Impact of reforestations with exotic and native species on water repellency of forest soils

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Summary
Forest duff layer is usually water repellent due to the hydrophobic organic compounds resulting from degradation of tree tissues. Transition from hydrophobic to wettable conditions, or vice versa, is largely controlled by water content. The objective of this investigation was to assess the influence of soil moisture on the degree of soil water repellency (WR) in exotic and native tree forests. Occurrence of WR was investigated by the water drop penetration time (WDPT) and the ethanol percentage (EP) tests. Sampling was conducted in the forest soils of two exotic species (*Pinus pinaster*, P, and *Eucaliptus camaldulensis*, E), used in the past for reforestation, and two native species (*Quercus ilex*, L, and *Quercus pubescens*, R). The WDPT vs. θ relationships exhibited a decreasing trend with a transition from hydrophobic to wettable conditions in the range θ = 0.14 - 0.19 cm^3cm^{-3}. The EP vs. θ relationships showed a maximum in the range θ = 0.10 - 0.15 cm^3cm^{-3}. Hydrophobicity in soils of native species persisted at relatively higher water content compared to exotic ones and it is expected to influence the hydrological processes to a greater extent.

1. Introduction
Forest duff layer usually contains amphiphilic organic molecules, resulting from degradation of tree tissues, that coat soil particles and may be responsible for water repellency (WR) (Doerr et al., 2000). The interaction between these molecules and soil particles is largely governed by water content (Doerr et al., 2000; Ellies et al., 2005). The transition from wettable to hydrophobic status (and vice versa) was generally associated to a critical water content even if several studies defined it as a range of soil moisture rather than a single value (e.g. Dekker et al., 2001). The lower water content of this range defines the condition below which the medium is water repellent, the higher identifies the condition above which the medium is wettable. In Sicily, reforestation strategies have been undertaken to prevent soil degradation (La Mantia, 2002). To achieve timely and effective soil cover, fast-growing exotic evergreens species were preferred to native species but the potential negative impact on soil hydrophobicity has not been specifically assessed. The objective of this investigation was to compare the degree of soil WR induced by reforestations and, specifically, to explore the influence of soil water content on the WR of two exotic species, *Pinus pinaster* (P) and *Eucaliptus camaldulensis* (E), and two native ones, *Quercus ilex* (L) and *Quercus pubescens* (R).

2. Materials and Methods
Soil samples were collected in the duff layers (approximately 5 cm thick), air-dried and carefully sieved at 2-mm sieve. Soil was compacted into aluminum trays (19.7 x 14.7 cm^2) at a height of 1 cm and porosity, ϕ, determined from mass of soil and air-dried

moisture content. Trays were then wetted to volumetric water content, θ, corresponding to fixed saturation ratios θ/ϕ = 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30. To explore a higher range of θ, two further trays were prepared using soil samples oven-dried at 40 and 70 °C. The persistence of WR was investigated by the water drop penetration time (WDPT) test (Wessel, 1988) whereas the degree of WR by the ethanol percentage (EP) test (Watson and Letey, 1970). The WDPT test involved placing 30 drops of distilled water onto the sample surface and recording the times required for their complete penetration. The EP test was carried out using ethanol concentrations of 5%, 7%, 10%, 13%, 15%, 20%, 25%, 30%, 35% by volume. For each soils, 30 EP values were obtained by interpolation of pairwise EP values characterized by infiltration times immediately higher and lower than t = 5 s. A medical dropper was used to displace the drops on the soil surface according a 1.5 x 1.5 cm^2 grid inside the tray.

3. Results and Discussion

The Lilliefors (1967) test (P = 0.05) showed that WDPT values were better represented by log-normal distribution whereas the EP values by normal distribution. Consequently, the results were summarized by calculating the associated statistics. For θ values corresponding air-dried conditions, the mean WDPT values ranged between 363 and 1767 s that corresponded to a WR classification from strong to severe (Bisdom et al., 1993). In particular, the most hydrophobic soil was that of Eucaliptus (E) and the different forest tree species affected soil WR in the following order: E>L>P>R.

