm (Fig. 1).

**Table 4 Physical properties of sediments**

| | Mean (g· $kg^{-1}$) | Coefficient of variation |
|---|---|---|
| Particle size* | | |
| Coarse fragments | 19.0 | 19.2 |
| Clay | 383 | 11.8 |
| Silt | 572 | 22.3 |
| Sand | 47 | 19.1 |
| Aggregate size (mm)** | | |
| >6.3 | 32 | 82 |
| 6.3—4.0 | 60 | 39 |
| 4.0—3.2 | 54 | 23 |
| 3.2—2.0 | 122 | 22 |
| 2.0—1.0 | 175 | 24 |
| 1.0—0.5 | 162 | 20 |
| 0.5—0.1 | 365 | 27 |
| Dispersed clay, silt and sand | 30 | 38 |

*Na-resin method (*Bartoli et al.*,1991) **Wet-sieving method

**Table 5 Aggregate size distribution of soil surface horizon**

| Aggregate size (mm)* | >6.3 | 6.3—4.0 | 4.0—3.2 | 3.2—2.0 | 2.0—1.0 | 1.0—0.5 | 0.5—1.0 |
|---|---|---|---|---|---|---|---|
| g· $kg^{-1}$ | 112 | 94 | 127 | 169 | 152 | 198 | 156 |

*Dry-sieving method

When the water-drop test was applied results were also different and it was seen that smaller-sized aggregates (<2 mm) remained almost intact upon water-drop impact (there was no splash) and only presented a slight swelling and tendency to produce humectation on dispersing.

In larger aggregates a fragmentation of the same was produced up to total breakage of the aggregate into others of a smaller size at the start, but always larger than 0.2 mm. Only 4%—5% of material was observed to pass through the 0.2 mm sieve, which was probably due to dispersion by humectation of the larger aggregates (Fig. 2).

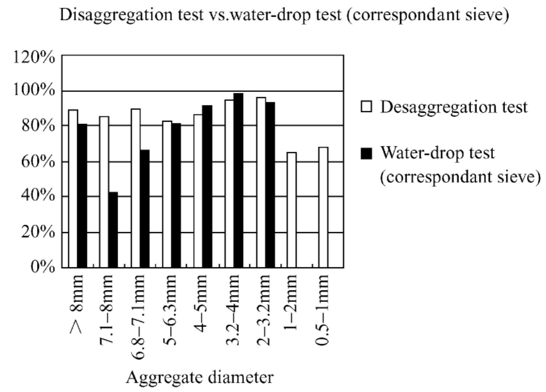


**Fig.1** Disaggregation test and water-drop test

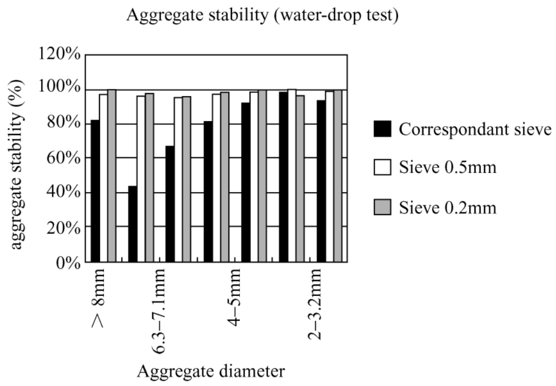


**Fig.2** Aggregate stability (water-drop test)

In general it can be said that with the used methods, even more violent than natural rain or humectation under field conditions, total aggregate dispersion never took place.

## 5 Conclusions

In accordance with the obtained results, the erosive process in these soils seems to come about through a picking off of surface material of larger aggregates, due to the impact of raindrops. The intensity of pull off and fragment size from larger aggregates depends on the kinetic energy of the drops (rain intensity), but the size generally ranges between 0.2mm and 0.5 mm.

Therefore interrill erosion initially proceeds by a washing down of smaller aggregates (<0.5 mm) (of less bulk density than larger aggregates 0.4 $MgM^{-3}$ against 0.9 $MgM^{-3}$), enriching the soil in larger-sized aggregates that, on being fragmented by picking off of raindrops, supply new material for washing down by interrill erosion.

Moreover, the largest rates of sediment yield and runoff were observed when the rains fell on dry soil.. Given the known hydrophobicity of the surficial organic horizons of andosols, a high rate of runoff is generated that pulls the surface aggregates off the bare soil, independently of the intensity of the rainfall. Upon the slow humectation of the soil, the high rate of infiltration and, in particular, the high water retention capacity of these soils (up to 300 mL/100 grs) lead to a very low degree of runoff and to the fact that it is only brought about when the volume of rainfall is high (independently of its intensity), which then pulls by sheet flow the moistened aggregates that have been fragmented by prior, high-intensity water-drop impact.

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