Soil properties related to water repellency in volcanic soils at Tenerife (Canary Islands, Spain): relationships with vegetation and soil parent material

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Abstract
Soil water repellency (SWR) was studied in 64 surface soil samples from Tenerife (Canary Islands, Spain), distributed over three different plant communities (natural and afforested Canarian pine forest, and high mountain legume scrub) and three types of soil parent materials (basaltic and salic rocks and basaltic tephra). Soils were studied for physicochemical properties (soil pH and salinity, nutrient contents, organic C and total N, particle size fractions and parameters related to andic soil properties), as well as for common SWR tests (Water Drop Penetration Time and Molarity of the Ethanol Droplet). The results suggest that SWR is more intense in silty-textured soils, with relatively high contents in organic C and nutrients, as well as in Al-humus complexes, under afforested pine forest. Soil parent material was shown to be less decisive in this sense.

Key Words
Soil water repellency, volcanic soils, andic soil properties, pine forest, broom scrubland, soil parent material.

Introduction
Soil water repellency (SWR) has recently become a first-order research issue for soil scientists (Dekker *et al.* 2005). Concerns about this soil property are currently enhanced by the threat of global warming and the increasing impact of wildfires, very especially in areas under mediterranean-type climate. Studies on SWR comprise a wide variety of locations and soil types. However, soils derived from volcanic parent materials have received comparatively less attention in this sense (DeBano 2000). It is generally accepted that SWR relates basically to soil organic matter content and features and tends to be more intense in coarse-textured soils (Del Moral *et al.* 2005). Soils in volcanic areas are rich in short-range ordered minerals (allophane-like silicates) and organometallic complexes that accumulate in the upper soil layers, which stabilize soil humus, thus giving rise to dark, porous and well structured surface horizons. Both the structure and the accumulation of humus may influence water dynamics in these particular soils.

It is also known that SWR varies in space (Regalado and Ritter 2006) and in time, according to the climatic conditions, being usually highest along the dry season. In western Canary Islands, a volcanic archipelago, the main water supplies come from rainfall, especially along the forest belt lying between 800 and 1600 m in altitude, consisting mostly of moist (laurel, lower height) and xeric (pine, upper heights) forests. Therefore, SWR is particularly relevant in these ecosystems. Its knowledge could provide a basis for research efforts in similar ecosystems elsewhere.

In this work, we study the water repellency in a set of soil samples collected in the xeric, Canarian pine forest (natural and afforested) in Tenerife, the greater island in the archipelago. Additional samples have been collected in the high mountain scrubland (above 2200 m in height) for comparison purposes. Soil water repellency will be related to relevant soil physicochemical properties, including those related to the andic reactivity (i.e., active Al, Fe and Si contents, and P retention capacity).

Methods
Sampling tasks
Sampling areas were selected from a previous GIS study, taking into account the following factors: plant community (natural or newly forested Canarian pine forest, and broom scrubland), soil parent material (the most representative rock types are basaltic and salic -trachytic and phonolitic- rocks and basaltic tephra), accessibility (roads or pathways nearby) and absence of wildfires in the last fifteen years, as wildfires are known to increase SWR, either directly or indirectly, often for a long time (Shakesby and Doerr 2006). After this, 64 sampling locations were selected (Figure 1). We have distinguished between natural and afforested pine forest because the first one is open enough to allow the establishment of an understorey (scrubs + herbs) plant stratum, whereas in the second one the canopy is denser, thus limiting biodiversity, but also increasing litter supplies to the soil, and therefore increasing organic matter content in soil surface layers.