The results of WDPT tests conducted at different water contents are shown in Figure 3.1a. In general, the WDPT values for the four investigated forest soils followed the same trend. In particular, for low θ values, WDPT was almost constant and independent of water content until it reached a critical moisture threshold value that varied between 0.08 and 0.14 cm^3 cm^{-3}, depending on the different tree species. Above this threshold, the WDPT values decreased to the condition of wettability (WDPT $\leq$ 5 s). The coefficients of variation were small in both the hydrophobic and wettable conditions but generally increased in the transition interval. In order to identify the critical θ values discriminating the transition interval from hydrophobic to wettable conditions, a Tukey test (P = 0.05) was applied to the mean values of ln(WDPT) corresponding to different soil moisture. For low θ values of the sequence, differences in WDPT values were generally not significant, but they became significant at higher θ values. In particular, it was possible to detect a critical water contents (CWCH) below which the soils are hydrophobic (Table 3.1). For θ > CWCH, WDPT values decreased linearly from the value corresponding to CWCH to a critical water content (CWCW) above which the soil was wettable. The CWCW values were determined as intersection of the regression line ln(WDPT) vs. θ for the transition zone and the line WDPT = 5 s (Figure 3.1a). The substrates of exotic trees (P and E) generally showed CWCH values higher and CWCW values lower than those of the native species (Table 3.1). As a consequence, transition from hydrophobic to wettable conditions was more gradual in the native species (Figure 3.1a). In the soil of the L forest, the water content needed to restore a complete wettability increase up to 0.28 cm^3cm^{-3}. Among the exotic species, E soil showed WR levels that were generally higher than those of the P soil (Figure 3.1a). The L soil was always more hydrophobic than the soil of the other native tree forest (R). The results of EP test conducted for θ values corresponding to air-dried conditions allowed to classify the L and R soils as very strongly hydrophobic and the P and E ones as extremely hydrophobic (Doerr et al., 2000).

