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Water repellency of soils in the lower Himalayan regions of India: impact of land use

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Although soils are generally considered to wet readily, some are actually water-repellent at the surface. This communication presents the recent progress in relating the severity of water repellency to different soil management practices and land uses under the lower Himalayan region of India. All soils under sal forest, chrysopogon and cropland had less water drop penetration time (<5 s) and therefore were classified as wettable. However soils under eucalyptus plantation and panicum stand showed considerable hydrophobicity. This is considered as being caused by differences in organic matter composition rather than amount of organic carbon. If planted indiscriminately and particularly where there is significant competition for land area, nutrients or water, notable problems can occur under the eucalyptus stand.

Keywords: Environmental implications, land use, soil hydrophobicity, soil infiltration rate, water repellency.

ALTHOUGH soils are generally considered to wet readily under rainfall or irrigation, some soils exhibit a reduced, or no affinity to water (water repellency) at the surface and within the root zone. This phenomenon occurs at low to moderate moisture content and has been reported from soils under a range of vegetation types and from many regions around the globe[1]. Water repellency in soils can have serious environmental implications, including reduced seed germination and plant growth as well as irrigation efficiency, accelerated soil erosion and enhanced leaching of agrochemicals through preferential flow[2–5]. Soils containing a large amount of hydrophobic materials (such as plant litter, residue and microbial by-products) may become water-repellent or less wettable[6,7]. These are generally thought to be present as a coating on soil particles or aggregates[8]. The accumulation of hydrophobic waxes on soil particles[9], humic and/or fulvic acid soil coatings[10] and other long-chained organic compounds on or between soil particles[11,12] are all accepted as factors contributing to this negative-impact phenomenon. Soil water repellency often leads to severe run-off and erosion, rapid leaching of surface-applied agrochemicals and loss of water and nutrient availability for crops. The degree of repellency and wettability is traditionally judged using the water-solid contact angle (γ). A solid is classified as being water-repellent if $\gamma > 90°$ and water wettable if

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$\gamma < 90°$. However, due to gradual breakdown of soil water repellency and granular soil surface condition, direct measurement of the contact angle has not been possible. Presently, many indirect methods are being used to measure soil water repellency. In this communication, we use water entry and sorptivity values as alternative indicators of soil water repellency. Water repellency has been observed in sand, loam, clay and peat soils all over the world[13,14]. Although an increasing number of researchers are aware of the occurrence and consequences of water repellency in a wide range of soils, it is yet to attract adequate attention of the scientists. Information on the effect of land use on water repellency in India is meagre[15]. Since other countries with similar climatic and soil conditions have extensive areas with water repellent soils, it is important to acquire data on the Indian soils for water repellency.

Recent studies suggest that water-repellent soils are the rule rather than the exception in many regions. During the last few years, millions of hectares of water-repellent soils have been identified throughout the world, often as a consequence of their impact on agricultural production. However, little is known about their precise causes and effects along with their actual extent and effective management practices. Consequently, current soil and water management practices in water-repellent regions are far from being efficient and environment friendly. In some arid regions, water repellency has deteriorated so much that agricultural production is impossible without costly amelioration[16]. The objectives of the present study were to investigate the occurrence of potential water repellency in medium-textured soils under different land-use systems in the Doon valley region, India.

The present study was carried out in five land-use systems in the Doon valley region of the lower Himalayas. The Doon valley lies between the Himalayas running on its northeastern side and the Shiwalk range of hills running on its southern side. It is approximately situated between 77°35′–78°19′E long. and 29°57′30″–30°30′N lat., with an elevation between 315 and 2500 m amsl. It has subtropical climate[17] with average annual rainfall varying from 1600 mm (hills and piedmont plain) to 2200 mm (mountainous area), and mean annual temperature of 19.6°C. The two most important rivers of North India, the Ganges and the Yamuna, demarcate its southeastern and northwestern boundaries respectively. Thus the Doon valley forms a sub-catchment for the Ganges and Yamuna river system, which carries the vital water resources to the northern part of the Indian subcontinent. The average width of the valley is about 20 km and the length is nearly 70 km.

Soil samples have been collected under different land-use systems from the Doon valley region under different landscape positions during summer months (May 2006). The land-use systems were selected based upon proximity to different hydrological behaviour. In each sampling area, soil samples were collected from the topsoil with a spade to 15 cm depth for measuring wettability of dry aggregates. The soil texture of the area varies from silty clay loam to silty clay with increase in soil profile depth. There are two prominent soil series, namely Dhulkot and Bainkhala[18]. The Dhulkot soil series (Inceptisols) is derived from heavy-textured, deep alluvium, yellowish-brown to dark yellowish-brown in colour, with few gravel and coarse rock fragments. The Bainkhala (Entisols) soil series has originated from the recent alluvium of stream-bed material. Cobbles forming 15–60% are present throughout the soil profile. The bulk density (ρ_b) was measured by the core method[19]. The infiltration rate was measured by double-ring infiltrometer using the water-ponding method. Organic carbon content was determined by Walkley and Black method. Some relevant information about different land-use stands is presented in Table 1.

