EFFECTIVENESS OF WETTING AGENTS FOR IRRIGATING SANDY SOILS

The improved wettability was short-lived, often decreasing within a week

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Abstract

Soil hydrophobia, or water repellency, in the coarse sand typical of the Swan Coastal Plain in Perth in Western Australia is common, leading to reduced water infiltration. The main practice recommended to alleviate water repellency is the use of wetting agents, most of which are surfactant-based. Five commercial wetting agents were evaluated for their effects on water infiltration into samples of native sandy soils. Capillary rise and double-ring infiltrometer methods were used for this purpose.

The infiltration of water was somewhat improved with the application of wetting agents, but this was short-lived and, when measured a few days later, was similar to or lower than the infiltration in the untreated sand. These findings raise questions on the efficiency of surfactant-based wetting agents to treat water-repellent soils. Further investigation into the interaction and adsorption between surfactants and soil particles is needed.

Keywords: Wetting agents, water repellent soils, infiltration, capillary rise.

Introduction

Soils of the Swan Coastal Plain in Perth in Western Australia are typically characterised as coarse sands with low moisture-holding capacity. Soil hydrophobia, or water repellency, is also common. It is estimated that more than five million hectares of western and southern Australian soils exhibit severe water repellency, which often results in uneven water distribution in the soil profile, reduced plant growth, patchy and uneven plant emergence, water ponding and enhanced runoff and erosion (Blackwell, 1996). The sandy soils are more prone to water repellency, as it takes less hydrophobic material to coat relatively large particles compared to silt or clay (Karnok & Tucker, 2002).

Water repellency is generally considered to be the result of coating by a range of hydrophobic organic materials which have non-polar sections such as humic acids, plant waxes (for example, fatty acids, alkanes and alcohols), fungal hyphae and others that are adsorbed onto the surface of sand grains as demonstrated in Figure 1 (Ritsema and Dekker, 1994; Karnok and Tucker 2004).

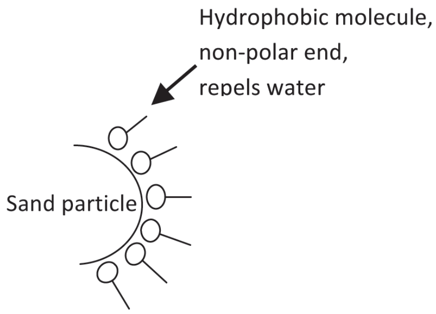

Figure 1: Schematic representation of a sand particle with hydrophobic organic coating.

The most common strategy for alleviating soil water repellency in gardens around Perth is to apply surfactant-based wetting agents, and there are a number of products available on the market in both liquid and granular forms. Wetting agents are strongly promoted by the Western Australia Water Corporation, as well as by the nursery garden industry and horticultural media, as being the most effective means to improve soil wettability (Water Corporation, 2010). For example, the Water Corporation suggests in its website the following: "…a soil wetting agent should be applied during the planting or laying process and again at regular intervals to prevent soils becoming non-wettable … Soil wetting agents should be applied to sandy soils at the start of the winter rains, in early summer and again as recommended by the manufacturer…".

Surfactants (surface-active material) are organic molecules that have a "hydrophobic tail" and a "hydrophilic head" (Figure 2). When in solution, they reduce the surface tension and attraction of water molecules to each other, which is likely to increase the downward movement of water through the soil (providing there is subsurface drainage).

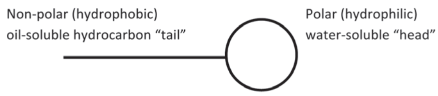

Figure 2: Schematic representation of surfactant molecule.

Theoretically, when a surfactant-based wetting agent is added, with water, to the soil, the non-polar portion bonds with the non-polar organic coating, while the polar portion of the wetting agent surfactant faces the pores, thus allowing the soil or sand particle to wet (Figure 3). As long as there is sufficient wetting agent bonding with the organic coating, the soil or sand particle is not expected to be water-repellent (Karnok and Tucker, 2004).
It was also noted that in the absence of water-repellent soil, a wetting agent would have little effect on the soil itself.

