Surfactant Chemistry Effects on Organic Matter Removal from Water Repellent Sand

Soil surfactants, which represent a wide range of wetting agent chemistries, have been used as the primary tool for mitigating drought issues caused by soil water repellency (SWR). However, the residual effects of soil surfactants are often short-lived, requiring repeated applications. Alternatively, certain groups of wetting agents may remove hydrophobic organic matter for extended control of SWR. This laboratory study investigated the effects of selected wetting agent chemistries, including products of alkyl block polymer (ABP), nonionic surfactant + acidifiers (NIS), and polyoxyalkylene polymer (PoAP), for removing organic matter and reducing SWR. Naturally-occurring hydrophobic sand was packed into sand columns and subjected to wetting agent application. The treated columns were then washed three times with deionized water, and the volume of the leachates from each wash event was determined. Sand treated by PoAP showed enhanced water-holding capacity, although the effect diminished after the second wash. In comparison, ABP resulted in 2.3-fold greater output of combined dissolved organic carbon (DOC) and particulate organic carbon (POC) in the leachates than PoAP, and made the hydrophobic sand completely wettable. Alternatively, NIS showed similar effects compared with the control. Although PoAP reduced SWR to a minimum level, it was sorbed strongly to the sand, which resulted in 27% greater solid phase organic carbon (SOC) in treated sand, compared with the untreated control. However, the exact mechanisms underlying surfactant effects on DOC and POC are unclear and the long-term effects of surfactants following repeated application in the field are yet to be determined.

Abbreviations: ABP, alkyl block polymer; COC, cumulative organic carbon; DD water, distilled deionized water; DOC, dissolved organic carbon; DOM, dissolved organic matter; FPOC, fine particulate organic carbon; LDS, localized dry spot; MED, molarity of ethanol droplet test; NIS, nonionic surfactant; OC, organic carbon; PoAP, polyoxyalkylene polymer; POC, particulate organic carbon; POM, particulate organic matter; SOC, Solid phase organic carbon; SWR, soil water repellency; USGA, United States Golf Association; γ, surface free energy.

Core Ideas

- Confirmed for the first time that certain wetting agents can remove organic coatings that cause soil hydrophobicity.
- A novel laboratory experiment was performed to precisely quantify this effect.
- Possible mechanisms regarding the removal of organic coatings following application of certain wetting agents were discussed.
humus, including biomolecules such as waxes (Franco et al., 1995) and cutin (Chen et al., 2018), lipids and fatty acids (Grabert et al., 2009; Mainwaring et al., 2004), as well as humic substances (de Blas et al., 2010). Accumulation of organic compounds in soils is often inevitable, as a natural outcome of soil microbial activity of plant debris decomposition (Feeney et al., 2006).

Accumulation of nonpolar organic coatings and development of SWR on sand-based growing media can be mitigated by wetting agents (Cisar et al., 2000; Kostka, 2000). Most wetting agents are nonionic surfactants, which have amphiphilic structures consisting of polar hydrophilic heads and nonpolar hydrophobic tails. Due to the high affinity among nonpolar structures, once wetting agents are watered in through irrigation/precipitation, these amphiphilic surfactants attach their nonpolar tails onto nonpolar hydrophobic surfaces, and subsequently increase the overall soil wettability by facing the polar heads toward the by-passing water (Cisar et al., 2000; Dekker et al., 2005; Kostka, 2000). Addition of wetting agents can hence reduce the surface tension of water from 73 to 32 mN m⁻¹ or lower depending on the wetting agent selected and rate used, ultimately facilitating spontaneous wetting and water infiltration into hydrophobic sand (Song et al., 2014a). This effect, however, diminishes over time as the wetting agent molecules degrade, and often repeat applications are needed to maintain soil wettability year-round (Song et al., 2014b).

Alternatively, research efforts have also been focused on the removal of organic coatings that causes SWR. Karnok et al. (1993) conducted a field experiment on a sand-based golf course putting green and investigated the effect of high pH-solution on SWR. After consecutive application of NaOH at 0.1 M with 12 mm ponding for 3 d, the authors discovered significant removal of humic substances and a reduction of SWR from a strong to moderate level. However, repeat applications of NaOH led to substantial increase of soil pH from 5.9 to 8.3, which may negatively impact plant growth. Other research evaluating SWR removal includes investigation of actinomycetes, such as Streptomyces spp. (Roper, 2004), Rhodococcus spp. (McKenna et al., 2002), and Mycobacterium spp. (Dinkelberg et al., 2006), as a bioremediation approach. The concept behind this approach is to utilize these wax-dependent metabolizing bacteria and biosurfactant-producing bacteria (Lang and Philip, 1998; Roper, 2004) to decompose complex organic hydrophobic coatings and increase γ. However, this approach has proven to be time-consuming and results are highly environment-dependent.

