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Occurrence and distribution of water repellency in size fractionated coastal dune sand in Sri Lanka under *Casuarina* shelterbelt

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ABSTRACT

The occurrence of water repellency in Sri Lankan soils has not been extensively studied and reported so far. Although most Sri Lankan soils are readily wettable, some soils show water repellent conditions. In this study, we examined a dune sand under *Casuarina equisetifolia* shelterbelt in Sri Lanka. The objectives were to ascertain the occurrence and the distribution of water repellency along the particle size fractions and to perceive the role of intermixed organic material in producing water repellency. The soil type is locally known to be sandy Regosols (USDA classification: Ustic Quartzipsamments). Bulk soil samples were taken from 0–5, 5–10, and 10–15 cm depths. Soil samples were separated into six size fractions by passing through a set of sieves and further separated into two sets as washed (with water) and untreated. Soil organic matter (SOM) content and the water repellency were discretely determined in untreated and washed samples. Water drop penetration time (WDPT) test and modified sessile drop method were used to estimate the water repellency. Despite the low SOM content (<2%), water repellency was extreme (contact angle >118°; WDPT >3600 s) on the topmost layer (0–5 cm) and decreased with increasing soil depth. All the size fractions of the topmost layer showed significantly high repellency compared with those of the other two layers. Both the water repellency and the SOM content showed the highest values in the finest fraction and the lowest in the coarsest fraction. Washing samples with water decreased the WDPT in >96% of all size fractions in the 0–5 cm layer, and by lower proportions in the lower layers. Washing samples significantly decreased the contact angle of most size fractions although the decline did not exceed 15%. Washing with water removed a considerable portion of organic material. Despite the obvious declining through washing, both the SOM content and the water repellency showed the highest values in the smallest particle size fraction. Water repellency in both washed and untreated samples showed a considerably strong positive linear correlation with the SOM content suggesting that water-insoluble hydrophobic organic coatings might not be the dominant factor triggering water repellency in the tested sandy soils.

1. Introduction

Although most soils are considered to be wettable, some are actually water repellent at the surface and in the rhizosphere. Soil water repellency is a dynamic phenomenon which is caused by low-energy surfaces where the attraction between solid and liquid phases is weak. It adversely affects infiltration, evaporation, and erosion (Wallis and Horne, 1992) and has a wide range of implications on soil fertility (Blackwell, 2000), hydrology, and stability (Doerr et al., 2000).

Mineral soil particles are usually thought to be wettable. The appearance and the magnitude of water repellency in soils are expected to be positively related with the soil organic matter (SOM) (Mataix-Solera and Doerr, 2004). Most of the previous investigations around the world have attributed water repellency primarily to coatings on soil particles (Roberts and Carbon, 1972; Leelamanie and Karube, 2009). It is argued that a relatively small amount of hydrophobic organic materials would be sufficient to coat coarse soil particles compared with the fine soil particles (Giovannini and Lucchesi, 1983; Blackwell, 1993) because of the low specific surface area. The general assumption according to which water repellency is associated with coarse-textured soils has been evidenced over the past decades. Still, evidence reported during the recent years have revealed that severe water repellency is not uncommon in soils with considerable clay contents as well (Giovannini and Lucchesi, 1983; Dekker and Ritsema, 1996a, 1996b; Doerr et al., 2005; Rasa et al., 2008; Zavala et al., 2009; Wijewardana et al., 2016), affirming that it is not restricted to soils with sandy nature. Studies on water repellency in size fractionated soils reported a higher degree of water repellency in the finest fraction (De Jonge et al., 1999; Rodríguez-Alleres et al., 2007b; Arcenegui et al., 2008) as well as in all the size fractions (Rodríguez-Alleres et al., 2007b). Using artificially hydrophobized fine sand, González-Peñaloza et al. (2013) reported that the coarser fraction of the sand become more repellent because a limited amount of organic material may cause higher water repellency in coarse-textured soils due to lower specific surface. However, it is understood that mineral particles need not to be individually coated with

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hydrophobic substances to become water repellent. Merely intermixing mineral soil particles with organic materials is capable of inducing severe water repellency in some soils (DeBano, 1969, 1981).

Over the past decades, soil water repellency has been encountered in numerous countries on all inhabited continents (Dekker et al., 1998; DeBano, 2000; Doerr et al., 2000; Kobayashi and Shimizu, 2007; Lichner et al., 2012, 2013a, 2013b; Jordán et al., 2013; Leelamanie and Karube, 2014a, 2014b). Although water repellency has been reported for all major soil types in the world, the occurrence of water repellency in Sri Lankan soils has not been extensively studied and reported so far. Sri Lankan soils are mostly found to be readily wettable, which might possibly be due to low SOM contents resulting from rapid decomposition rates of organic fraction in consequence to the prevailing high temperature and humidity throughout the year.