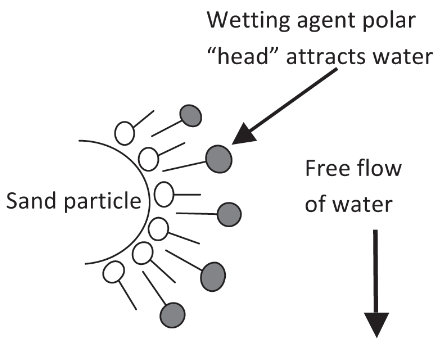

Figure 3: The theoretical mode of action of a wetting agent to alleviate water-repellent soils.

The effectiveness of different wetting agents in improving soil wettability has been demonstrated in several studies (for example, Miyamoto, 1985, Throssell, 2005 and Karnok, 2006). However, other observations have demonstrated that the coating of sand by anionic and non-ionic surfactants resulted in enhanced water repellency (Wiel-Shafran *et al*., 2005).

The authors suggested that even at the low concentration of 10mg/kg of anionic and non-ionic surfactants significant water repellency was observed. Although not directly tested, it was suggested that in contrast to the theoretical mode of action (Figure 3), the hydrophilic head is attached to the sand surface, leaving the hydrophobic tail facing the aqueous phase. In other words, the surfactant molecule behaves just like natural hydrophobic molecules once absorbed on the sand, thus enhancing its hydrophobicity. Therefore, the aim of this current study was to test the potential effect of commercial surfactant-based wetting agents on soil water-repellency.

Materials and Methods

The efficiency of five commercial wetting agents (two granular and three liquid-based products) was tested by studying their effect on capillary rise and infiltration of water into typical native, partly hydrophobic, sand that is used for gardening in Perth, WA. About 1m^3 sand was collected from a garden area at Murdoch University. The soil was sieved using a 2.0mm sieve and re-mixed. A representative subsample was dried (105^{0}C) and characterised. The sand properties are summarised in Table 1. Note the low content of clay and silt.

Capillary Rise Experiments

The effect of surfactants and wetting agents on capillary rise was determined on a subsample by laboratory experiments according to a procedure suggested by Wiel-Shafran *et al*. (2006). A number of polypropylene tubes (length 295mm, internal diameter 38mm) were used and their bases covered with a fine mesh net. The columns were then packed with the native sand (control), native sand that was pre-coated with product D (one of the commercial wetting agents), native sand that was pre-coated with anionic surfactant, *Linear Alkylbenzene Sulfonate* (LAS), and native sand that was burned in a muffle furnace for four hours at 450^{o}C to remove the organic matter. Each experiment was replicated four times. Coating the sand with wetting agent was done by mixing at a volumetric ratio of 2:1 sand to wetting agent solution that was prepared according to the manufacturer's instructions. The sand was then dried in 105^{o}C overnight, and packed into the columns. Similarly, sand was pre-coated with 100 mg/L LAS surfactant solution.

The columns were attached to a stand and placed on a balance, as illustrated in Figure 4. An open reservoir containing tap water was then raised beneath the column until the water surface touched the bottom of the column. As a measure for water repellency, capillary rise was assessed as the weight of water rising in the column. The weight change was recorded with a data logger once every five seconds.

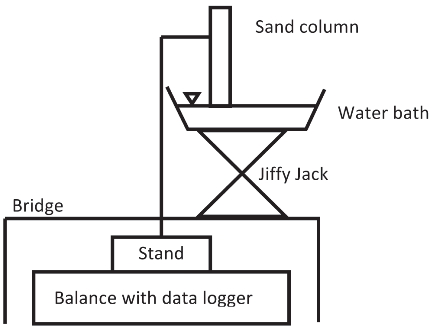

Figure 4: Illustration of the capillary rise experimental set-up.

Measurement of Infiltration Rate using a Double-Ring Infiltrometer

Experimental procedure

This procedure was conducted to mimic common irrigation practice of large pots.