Some wetting agents may remove or extract organic coatings as well. Frankewich and Hinze (1994) conducted a laboratory experiment and evaluated certain nonionic surfactants for extracting and concentrating hydrophobic organic species from water via a micelle-mediated phase separation method at the cloud point. The authors found that a nonionic surfactant containing polyoxyethylene glycol monooctyl ether showed > 60% extraction efficiency of phenols and anilines, including chlorinated phenols (88 to 90% extraction) and dinitroanilines (76 to 98% extraction). While the nonpolar and hydrophobic features of soil organic matter have been related to aromatic structures such as phenols and chlorinated hydrocarbons (Karickhoff et al., 1979; Richardson and Epstein, 1971), it is reasonable to hypothesize that certain wetting agents with strong amphiphilic properties have the potential to extract or remove hydrophobic organic substances from soil. Thus, the objective of this laboratory study was to investigate the effect of selected wetting agents on hydrophobic organic coating removal from sand surfaces and their effect on SWR.

**MATERIALS AND METHODS**

**Experiment Setup**

Naturally occurring water-repellent sand was collected from a LDS area on a 7-yr old creeping bentgrass (Agrostis stolonifera L.) putting green constructed based on United States Golf Association (USGA) recommendations at the Turfgrass Research Facility of the University of Missouri, located in Columbia, Missouri. The climate in this region represents typical transition zone characteristics, in which neither cool- nor warm-season turf species adapt well. Sands collected were bench-dried under room temperature prior to use. Dried sands were passed through a 2-mm sieve to remove plant residues and thoroughly mixed. The degree of SWR was determined as moderate via the molarity of ethanol droplet (MED) test (King, 1981) with a result of 2.2 M.

Sand column systems were built using PVC tubes (Georg Fischer Harvel LLC, Easton, PA) with 5.08 cm internal diameter and 0.48 cm wall thickness. Tube bottoms were covered with a layer of fine synthetic fabric (maximum opening size < 0.05 mm) to retain sand particles but permit liquid drainage. A total of 254 g of sand was packed uniformly into the PVC soil columns to a depth of 7.62 cm, yielding a bulk density of 1.65 g cm⁻³. Particle density of the sand was measured as 2.64 g cm⁻³, and porosity was determined to be 37.5% and equivalent to a pore volume of 58 mL.

**Application of Surfactant**

Surfactants applied in this experiment belonged to the group of alkyl block polymer (ABP) (Matador, 100% alkyl block polymer; EnP Investments LLC., Mendota, IL), polyoxyalkylene polymer (PoAP) (OARS, 80% polyoxyalkylene polymers and 10% potassium salt of alkyl substituted maleic acid; AQUA-AID Inc., Rocky Mount, NC), and nonionic surfactant (NIS) + acidifiers (pHAcid, combination of a blend of acidifying agents and a high molecular weight nonionic surfactant; Numerator Technologies Inc., Sarasota, FL). A non-treated control, distilled deionized (DD) water only, was also included. All wetting agents were mixed with DD water at the highest label rates at 50, 29, and 267 mL L⁻¹ for ABP, PoAP, and NIS, respectively. To ensure sufficient solution to saturate the sand profile theoretically, 70 mL of wetting agent solutions were applied to the top of sand columns from a consistent height (2 cm) at a rate that prevented ponding. At 24 h after treatment, sand columns were washed three times with a pore volume (58 mL) of DD water, at a 30-min interval between each wash to allow complete drainage.

**Measurements and Statistics**

All leachates drained from the bottom of the column were collected for volume measurement before being acidified using
H$_2$SO$_4$ to pH < 2 to remove inorganic carbon and stored at 4 °C in the dark for determination of dissolved organic carbon (DOC) and particulate organic carbon (POC). After drying to a constant weight in an oven at 50 °C, the washed sand columns were tested for water repellency again via the MED method. To compare overall organic carbon (OC) changes in the sand profile before and after treatment, solid phase organic carbon (SOC) in the untreated and treated sands was measured utilizing LECO TruSpec CN Carbon/Nitrogen analyzer (LECO Corporation, St. Joseph, MI). Total amount of SOC mass was reported for each column based on 254 g of sand it contained.