Soil water repellency is determined in this study with the empirical water drop penetration time (WDPT) test described by several investigators. Soil aggregates of 10 mm size (5–15 mm) were selected from the 2–25 mm fraction, which had been separated by dry sieving soil samples from the topsoil (0–15 cm depth). Drops of 100 ± 5 μl of de-ionized water were deposited on the surface of individual soil aggregates, and the time for penetration was recorded[20]. Measurements were repeated for 100 aggregates per land-use treatment. Aggregates were considered hydrophilic if <5 s was necessary for water penetration, and hydrophobic if ≥5 s was necessary for water penetration[7,8,21]. A soil is considered to be water-repellent[22–24] if the WDPT exceeds 5 s.

The water entry values and calculated apparent contact angles with different degrees of water repellencies are given in Table 2.

Sorptivity was calculated according to Philip's equation given below[25].

$$I = St^{1/2} + At, \tag{1}$$

$$\frac{dI}{dt} = i = \frac{1}{2} S^{t-1/2} + A, \tag{2}$$

where I is the cumulative depth infiltrated t the time (min), i the infiltration rate, S the sorptivity (cm min$^{-0.5}$),

Table 1. Land use descriptions

Land use	Description
Sal forest (*Shorea robusta*)	60-yr-old dense natural forest along with associates
Eucalyptus plantation (*Eucalyptus* sp.)	27-yr-old forest with density of 1600 tree ha^{-1}
Golda grass (*Chrysopogon fulvus*)	15-yr-old pasture
Guinea grass (*Panicum maximum*)	15-yr-old pasture
Cropland	Mature agricultural land under maize–wheat rotation

which indicates the capacity of a soil to absorb water, A the transmissivity (cm/h) and q the infiltration rate (cm/h).

If I is plotted against $t^{1/2}$, then a linear relationship is usually found. Soil sorptivity can be measured as the slope of the linear relationship and has units cm $\text{min}^{0.5}$.

The ranges of original soil properties of the representative sites are presented in Table 3. The distribution of native soils in the landscape, generally influenced by erosion, geological substrate and altitude, permitted the identification of various environments. However, some characteristics of soils under investigation are influenced by management practices, including land-use type. Soil depth is medium to a depth of 60–90 cm for chrysopogon and panicum grassland areas, respectively. Cropland had deep (90 cm) to very deep (>150 cm) soil depth, whereas sal forest had a maximum 150 cm soil depth. However, soil depth varied from 45 to 150 cm under eucalyptus plantation. Bulk density varied from 1.12 to 1.42 mg m^{-3}, with mean values of 1.20 to 1.40 mg m^{-3} (Table 3). Natural sal forest had significantly smaller bulk density than all other land-use systems because of less compaction and high concentration of organic carbon (1.94–2.31%). Cropland agriculture land use had significantly greater bulk density with a range of 1.36–1.42 mg m^{-3} (mean of 1.40 mg m^{-3}) than the forest stand, eucalyptus stand and grassland (except panicum stand) because of compaction caused by tillage and other agricultural operations. Organic carbon (OC) content ranged from 0.60 to 3.07% (Table 3). OC content varied greatly within each land-use group, so that the mean values were significantly different from each other. However, the significantly higher values of OC in natural sal forest and eucalyptus plantation area are probably because of a more rapid recovery of the natural vegetation, less erosion and slower oxidation of the new organic material.

Table 2. Water drop penetration time (WDPT) test

Water repellency	WDPT (s)	Apparent contact angle (°)
Wettable	<5	0
Slightly to moderately repellent	5–60	67
Strongly water-repellent	60–600	90
Severely water-repellent	600–3600	98
Extremely water-repellent	>3600	122

The WDPT test consists of randomly applying water drops (100 ± 5 μl) onto the soil surface and measuring the time (in sec) it takes to infiltrate the soil.

The infiltration rate followed the order sal forest > chrysopogon > panicum > cropland > eucalyptus plantation, with higher values (2.4–3.07 cm h^{-1}) in natural sal forest. The influences of land use were insignificant between the two grasslands. The differences in infiltration rate were probably due to a combination of both farming practices and inherent soil characteristics. The most obvious effect of water repellency is a reduction of infiltration rate. The result was in accordance with the findings of Lal[26].