The mixed, sieved sand (50L into each barrel) was introduced into 18 plastic barrels (length 650mm, inner diameter 420mm, height 470mm). Barrels were shaken after each sand load was introduced to settle the sand. The infiltration rates were measured by the double ring infiltrometer technique, as commonly used to evaluate the saturated infiltration rate in soils (Lai and Ren, 2007) and illustrated in Figure 5. Two 22 cm high plastic rings were driven concentrically 10 cm deep into the soil with minimum soil disturbance. The outer and inner ring diameters used were 170mm and 83mm respectively.

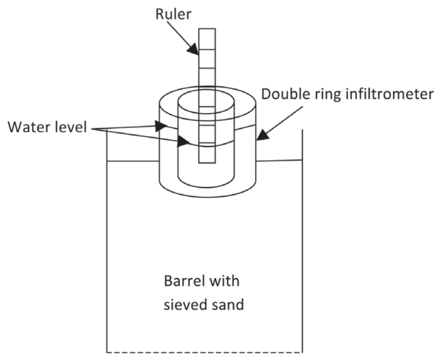

Figure 5: Illustration of the double-ring infiltrometer experimental set-up.

The outer ring was filled with water, after which the inner cylinder was filled to a level equivalent to an initial 70mm-80mm head. The time taken for the water level in the inner cylinder to drop to 20mm was recorded using a timer. Thereafter, a measured volume of water equivalent to 20mm in depth in the ring was filled successively and the time taken to infiltrate this amount was recorded.

When the amount of water entering into the soil was fairly constant over time for five consecutive measurements, steady-state saturated flow was assumed and the average saturated infiltration rate was calculated (based on these last five measurements). In order to mimic more closely pot irrigation, the "initial" infiltration rate was determined by recording the time taken for the water level in the inner cylinder to drop 20mm for the first time. The water level in the outer ring was maintained at a level approximately the same as the water level in the inner ring.

Initially all 18 barrels were conditioned by wetting with water; overall 1830ml of water was added in the inner ring, which was 130% of the void volume of the sand bed underneath this ring. The barrels were left for five days before the study was commenced. Five commercial wetting agents designated as Products A, B, C, D and E were studied (Table 2). Each wetting agent was applied into three barrels and

Table 1: Physical and textural characteristics of sandy soil used in the study.

Org C (%)	CEC* (meq/100)	Water content (%)	Sand fraction (%)		Sand (%)	Silt (%)	Clay (%)
			Fine (20-212µm)	Coarse (212-2000 µm)			
0.4 + 0.02	4.6 + 0.02	0.4 + 0.02	49.21 + 0.21	47.37 + 0.13	96.6+ 0.3	0.6 + 0.02	2.2 + 0.05

Cation Exchange Capacity (CEC) is Na+ + K+ +Ca2+ +Mg2+ (meq/100g).

three barrels were used as controls with untreated tap water. The experiment was set in randomised block design. The wetting agent solutions were prepared according to the manufacturer's instructions on the product. The barrels were left to drain for three more days and the infiltration rate was measured again using tap water in all treatments. The barrels were left to drain again for seven days and the infiltration rate was re-measured.

Results and Discussion

The conceptual approach of this research was to simulate an irrigation regime in a garden (i.e. pot irrigation), while studying the effect of common wetting agents.

Capillary rise

Initially, the capillary rise test was used as an indication of changes in the sand hydrophobicity. As expected, the capillary rise of the burnt sand was significantly higher than in the native sand, demonstrating the contribution of organic matter to the sand hydrophobicity (Figure 6). When wetting agent D was coated on the sand, the capillary rise was significantly reduced, as previously described by Weil-Shafran *et al*. (2006), who demonstrated that the capillary rise in clean sand that was pre-coated with non-ionic and anionic surfactants at a rate of as low as 10 mg/kg was significantly less than in the uncoated sand.