Determination of DOC was performed by filtering 0.5 mL of leachate through a 0.45 μm Acrodisc nylon membrane syringe filter (Pall Corporation, Port Washington, NY), before analysis using a Shimadzu TOC-VWP analyzer (Kyoto, Japan) equipped with an autosampler ASI-V. The amount of DOC in wetting agent solutions was also determined as OC input. Remaining leachate were centrifuged at 10,000 × g for 15 min to remove particles from solution. The collected particles were then dried at 105 °C for 12 h prior to determination of mass. Particulate organic matter (POM) content was determined via combustion at 550 °C for 12 h (Page, 1982), and POC content was determined as OC content. The collected particles were then dried to 55 °C in the dark for determination of dissolved organic carbon (DOC) and particulate organic carbon (POC). After drying to a constant weight in an oven at 50 °C, the washed sand columns were tested for water repellency again via the MED method. To compare overall organic carbon (OC) changes in the sand profile before and after treatment, solid phase organic carbon (SOC) in the untreated and treated sands was measured utilizing LECO TruSpec CN Carbon/Nitrogen analyzer (LECO Corporation, St. Joseph, MI). Total amount of SOC mass was reported for each column based on 254 g of sand it contained.

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The experimental design for this study was a completely randomized design with three replications, and the entire experiment was conducted twice. Analysis of variance was conducted using the PROC GLM procedure of SAS 9.4 (SAS Institute, Cary, NC). There was no treatment by study interaction for all measurements; thus, data of the two experiments were pooled together and significant means were separated based on Fisher’s Protected LSD at P < 0.05 (Fisher, 1935).

RESULTS AND DISCUSSIONS

Effects of Surfactant on Water Infiltration/Retention

Leachate volumes collected from all leaching events showed significant differences following different treatments (Table 1). Although all treatments were applied at a volume (70 mL) greater than the estimated pore volume (58 mL) of the sand profiles, sand columns treated with ABP and PoAP nearly retained all applied solutions. In comparison, water-treated control columns and NIS-treated columns retained 54 and 58 mL of water, respectively, which were comparable to the estimated pore volumes. After the first wash, sand columns treated with ABP exhibited increased water drainage (76% of the applied solution). PoAP-treated sand columns, however, showed greater water retention and only leached out 28% of the applied water. Treatments with water and NIS resulted in 67% or 71% of applied water draining as leachate, respectively. Following the second wash, water held in both PoAP- and ABP-treated columns decreased to 5% of the volume applied in each washing event (Table 1). In comparison, NIS-treated columns and the control columns retained 3 mL or more water after the second wash than PoAP- and ABP-treated columns. After the third wash, only minimum differences in water retention were observed among the wetting agent-treated columns.

The effects of wetting agents on soil physical properties, including water infiltration and percolation, are influenced by their chemical properties (Zontek and Kostka, 2012). Mobbs et al. (2012) evaluated four wetting agents and found no noticeable effect of the wetting agents on water movement. However, lower capillary rise and unsaturated hydraulic conductivity in wetting agent-treated sand was observed, indicating reduced soil water retention. Likewise, Oostindie et al. (2008) observed greater water content in soil cores treated with a nonionic copolymer wetting agent, compared with the untreated cores. Those findings agree with the water retention effect observed in PoAP-treated columns in our experiment following the first wash (Table 1). In contrast, other researchers have reported improved water drainage and substantially reduced soil water content following nonionic wetting agent applications (Feng et al., 2001, 2002; Karagunduz et al., 2001; Karnok and Tucker, 2008; Song et al., 2014b). In our experiment, ABP-treated columns resulted in a 13% greater drainage following the first two washes, compared to the water-treated columns (Table 1). Their influences on water movement, however, diminished overtime and after the third wash, minimum differences in water drainage were found between ABP- or PoAP-treated columns and water-treated columns.

Effects of Surfactant on DOC and POC in Leachate

The amount of DOC and POC found in leachates following the four leaching events, including leachates collected after treatment applications and after the first, second, and third washes, showed a significant treatment effect (Table 2). The greatest amounts of DOC and POC leached from the sand columns were found following the first wash, with exceptions for columns treated with NIS and water where no statistical differences were found in leachate POC among sequential washes. After the second wash, ABP and PoAP resulted in a 16- or nine-fold greater amount of DOC in leachates, respectively, than the control. Compared with
### Table 2. Dissolved and particulate organic carbon (DOC and POC) in each leachate collected after wetting agent treatment in columns with hydrophobic sand.

