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Oration

Water repellent Soils: Origin, Characteristics, and Significance in Sri Lankan context

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Introduction

In general, dry soils readily absorb water. Usually a strong attraction exists between mineral soil particles and water. However, all soils do not exhibit these wettable characteristics, as some soils may repel water. A water repellent soil can be defined as a soil that does not wet spontaneously when water is applied on the surface.

When placed on a water repellent soil, water just remain on the surface or runs off instead of soaking into the soil. Reduced water entry, or the infiltration, into water repellent soils will consequently lead to increased surface runoff and topsoil erosion, contributing to the land degradation. In addition, water repellency induces the development of fingered or preferential flow paths, and creation of unstable, irregular wetting fronts. As a result of reduced infiltration, getting the required water into the root zone becomes a major problem. Less availability of water in the root zone retards plant growth, reducing the quantity and the quality of crop production. In contrast to its negative impacts, water repellency (hydrophobicity) of soil aggregates reduces their affinity for water. Reduction of the rate of water entry into the aggregates may help in hampering the pressure buildup within aggregates, improving their stability against slaking.

Causes of water repellency in soils

Soil water repellency is a dynamic phenomenon that is caused by low-energy surfaces where the attraction between solid and liquid phases is weak (Heslot et al. 1990). If molecules of a liquid surface have a stronger attraction to molecules of a solid surface than to each other, surface wetting occurs. Alternatively, if liquid molecules are more strongly attracted to each other than to molecules of solid surface, liquid beads up and repellency appears.

Mineral soil particles are generally proved to be wettable in nature. Water repellency of soil is a function of the type of the organic matter incorporated in it (Leelamanie and Karube, 2009a). Organic matter induces water repellency in soils by (1) drying processes in organic matter. which make it difficult to rewet after drying (Ex. surface layers of peat soils); (2) coatings of hydrophobic plant decompositional, microbial, or

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fungal by products around mineral soil particles (3) intermixing of mineral soil particles with particulate organic matter, such as remnants of roots, leaves, and stems.

Water repellency in soils tends to be spatially and temporally highly variable making its numerous effects difficult to observe and to predict under natural conditions. It varies non-linearly with soil water content and is generally found to be most extreme when soils are air-dried, declining to be eventually disappeared as soils become wet. As a result, water repellency is often most prominent after prolonged dry spells and usually disappears as the surface water content increase due to prolonged contact with water.

Occurrence of water repellent soils

Water repellency in soils is a widespread phenomenon that has been known for many years. It was first described by Schreiner and Shorey in 1910, who found that some Californian soils were not suitable for agricultural purposes because they are not wettable.

Researchers claim that coarse textured sandy soils are more likely to become repellent as they have a relatively low surface area compared with finer materials. However, according to recent findings, water repellency is reported in sandy, loamy, and clayey textured mineral soils and peat, at least to some extent. There are indications that under certain conditions all soils may exhibit water repellency, only with the degree of water repellency being variable.

Although water repellent soils are commonly found in drier parts of the world, it has more recently been reported from much wetter countries. The occurrence of soil water repellency has now been recognized in various parts of the world including Australia, India, Canada, Egypt, Japan, Italy, Poland, The Netherlands, New Zealand, Africa, Spain, Portugal, Colombia, the USA, Greece, United Kingdom, and most recently in Sri Lanka.

Experimental

Until the mid 1980's, most studies related to soil water repellency had been conducted in regions in the world with the Mediterranean, semi-arid/Mediterranean climates where its symptoms are most prevalent. Research on soil water repellency has gathered significant momentum to the subject in the last several decades.

Compilation of our research

Reports on individual effects of factors affecting water repellency are not always consistent. Therefore, experiments were conducted to assess the combined effects of organic compounds, water content, and clays on soil water repellency (Leelamanie and Karube, 2007, 2009a, 2011; Leelamanie et al. 2010).