Double-ring infiltrometer tests

The saturated infiltration rates of water and five wetting agents through the sand were similar or slightly faster when the wetting agents were introduced to the soil as compared to the water control (Figure 7). Wetting agent C demonstrated significantly better results than the others; however, when the infiltration rate was re-measured three days later, using tap water as the irrigation medium, two observations were made: a) the average infiltration rate of the water control where no wetting agents were used was 14% lower than when initially measured, and; b) the infiltration rates of all treatments were either similar to or lower than the water control (Figure 8). These phenomena were repeated when the infiltration rate was re-measured after 10 days from the application of the wetting agents. The initial infiltration rate in all treatments was also measured (Figure 9), as it may more resemble irrigation of a pot. Similarly to the

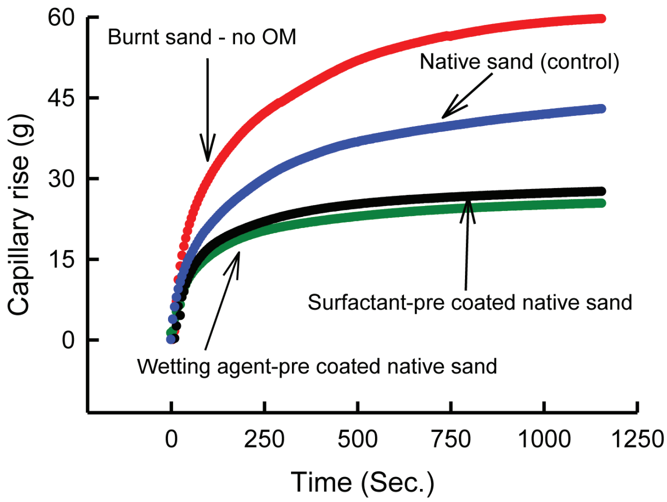

Figure 6: Illustration of the effect of anionic surfactant (Linear Alkyl Benzene Sulfonate) and a commercial wetting agent on capillary rise in pre-coated sand as compared to the capillary rise in native sand with and without the organic matter (OM).

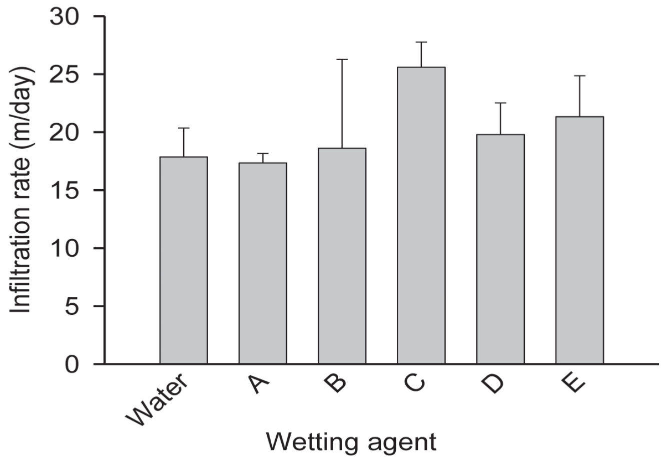

Figure 7: Average (± standard deviation) saturated infiltration rate as measured by the double ring infiltration method of five wetting agent solutions and tap water into partly water-repellent sand. Results are based on three replicates.

Table 2: Chemical ingredients of five commercial wetting agents.

	Chemical ingredients	
Wetting agents	Chemical entity	Proportion
Product A	Ethylene glycol-propylene glycol block polymer	80%
(granular)	Seaweed (*Durvillea potatorum*)	20%
Product B	Non-ionic surfactant	100%
(liquid)		
Product C	Clinoptilolite (zeolite)	69%
(granular)	Propylene oxide-ethylene oxide block polymer	15%
	Lignin	10%
	Cellulose	6%
Product D	Surfactant	10 to <30%
(liquid)		
Product E	Poloxypropylene polyoxythelene ether	<15%
(liquid)	Poloxypropylene polyoxythelene ether	< 25%