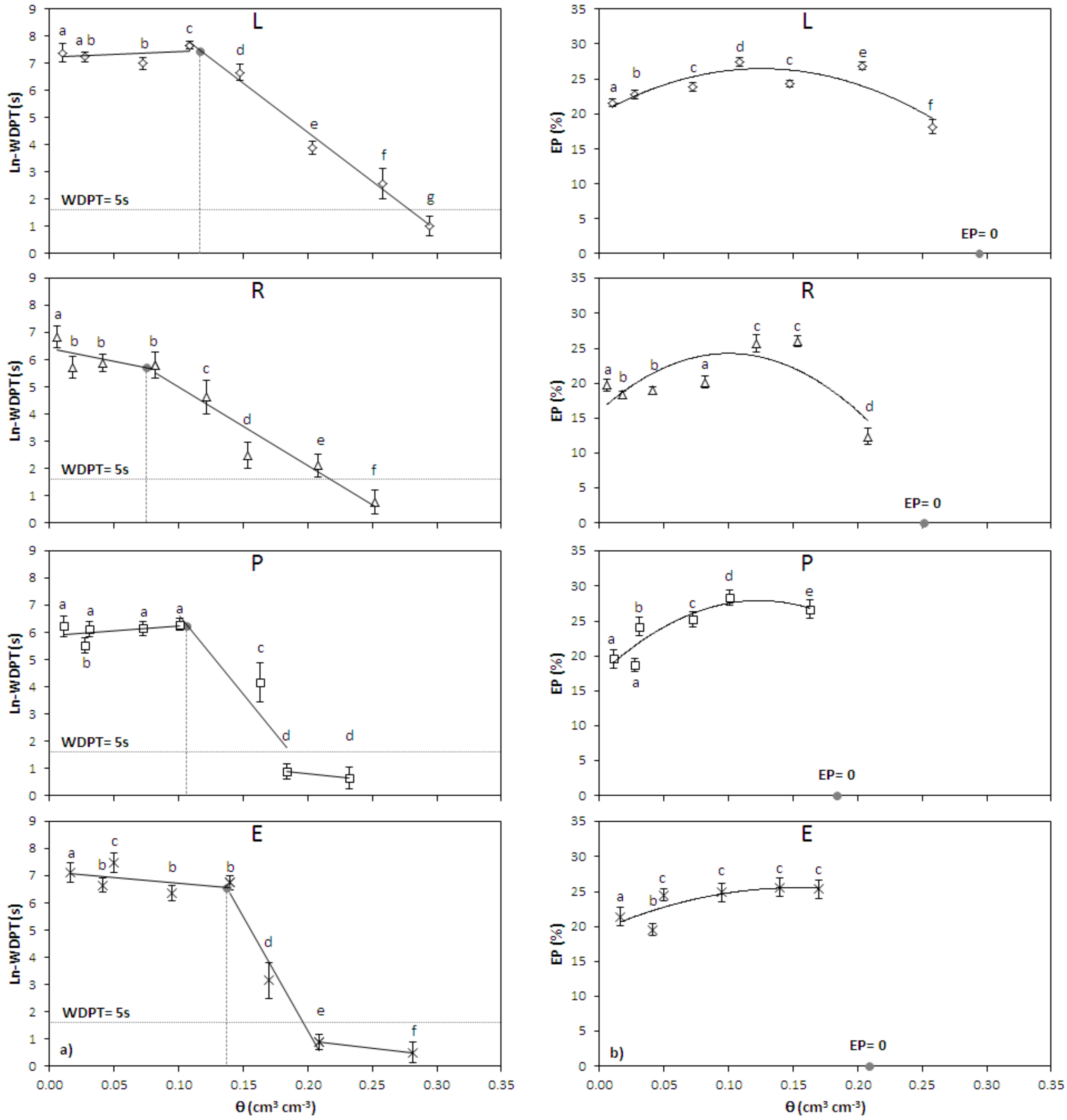

Figure 3.1: Measured WDPT (a) and EP (b) values for different initial soil water contents. Data points in a plot associated to the same letter were not statistically different according to a Tukey HDS test (P = 0.05).

The results of EP test were in agreement with the WDPT ones given that hydrophobicity affected the considered forest soils in the following order: E=P=L>R. However, the degree of WR increased in the θ range up to approximately 0.15 cm^3cm^{-3} and then decreased. In particular, the maximum degree of WR was obtained for a critical water content, CWCM, equal to 0.10 cm^3cm^{-3} for P and L soils and 0.14-0.15 cm^3cm^{-3} for E and R ones (Table 3.1). Beyond these values, the severity of WR sharply vanished to reach the condition EP = 0 for a critical water content, CWCO, varying between 0.18 and 0.29 cm^3 cm^{-3} depending on the considered soil (Table 3.1). In the soils of exotic species (P and E), WR severity vanished before than in native species soils (L and R) confirming the findings obtained by WDPT test (Table 3.1). Significant differences between EP values measured at different water contents were generally found (Figure 3.1b) probably as a consequence of the lower variability of EP data.

However, this last result could also be a consequence of a poor reliability of WDPT test compared to EP one. Particularly at high hydrophobicity levels, the identification of the complete infiltration of a water droplet can be subjective and, therefore, affected by operator's error. Instead, the EP test required a simple assessment of the status of an ethanol drop (completely infiltrated or not) at a given time (t = 5 s) and, therefore, the evaluation of this index is less affected by intrinsic errors.

Table 3.1: Critical water contents identifying the condition of hydrophobicity and wettability according to WDPT and EP tests

	L	R	P	E
CWCH ($cm^3\ cm^{-3}$)	0.117	0.074	0.106	0.137
CWCW ($cm^3\ cm^{-3}$)	0.279	0.218	0.187	0.197
CWCM ($cm^3\ cm^{-3}$)	0.108	0.154	0.100	0.140
CWCO ($cm^3\ cm^{-3}$)	0.294	0.252	0.184	0.209

4. Conclusions

The persistence and the degree of WR on the forest soils of two native and two exotic trees species used in Sicilian reforestation was investigated by WDPT and EP tests. Both of them detected strong or even extreme hydrophobic conditions for water contents corresponding to air-dried condition. The highest WDPT values were measured at low θ contents ($\theta < 0.14$ $cm^3\ cm^{-3}$) but soils rapidly become wettable when θ increased to around 0.19 $cm^3\ cm^{-3}$. Two critical water contents discriminating, respectively, the upper threshold for hydrophobicity and lower threshold for wettability were identified. The relationship between EP and θ showed a maximum in the range of θ values around 0.10-0.15 $cm^3\ cm^{-3}$. For higher θ values (θ = 0.18-0.29 $cm^3\ cm^{-3}$) EP sharply declined to zero. Hydrophobicity in soils of native species persisted at relatively higher water content compared to exotic ones with potential negative effects on water infiltration and availability.

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