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Many techniques are available to measure the water repellency of soils, such as water drop penetration time (WDPT), capillary rise method (CRM), molarity of an ethanol droplet (MED), and ninety-degree surface tension (Wallis and Horne 1992). Experiments were carried out to compare the contact angles obtained using three different techniques, to examine the relationship between contact angle and WDPT, and to determine the effects of relative humidity (RH) on this relationship (Leelamanie et al., 2008a,b) and water repellency (Leelamanie 2010).

Soil water repellency exhibits temporal variability (Dekker et al. 2001). The time dependence of repellency has been attributed to reductions in liquid surface tension due to soil-water surface interactions (Goebel et al. 2004). The WDPT determines how long water repellency persists in the contact area of a water droplet. Therefore, the time dependence of the contact angle and its relation to the repellency persistence were studied (Leelamanie and Karube, 2009b).

Droplet shape and the dynamics of its spreading play an important role in science and technology. Almost all the reported findings in literature on contact angle as a function of drop size are on smooth, planar, and homogeneous solid surfaces (David et al. 2009; Gajewski 2008) or artificial heterogeneous surfaces (Yang et al. 2009). Experiments were conducted to determine how the soil-water contact angle varies with drop size, considering its relation to the droplet geometry and line tension (Leelamanie and Karube, 2012).

Dissolved salts in irrigation water cause numerous challenges in the agriculture sector. All irrigation water contains dissolved mineral salts with varying concentration and composition of salts. An experiment was carried out to examine the effects of aqueous electrolyte concentration on soil-water contact angle using aqueous solutions of NaCl and $CaCl_2$ (Leelamanie and Karube, 2013).

Topsoil erosion linked with slaking and mechanical breakdown of aggregates due to their rapid wetting rates is a major problem in the low country wet zone of Sri Lanka, which is characterized by the hot humid climate. Experiments were conducted to examine the effect of hydrophobicity on reducing wetting rates and improving stability of aggregate in Sri Lankan red yellow podzolic soils amended with organic manure (Leelamanie et al. 2013) and Japanese Andisols (Leelamanie and Karube 2014a). Furthermore, surface hydrophobicity of Japanese Andisol and its behavior on exposure to heat were studied (Leelamanie and Karube 2014b) as heating of potentially water repellent soils is known to influence their wettability

One option to mitigate global climate change caused by elevated atmospheric CO_2 is to improve the capacity of soil to act as a carbon sink (Lal et al., 2007), which may be achieved through reduced mineralization of organic carbon in soils. An experiment was

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done to examine the relation of initial water repellency to organic matter depletion rates of soils (Leelamanie, 2014a).

Discussion

Factors affecting water repellency:

Effects of Organic matter

Presence of hydrophobic organic matter in soil causes extreme water repellent conditions, whereas hydrophilic organic matter induces only slight water repellency (Leelamanie and Karube, 2007). Results confirmed that both hydrophobic and hydrophilic organic matter increases soil-water contact angle, where the effect is stronger with hydrophobic matter. We found that the hydrophobic / hydrophilic organic matter ratio and the total organic matter content would not provide satisfactory information about soil water repellency (Leelamanie and Karube, 2009a).

Effects of water content and clay

In general, soils are non-repellent at high water contents near saturation and become repellent with drying at a marginal water content that is specific to a particular soil. Further drying increases the soil water repellency to a maximum level and extreme drying decreases the repellency to a lower level (Leelamanie and Karube 2007). At air-dried condition, water repellency increases with increasing RH (Leelamanie et al. 2008b).

We found that both the marginal water content at which water repellency appeared with drying and the highest water content at which soils reach maximum repellency increased with increasing clay content. In contrast, the lowest water content at which soils indicate maximum repellency was independent of the clay content, showing that the water-dependent repellency curve expanded towards the higher water content with the increase in clay content (Leelamanie and Karube 2009a, 2011; Leelamanie et al. 2010).