The pH varied from 5.8 to 6.7 for the whole region. The mean pH value differed significantly between the land-use systems, except between the grasslands. The pH differed significantly among the land-use systems. The soil pH of natural woodlands and eucalyptus plantation was significantly lower than that of the remaining land-use systems. This indicates that natural woodlands have caused soil acidification. Appreciable difference was observed in terms of electrical conductivity (EC) among the land uses. EC ranged between 0.04 and 0.33 dSm^{-1}, with significantly higher values in the eucalyptus stand (0.26–0.33 dSm^{-1}). The substantial decrease in EC, infiltration and OC content in croplands indicates that the process of accelerated erosion is the principal cause of surface soil property changes in these areas. The soil characteristics most sensitive to land use, showing significant differences at 0.05 probability level with respect to the reference sal forest, were soil pH, OC, infiltration rate, bulk density and EC. Water repellency in soils can result in a

Table 3. Soil characteristics of different sites

Soil characteristics	Sal forest	Eucalyptus plantation	Panicum grass	Chrysopogon	Cropland
Soil depth (cm)	>150	45–150	90	60	90–150
Soil texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Silty loam
Bulk density (mg m^{-3})	1.12–1.26 $(1.20 \pm 0.05)^{a}$	1.26–1.38 $(1.33 \pm 0.05)^{b}$	1.38–1.42 $(1.39 \pm 0.02)^{c}$	1.32–1.38 $(1.34 \pm 0.03)^{b}$	1.36–1.42 $(1.40 \pm 0.03)^{c}$
Infiltration rate (cm h^{-1})	2.4–3.07 $(2.78 \pm 0.27)^{a}$	0.4–0.9 $(0.64 \pm 0.18)^{b}$	0.9–1.5 $(1.12 \pm 0.24)^{c}$	0.91–1.73 $(1.23 \pm 0.36)^{c}$	0.72–0.92 $(0.81 \pm 0.9)^{b}$
Organic carbon (%)	1.94–2.31 $(2.04 \pm 0.15)^{a}$	2.66–3.07 $(2.84 \pm 0.14)^{b}$	0.09–1.38 $(1.10 \pm 0.17)^{c}$	0.76–0.88 $(0.82 \pm 0.04)^{d}$	0.6–0.72 $(0.65 \pm 0.04)^{e}$
pH	6.1–6.3 $(6.2 \pm 0.08)^{a}$	5.9–6.1 $(6.0 \pm 0.1)^{b}$	6.4–6.6 $(6.5 \pm 0.8)^{c}$	6.5–6.7 $(6.6 \pm 0.1)^{c}$	5.8–5.9 $(5.8 \pm 0.08)^{d}$
EC (dSm^{-1})	0.08–0.15 $(0.01 \pm 0.02)^{a}$	0.26–0.33 $(0.28 \pm 0.03)^{b}$	0.18–0.20 $(0.19 \pm 0.007)^{c}$	0.12–0.18 $(0.14 \pm 0.02)^{d}$	0.04–0.07 $(0.05 \pm 0.01)^{e}$

Values in parenthesis are mean ± SD.
Different letters in the same row are significantly different at $P < 0.05$.

Table 4. Sorptivity parameter of Philip's equation in different land use systems

Land use	Philip's sorptivity parameter *S* (cm min$^{-0.5}$)
Sal forest	22.3 ± 2.8
Eucalyptus plantation	2.2 ± 0.3
Panicum grass	2.8 ± 0.4
Chrysopogon	3.6 ± 0.5
Cropland	3.16 ± 0.5

Values are mean ± SD.

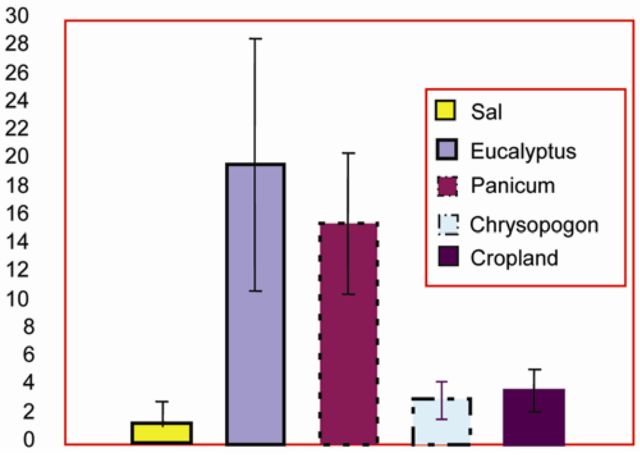

Figure 1. Water drop penetration times (s) of soils under different land uses.

number of problems caused by poor water movement patterns and subsequent accumulation of salt on surface soils. These dynamic soil attributes could be used as indicators of the ability of soils to carry out bicycling, storage and release of nutrients and buffering of soil solutions.