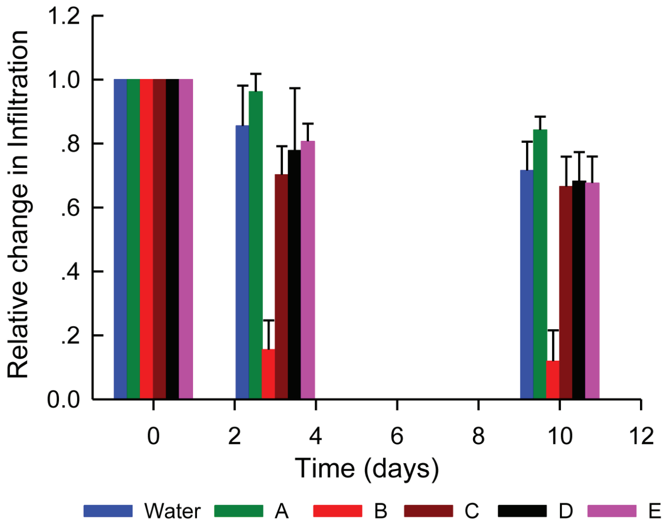

Figure 8: Average (± standard deviation) relative changes in saturated infiltration rates (as measured by the double ring infiltration method) of tap water over time after application of wetting agents (time 0). Results are based on three replicates.

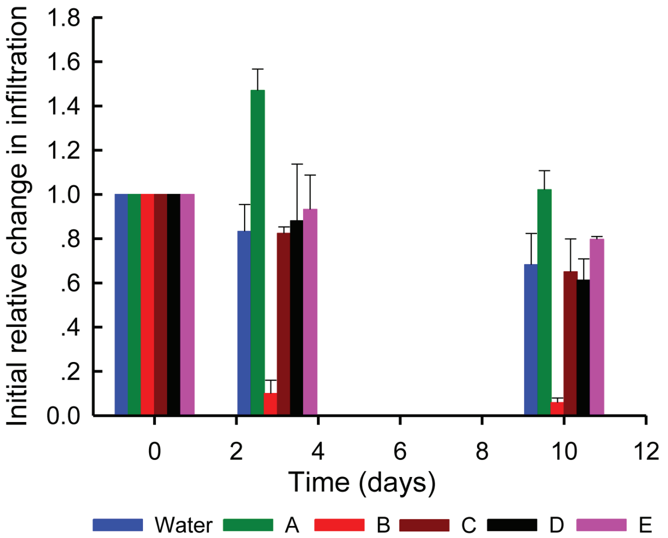

Figure 9: Average (± standard deviation) relative changes in the initial infiltration rate (as measured by the double ring infiltration method) of tap water over time after application of wetting agents (time 0). Results are based on three replicates.

saturated infiltration rate the same phenomena were observed with the commercial agents. Treatment A seemed to improve the initial wettability of the sand after three days, but its effect was significantly reduced a week later. It should be noted that recording the initial infiltration rate is problematic as the soil moisture which affects soil infiltration was not measured and is likely to vary between individual barrels.

These observations clearly demonstrate that the simplistic model presented in the introduction section (Kranok & Tucker 2004) regarding the mode of action of wetting agents did not apply in the current study. It appears that in this study, for most wetting agents, the surfactant molecules behaved just like the natural hydrophobic organic molecules once absorbed on the sand, resulting in enhancement of soil hydrophobicity. The interaction between the surfactants and soil particles seem to be the key to a better understanding of these observations. More so, it is likely that there is no one mechanism by which surfactant is absorbed on soil particles, making it impossible based on our current understanding to predict whether the implementation of wetting agent is going to enhance or reduce water repellency.

Summary and Conclusions

Overall, it was observed that the initial application of the wetting agents usually improved the wettability of the sand to some extent. This was likely to be because of the reduction in the water surface tension. However, the improved wettability was short-lived and for most cases the water infiltration rates into the sand decreased within a week from application. We postulate that surfactant molecules in the wetting agents were adsorbed on the sand particles in a similar way to the organic hydrophobic material that is coating them.

These findings raise a big question mark on the efficiency of surfactant-based wetting agents to treat water repellent sandy soils. Based on the current findings, not only that many products do not enhance long term wettability, some seem to enhance soil hydrophobicity. Further investigation on the interaction and adsorption between surfactants and soil particles is needed.

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