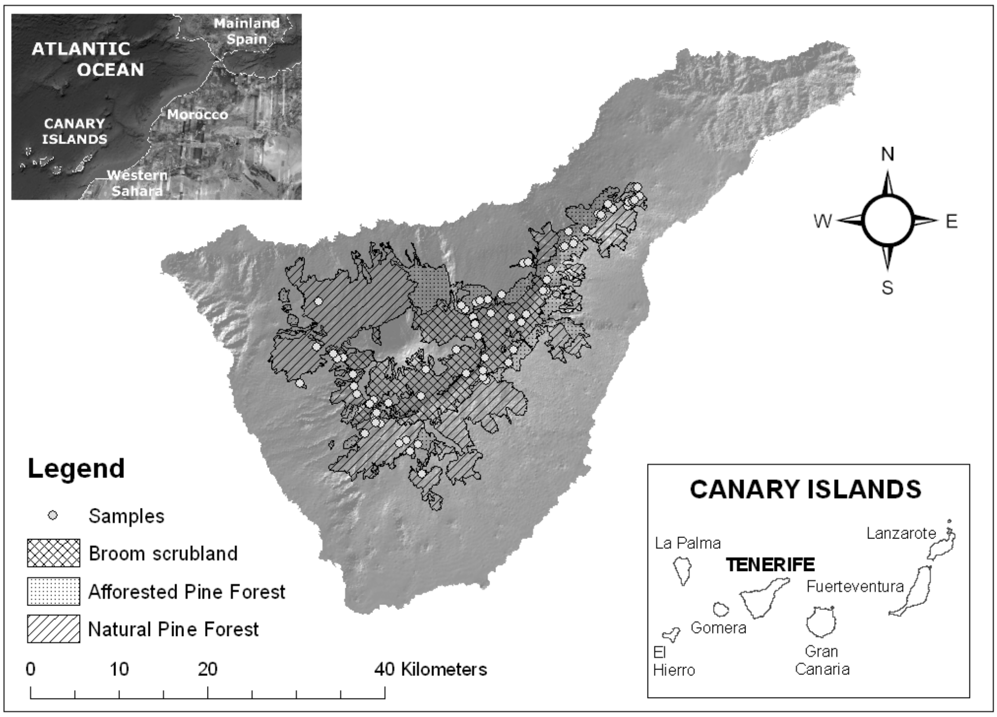

Figure 1. Geographical location of the Canary Islands (upper left and lower right), sampling areas and location Tenerife island.

Analytical procedures

In the field, sampling points were located with a Garmin eTrex GPS device. Surface (0-10 cm) soil samples were collected, air-dried and passed through a 2 mm sieve. In them, the following parameters were determined: pH and electrical conductivity (1:5 soil:water extract), available cations (neutral 1N ammonium acetate), and P (Olsen's method), total organic C (potassium dichromate wet oxidization), total N (Kjeldahl digestion), active Al, Fe, and Si (acid ammonium oxalate method), complexed Al and Fe (sodium pyrophosphate extraction), particle size fractions (Boyoucos densimeter), complexing organic C (sodium pyrophosphate), and P retention capacity (sorption from a 1000 ppm P solution). Determination techniques used included potentiometry (pH and E.C.), atomic absorption spectrophotometry (Ca, Mg, Al, Fe and Si), flame emission (Na and K), UV-VIS spectrophotometry (available P and P retention capacity), and titration (total and complexed organic C, total N). SWR was determined with the classical Water Drop Penetration Time (WDPT) and the Molarity of the Ethanol Droplet (MED) tests in soil samples previously heated at 105ºC and cooled in a desiccator over silica gel (Jaramillo, 2004). The statistical analysis were carried out using the Statistical Package for Social Sciences (SPSS^{TM}) v.17 software package.

Results

There was a great variability in the soil samples for the parameters studied (Table 1), save for pH values (coefficient of variation < 10%). With regard to the environmental factors considered (vegetation and parent material), plant community was associated with significant differences for the means (2-way ANOVA test) of soil nutrients (individual and total available cations), Fe_p, (Al+0.5Fe)ox, total and pyrophosphate-extractable C, P retention capacity and particle size fractions. These results evidence that soils under high mountain scrubland are less developed than those under pine forest (either natural or afforested), which are richer in nutrients and organic C forms, and also have silty textures. In terms of soil parent material, only pH, Alox:Alp ratio and silt content were statistically different among sample groups.

An initial determination showed that 31 out of the 64 samples were hydrophobic (WDPT > 5 s). The results for WDPT and MED tests are shown in Figure 2.