Other factors affecting contact angle

Contact angle in soils can be defined as the angle measured through the liquid, where a liquid/vapor interface meets a solid surface. When the soil–water contact angle is greater than 90°, a positive pressure is required for water to penetrate into the soil (Carrillo et al. 1999; Feng et al. 2001). We found that the contact angle decreased exponentially to reach an apparent equilibrium with soil–water contact time. Time dependence of the contact angle is attributed mainly to the adsorption of water molecules onto surfaces of low-energy organic compounds (Leelamanie and Karube 2009b). Contact angle decreases with increasing drop size, due to the effect of line tension, however, increases with increasing drop size when deformation of the drop occurs due to the effect of

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gravity (Leelamanie and Karube 2012). Presence of electrolytes in water also changes the contact angle. Increased contact angle with increasing electrolyte concentration was attributed to the increasing surface tension of the aqueous solutions (Leelamanie and Karube 2013).

Negative impacts of water repellency

Wettability of soils is important for many processes concerningthe interactions of soil and water. The initial rate of water uptake in a wettable soil is rapid because of the strong attraction between water and dry mineral soil particles. As a wettable soil getting gradually wet, the hydraulic gradient starts to decrease and the infiltration rate starts to decrease.

Conversely, a dry water repellent soil strongly resists water penetration at the initial stage. The initial infiltration rates in such soils are extremely slow, even nonexistent in case of extremely repellent soils. If water remains in contact with the repellent soil, generally the infiltration slowly increases, probably because water vapor advances into the soil get adsorbed on isolated wettable organic and inorganic sites, and change the original water repellency. Once saturated, the repellent soil allows the infiltration almost as rapidly as in a wettable soil, although some entrapped air in the water repellent soil may slightly lower the hydraulic conductivity (Leelamanie 2014b).

Slight or 'subcritical' water repellent conditions in soils have to be carefully monitored and recorded to identify its overall hydrological impacts. Actual water infiltration is reported to be impeded by subcritical water repellency despite the soil appearing to wet readily. This is referred as 'water resistance' and expected to influence almost all the surface soils (Woche et al. 2005). Water resistance in agricultural soils has been detected in many areas in the world, where the greater levels of water resistance have been detected from soils in drier climates (Wallis and Horne 1992; Doerr et al. 2000)

Positive impacts of water repellency

By reducing the rate of infiltration into the aggregates, water repellency helped in reducing the aggregate disruption by slaking. Hydrophobic organic matter has greater effect over hydrophilic organic matter in improving aggregate stability (Leelamanie and Karube, 2014a; Leelamanie et al., 2013). On the other hand, too much hydrophobic aggregates will float in the accumulated water on the soil surface, consequently increasing the top soil erosion. Extreme hydrophobicity will reduce infiltration rates, affecting hydrological processes in soils. Therefore, care should be taken not to exceed this critical hydrophobic condition.

Hydrophobic protection may prevent rapid microbial decomposition of SOM and it is conceivable that hydrophobic substances in appropriate composition may reduce organic

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matter mineralization in soil. Hydrophobic organic substances are found to contribute in bioresistance of SOM and their long-term accumulation in soils (Leelamanie 2014a).

However, improving aggregate stability or reducing the rapidness of SOM decomposition using hydrophobic organic matter is not as simple a process as it appears to be. Addition of hydrophobic materials may affect the hydrological balance of the soil. If aggregates are too much hydrophobic, the accumulation of water on the soil surface will make them float, consequently increasing topsoil erosion by aggregate floating with runoff water (Poulenard et al. 2001). This is, in fact, in addition to the negative impacts that a highly water-repellent soil would. Therefore, when introducing hydrophobicity to improve aggregate stability and to reduce SOM depletion, the amount of incorporating hydrophobic organic matter has to be minimized to the greatest extent possible.

Management of water repellent soils

Water repellency is a consequence of the decomposition of organic matter, which is an essential component of a healthy soil. Availability of organic matter is of vital importance for non-repellent soils with very high wetting rates to improve the stability of aggregates. Entire removal of these organic materials from soil system is not a practical solution. However, it is essential to control organic matter build up in potentially water repellent soils to maintain adequate infiltration and drainage.