Soils of many countries in lands covered by Eucalyptus (*Eucalyptus globulus*), Japanese cypress (*Chamaecyparis obtusa*), Casuarina (*Casuarina equisetifolia*), Cluster pines (*Pinus pinaster*) and Scots pine (*Pinus sylvestris*) (Doerr et al., 1998; Lin et al., 2006; Kobayashi and Shimizu, 2007; Lichner et al., 2007; Keizer et al., 2008; Lichner et al., 2013a) have been investigated in particular detail and the occurrence of water repellency has been identified and reported. *Casuarina equisetifolia* is one of the common land covers that can be seen in Sri Lankan coastal sand dunes, which were established as shelterbelts for the protection of beach sides. As revealed by Leelamanie (2014) and Leelamanie et al. (2013), application of dried leaves of *Casuarina equisetifolia* was identified to produce strong water repellent conditions in wettable soils.

The *Casuarina equisetifolia* coastal shelterbelt in Hambantota, Sri Lanka, was implemented in 1986 under a forestry development project funded by the Norwegian Agency for Development Cooperation (NORAD). The main objectives were to reduce the harmful effects of dry winds and dust storms, protect the natural sand dunes, and form a barrier to seawater salt spray. The particular *Casuarina* shelterbelt has become a focal point for discussion, because it was found to be the single area where casualties and material damages were minimum in Hambantota, a city that was totally destroyed by the devastating tsunami disaster in 2004 (Zoysa, 2007).

Although the *Casuarina* shelterbelt along the coastal sand dunes in Hambantota has proven its capacity as coastal vegetation to solve many coastal issues and helped to protect coastal settlements, its hydrophobic aspects and hydrological consequences are still to be studied in detail. The objectives of this study were to examine the occurrence and the distribution of water repellent conditions for a size fractionated coastal dune sand under the *Casuarina equisetifolia* shelterbelt in the dry zone of Sri Lanka, with particular consideration of the role of interstitial organic material on producing water repellent conditions.

2. Materials and methods

2.1. Study area

The study area is a sand dune in the dry zone of Sri Lanka under a thick cover of *Casuarina equisetifolia* (6°06′52″ N 81°05′02″ E). The area falls under the DL5 Agro-Ecological Region (AER). The DL5 AER of the Southern Dry zone is considered as the driest part of Sri Lanka with an annual average rainfall of 900 mm. A considerable amount of rainfall (~70%) of the annual total is limited to the period from mid-October to mid-January, and the remain between mid-March to mid-May. The period from mid-May to September is dry and windy with very high temperatures and evaporation rates. The daytime maximum temperature in this region could vary from 30 to 35°C depending on the time of the year (National Atlas of Sri Lanka, 2007).

The soil type is sandy Regosols according to the local classification and Ustic Quartzipsamments according to the USDA classification system (Soil Survey staff, 2014). Sandy Regosols are found along or proximate to the coastline in Sri Lanka usually as elongated strips. In general, Regosols show no structural development, where both surface and subsurface soils are single-grained. Although normal sandy Regosols show a rapid infiltration and high permeability, the infiltrated water is stored in the underlying static Gyben-Herzberg lens of fresh water, which permits stable human settlement and agricultural production in this region even in the very dry environment (Panabokke, 1996).

The floor of the studied sand dune is covered with a thick litter layer (3–10 cm thickness) of dried *Casuarina* leaves (Fig. 1), where the maximum litter thickness was observed during the driest period of the year. The basic properties measured in triplicates using standard laboratory tests of the studied dune sand are presented in Table 1. The pH (1:2.5 mass/volume ratio) and the electrical conductivity (EC) (1:5 mass/volume ratio) of the soil was measured in deionized water using a pH meter (sensION 1, HACH Company, USA) and an EC meter (sensION + EC5, HACH Company, USA). The soil is slightly alkaline with pH values in the range of 7.6–7.7, and non-saline with EC values in the range of 0.20–0.42 $\mu S\ cm^{-1}$. The bulk density and the particle density of the soils were determined using the core method and the pycnometer method, respectively.

Infiltration rate of the dune sand was determined using the standard double ring infiltrometer test (falling head method), in triplicates (Gregory et al., 2005). The total time needed to reach the steady-state infiltration rate was approximately 40 min. Water entry into the profile was examined using s $0.5 \times 0.5\ m^2$ plots. Thirty liters of water was added to the top of the surface, where the height of submergence was maintained at about 5 cm. After 30 min, the top layer of soil (2–3 cm) was removed to identify the wetted patches, and then a vertical cut was carefully made through the wet patches along the profile to identify preferential flow patterns.

A soil pit was cut to identify the soil horizons. Bulk soil samples were taken from 0–5, 5–10, and 10–15 cm depths separately. Before using for water repellency measurements, each bulk soil sample was air dried and passed through a 2 mm sieve to remove larger rock particles and other debris. Bulk soil samples were further separated into six size fractions (>362, 167–362, 149–167, 92–149, 44–92, and <44 μm) by passing through a set of sieves using a manual dry sieving apparatus (Dry sieve shaker, Humboldt Manufacturing Co., USA).

2.2. Assessment of soil organic matter

The SOM contents of bulk samples and size fractions were measured colorimetrically using the Walkley-Black dichromate oxidation of organic carbon (Nelson and Sommers, 1996) where the SOM contents were up to 6%. The loss on ignition method (400°C, 6 h) was used

Fig. 1. Floor of the studied sand dune, which is covered with a thick layer of *Casuarina equisetifolia* leaf litter.