Table 1. Descriptive statistics for the physicochemical parameters in the soil samples collected. S.D.: Standard Deviation. EC: electrical conductivity (□S/cm). Cations and sum of bases in cmol/kg. Oxalate- and pyrophosphate- extractable elements, total C, N, particle size fractions and P retention capacity (PRC) as percentages. Available P as mg/kg. Alpo: Alp:Alox ratio. AlFeo: %(Al+0.5Fe)ox.

	pH	EC	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	BS	Alo	Feo	Sio	Alp	Fep
Mean	6.7	88	4.7	1.5	0.5	1.5	8.2	1.2	0.9	0.4	0.4	0.08
S.D.	0.32	45	3.8	1.6	0.4	0.9	5.9	1.1	0.6	0.4	0.3	0.06
Max	7.36	230	18.4	7.9	2.8	4.6	25.3	5.1	2.9	1.9	1.5	0.23
Min	5.93	30	0.2	0.1	0.03	0.8	0.8	0.1	0.2	0.02	0.0	0.01
	Al_{po}	**N**	**OC**	**Cp**	**C_pC_T**	**PRC**	**$AlFe_o$**	**Sand**	**Silt**	**Clay**	**P**	
Mean	0.55	0.4	6.6	2.03	0.31	44.4	1.64	56.3	35.3	9.6	26.98	
S.D.	0.59	0.3	5.4	1.86	0.11	20.9	1.26	15.1	12.4	5.1	18.09	
Max.	3.22	1.4	22.7	7.4	0.6	82.9	6.0	89.3	62.2	24.5	78.21	
Min.	0.01	0.0	0.1	0.0	0.0	5.9	0.2	21.1	8.7	1.4	1.02	

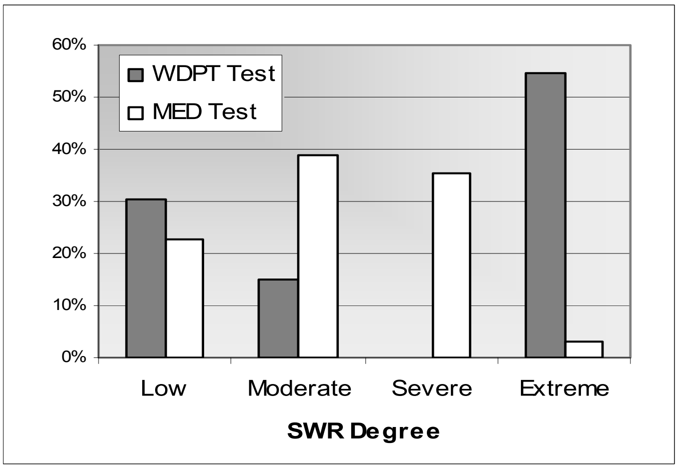

Figure 2. Frequency distribution for water-repellent soil samples. Categories are as follows: for WDPT, Low (5-60 s), Moderate (60-600 s), Severe (600-3600 s), Extreme (≥ 3600 s); for MED, Low (0.2-1M), Moderate (1.2-2M), Severe (2.2-4M), Extreme (≥ 4M).

There was a tight relationship between both repellency measurements (Spearman correlation model, $R = 0.951$, $p < 0.001$). A comparison of hydrophobic vs. non-repellent samples (Student's t test) showed that repellent samples were richer in nutrients (higher E.C., basic cations and P levels), pyrophosphate-extractable C, Fe and Al, total organic C and N, and clay content.

MED test classes for hydrophobic samples were used to analyse these parameters (Kruskall-Wallis test, due to the small size of the resulting groups), so as to elucidate whether SWR intensity might be related to changes in these properties. To do this, the Severe and Extreme (1 sample) classes were joined into one. The results showed that only total organic C and pyrophosphate-extractable C were useful to discriminate different repellency intensities. A further pair-wise comparison for the three groups (Mann-Whitney's U Test) showed that both Total organic C and Cp were statistically different in samples with the lowest intensity in water repellency. However, no significant distinction could be made for samples with moderate and (severe + extreme) hydrophobicity.