Wettability measured by the WDPT was significantly different in soils under eucalyptus plantation than from all other land-use except panicum grass (Figure 1). All soils under sal forest, chrysopogon and cropland had WDPT <5 s, and therefore were classified as wettable[27]. However, soils under eucalyptus plantation and panicum stand had shown considerable hydrophobicity. Higher water repellency was measured in the topsoil of eucalyptus with WDPT of 12–35 s and panicum with WDPT of 12–24 s compared with other land-use systems. Both stands showed higher WDPT under dry soil conditions, with eucalyptus presenting higher values of soil water repellency (Figure 1). This was pointed by Shakesby *et al.*[28] as a major factor in overland flow production and erosion yield. Differences in water repellency were suggested to be due to differences in the OC content induced by differences in land uses. When the water repellency and OC content were compared the result was not different, indicating that there was no systematic difference in the capacity of organic matter to induce water repellency in the research region. It appears that it is the nature of OC rather than its amount which is important in determining the adversity of water repellency[29]. Water repellency is considered to be particularly strong within the eucalyptus stand. It is therefore one of the major environmental changes arising from the current shift from traditional Bhimal (*Grewia optiva*) plantation to eucalyptus. Sorptivity (s) parameter of Philip's infiltration equation varied from 2.2 ± 0.3 cm min$^{-0.5}$ in eucalyptus stand to 22.3 ± 2.8 cm min$^{-0.5}$ in soils under sal forest stand (Table 4). Sorptivity values and infiltration rate clearly showed that sorptivity had a major influence in the process of vertical infiltration. It follows that it may be possible to manage water repellency by management practices, including selection of species[30].

Comparing the impacts on soil wetting pattern, infiltration rate and sorptivity under mature stands, it has been observed that the water repellency in soils from eucalyptus stands includes a significant impact on infiltration rates, and water repellency has also directly affected the infiltration, sorptivity and EC. This situation may cause soil loss through erosion, reduction in hydrological values, make the soil allelopathic to crops; create a poor habitat for wildlife, and have a negative impact on the landscape. As soil water repellency can lead to the development of unstable wetting and preferential flow paths, indiscriminate planting of eucalyptus in areas where significant competition is observed for land area, nutrients and water needs to be avoided. Future research is needed for a thorough assessment of the problem taking due account of spatial and temporal variations.

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Salinity status of tsunami-affected soil and water resources of South Andaman, India

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The 2004 tsunami has created havoc and excessive devastation in terms of human lives and loss of infrastructure in coastal areas of Andaman and Nicobar Islands, and rendered the soil and water resources salt-affected. In order to assess the changes in the relevant soil characteristics, viz. pH, electrical conductivity, sodium adsorption ratio, soluble cations (Na^+, Ca^{2+} and Mg^{2+}) and anions (CO_3^{2-}, HCO_3^-, SO_4^{2-} and Cl^-), periodical soil and water sampling was done from selected soil series/locations of South Andaman. The results revealed that irrespective of soil series and water resources, the soluble salt concentration increased markedly post-tsunami (2005), making the soil highly saline/saline sodic. However, high rainfall during the subsequent years (3774 mm in 2005 and 3072 mm in 2006) has drastically reduced the salinity levels at these sites to almost close to the pre-tsunami levels. The results indicate the gradual recovery process of the salt-affected sites, which can be further augmented by adoption of appropriate location-specific engineering and agronomic management strategies.

Keywords: Soil salinity, soluble salts, tsunami, water resources.

SOILS turn saline generally due to weathering of parent materials (causing fossil or primary salinity), or from anthropogenic activities involving the improper management of land and water resources (contributing to man-made or secondary salinity). Until recently, the occurrence of large-scale soil salinity due to natural disasters like the tsunami was thought to be a rare phenomenon. However, nature's fury in the form of a massive tsunami triggered by the 26 December 2004 earthquake has created devastation not only in terms of human lives and loss of infrastructure in the coastal areas of the Andaman and Nicobar (A&N) Islands, but also caused complete submergence of adjoining agricultural fields and plantations, and rendered the soil and water resources, including ponds and dug wells salt-affected. The direct environmental impact of the tsunami varied according to differrent factors, notably bathymetry and geomorphology of the coastline[1]. Thus, areas adjacent to the relatively steep continental shelves

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