At present, no optimum management strategies exist for water repellent soils that should be focused mainly on minimizing environmental hazards of soil water repellency while maintaining higher crop productivity. Addition of clays and surfactants are considered to be possible ways for the amelioration of water repellency. Mixing repellent soils with wettable soils (Jamison 1945) and inducing the biological degradation of organic coatings (Franco et al. 2000) has been suggested as methods of reducing repellency.

There is great scope to develop amelioration strategies to combat water repellency in the developed countries where advanced research is being conducting on water repellent soils commonly found on agricultural fields. These include more effective soil management, the addition of clays to increase particle surface area, tillage to break-up and abrade hydrophobic surfaces and the use of chemical wetting agents (Wallis & Horne 1992). Wetting agents are already used extensively in horticulture and their use in agriculture is increasing (Feng et al. 2002; Hopkins and Cook 2005). More expensive wetting agents are also used extensively for improving water infiltration and retention in amenity soils (Mitra et al. 2006). As the cost of water increases, the use of wetting agents in larger scale agricultural operations likely to become more attractive. However, as a developing country, the possibility and the ability of using these high cost techniques would not be a great support for Sri Lankan farmers.

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Fortunately, most Sri Lankan arable soils are still not showing water repellent conditions. Nevertheless, addition of higher amount of organic manure (30-40 tons/ha) is common in upcountry of Sri Lanka, threatening to the hydrological balance with possible reduction of infiltration rates due to subcritical water repellent conditions. Therefore, it would be more reasonable to concentrate on preventing of developing strong water repellent conditions in Sri Lankan arable lands.

Sri Lankan context

Water repellent soils are not commonly found in Sri Lanka. Most soils in the low country wet zone and some soils in the low country dry zone, and the upcountry wet zone of Sri Lanka, including wet zone forest soils are been identified not to be repellent. Most of these soils are characterized by extremely rapid wetting rates.

Sandy soils along the coastlines with land covers such as Eucalyptus globulus Labill., Pinus pinaster Ait, and Scots pine (Pinus sylvestris) (Lichner et al. 2013) are reported for the occurrence of water repellency. *Casuarina equisetifolia* is one of the common land covers that can be seen in Sri Lankan sand dunes, which were established as shelter belts in protection of coastlines. Dried leaves of *Casuarina equisetifolia* show strong water repellent conditions (Leelamanie et al. 2013).

Casuarina equisetifolia coastal shelterbelt in Hambantota City, 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 effect of dry winds and dust storms, protect the natural sand dune, and form a barrier to seawater salt spray. Dune sand under this *Casuarina* coastal shelterbelt is characterized by extreme water repellent conditions on the surface (Leelamanie 2014b). Although the *Casuarina* shelterbelt has proven its capacity as coastal vegetation to solve for many coastal issues and helped to protect coastal settlements, its hydrophobic aspects and the ultimate impacts to the hydrological balance have to be studied in detail.

Apart from the dune sands in low country dry zone, water repellent soils are observed under *Pinus caribaea* forests in upcountry wet and intermediate zones of Sri Lanka. Presence of thick mat of leaf litter on the surface is a common feature of both up and low country water repellent soils. Further investigations are required on water repellent soils of the upcountry.

Conclusions

Although soil water repellency is a subject that has been studied by researchers in different parts of the world over many decades, comparatively little is known to date about its precise causes, characteristics, the actual extent of water repellent soils in the

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world, and effective management practices in most areas of the world. Consequently, current soil and water management practices that are being used in water repellent regions are mostly far from being efficient and environmentally friendly.

However, most of the areas in Sri Lanka are still to be tested for the identification of water repellent soils and only a limited amount of information is available on the distribution of water repellent soils. A detailed survey of water repellent soils related to the soil classification system is needed to provide information on the distribution of water repellency. The occurrence of water repellency in Sri Lankan soils is therefore yet to be explored in advance.

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