A Principal Components Analysis (Figure 3) was also carried out for the standardized data matrix. Several approaches were necessary, rejecting those variables with low extraction (pH, E.C., Na^+, $\%Fe_{ox}$, Fe_p, C_p:C_T ratio and %Clay). From the plot of the remainder variables against the two main axes (accounting for 66.3% of the total variance), it can be seen that the first axis is positively associated with the organic C (total and Cp), total N, nutrient, silt and Al contents, and negatively with the sand content. The second axis is positively related to the total active Al and Si contents, as well as to the P retention capacity. Provided that SWR has shown to be related to most of the variables (save for the silt content) positively related to the first axis, it would follow that this factor could also be tightly related to SWR. It also seems reasonable to assume a connection between this axis and the age of the soil, represented by the opposite locations of the silt (more developed soils) and sand (vice versa) contents along it.

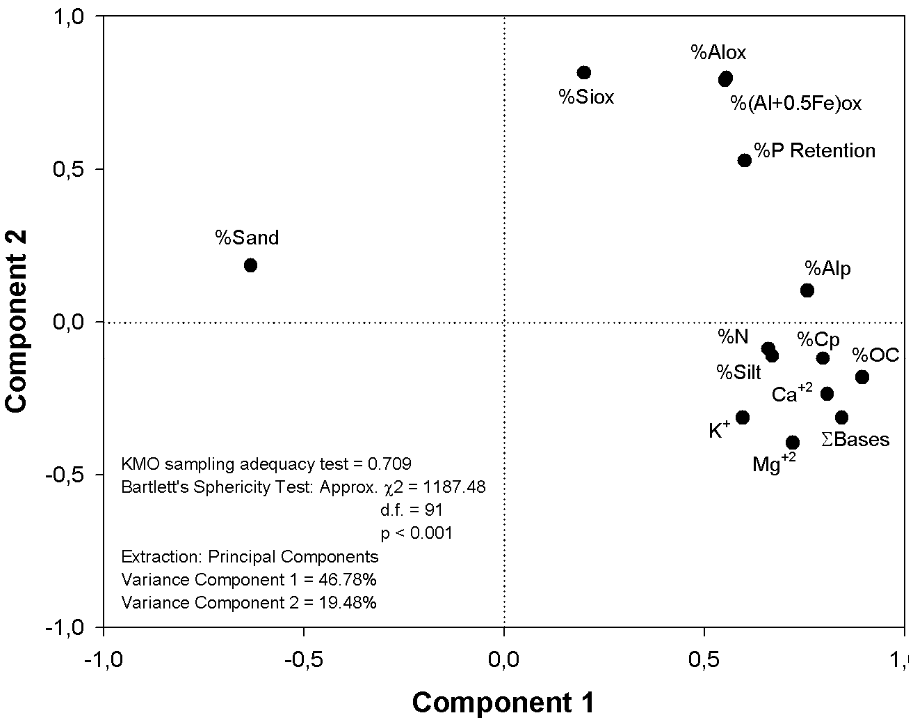

Figure 3. PCA plot for the variables studied, once disregarded those with low extraction (communality).

As far as the second axis is concerned, it seems to be clearly linked to the chemical reactivity of andic soils, whose relationship with SWR could come only from the levels of complexed Al (Al_p), which is part of the total active Al content (Al_{ox} and $[Al+0.5Fe]_{ox}$), and can also contribute to the P retention capacity. The active Si content keeps a low correlation with the first axis, but is also significantly related to the second one. Therefore, SWR can be expected to be more significant in Aluandic, rather than in Silandic Andosols.

Conclusions

Soil water repellency was shown to vary widely among the collected soil samples, although the results suggest that this soil property is more intense and persistent in relatively developed soils, which have high organic C and nutrient contents in the upper horizons which, in terms of vegetation, means: afforested pine forest ≥ natural pine forest > broom scrubland. The relative significance of soil parent material has been lower than that of vegetation type. Andic soil properties only relate partially to soil water repellency, especially in soil rich in Al-humus complexes.

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