<table>
<thead>
<tr>
<th>Wetting agent†</th>
<th>Application</th>
<th>First wash‡</th>
<th>Second wash</th>
<th>Third wash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DOC (mg)</td>
<td>POC (mg)</td>
<td>DOC (mg)</td>
<td>POC (mg)</td>
</tr>
<tr>
<td>ABP</td>
<td>48 aC§</td>
<td>1238 aA</td>
<td>295 aB</td>
<td>34 aC</td>
</tr>
<tr>
<td>PoAP</td>
<td>40 aC</td>
<td>516 bA</td>
<td>153 bB</td>
<td>34 aC</td>
</tr>
<tr>
<td>NIS</td>
<td>18 bB</td>
<td>51 cA</td>
<td>25 cB</td>
<td>11 bB</td>
</tr>
<tr>
<td>DD water</td>
<td>11 bB</td>
<td>28 dA</td>
<td>18 cAB</td>
<td>13 bAB</td>
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</tbody>
</table>

† ABP, alkyl block polymer; DD water, distilled deionized water; NIS, nonionic surfactant+ acidifiers; and PoAP, polyoxyalkylene polymer. Wetting agents ABP, PoAP and NIS were applied at 50, 29, and 267 mL L⁻¹, respectively. All treatments were applied at 70 mL.

‡ Treated sand was washed with one pore volume of water (58 mL) at 24 h post-treatment.

§ Means in the same column followed by the same letter were not significantly different based on Fisher’s Protected LSD at P < 0.05.

PoAP, application of ABP consistently yielded greater amounts of OC in leachates following the first two washes, and resulted in up to 2.4 or 6.3 times DOC or POC, respectively, following the first two washes. After the third wash, ABP- and PoAP-treated sand columns leached two times more DOC than control columns, but no difference in POC was found.

After combining DOC and POC from all four leaching events, it appeared that majority of OC recovered from the leachates was in the DOC form (Table 3). Alkyl block polymer–treated and PoAP–treated columns yielded 12 and 23 times more DOC than POC, respectively. Compared with the amount of OC introduced by treatment application, however, total DOC in leaches of ABP– and PoAP–treated columns accounted for only 92% and 51% of the OC input, respectively. All wetting agents included in this experiment are 100% water-soluble and hence, all OC introduced is in the form of DOC. It is not clear, therefore, if or how much of the leached DOC from ABP– or PoAP–treated sand columns was indigenous. It is clear though, at least half of the OC introduced by application of PoAP was retained in the sand systems despite three sequential washes, suggesting a strong sorption between PoAP molecules and the hydrophobic sand surface. Alternatively, control columns treated with water removed < 10% of DOC compared to ABP– or PoAP–treated columns, suggesting that a certain portion of organic matter in the soil was water soluble. In comparison, sand columns treated with NIS yielded a slightly greater amount of DOC, which was comparable to the amount of OC introduced by NIS plus the amount of DOC removed by water only treatment.

Dissolved organic carbon is usually defined as organic materials that can pass through a 0.45-μm pore size filter (Kalbitz et al., 2000). The main portion of soil DOC comes from complex and high molecular weight fractions, including humic substances (Herbert et al., 1995; Kalbitz et al., 2000). Studies have found that DOC can be fractionated into a hydrophobic component that contains more aromatic humic and humic acids and a hydrophilic component which consists of simpler aliphatic chains (Chen et al., 2003; Guggenberger et al., 1994). This amphiphilic nature likely leads to an affinity with applied wetting agents, also amphiphilic molecules, and the hydrophobic surface, and consequently contributed to the apparent sorption of PoAP and, perhaps, ABP.

Among treatments, application of ABP removed the greatest amount of DOC, equivalent to 6.9-fold of that removed in control columns (Table 3). Sand columns treated with PoAP and NIS, in comparison, resulted in the same amount of POC in leachates as in control. It is reasonable to assume that at least a substantial portion of POC is derived from the hydrophobic coatings. The processes of sand collection and homogenization likely weakened the attachment between the hydrophobic coatings and the sand surface, evidenced by POC removal from water only treatment. Alkyl block polymer, therefore, is likely to be the only treatment tested in this experiment that effectively removed the insoluble organic coatings following one application and three washes.

Soil organic matter can be grouped into POM and dissolved organic matter (DOM), which reflect POC and DOC carbon sources, respectively. The size fractions of POM range from 0.45 μm to 2.0 mm (Bormann et al., 1969). Based on characteristics of the fabric adhered to the bottom of sand columns and the filter we used, collected POM particles likely ranged from 0.45 μm to 0.05 mm, which can be attributed to the fine particulate organic carbon (FPOC) fraction (0.45 μm to 0.1 mm) (Fisher and Likens 1973). It has been reported that FPOC plays an important role in the formation of water-stable soil aggregates (Pugel et al., 2000; Tisdall and Oades, 1982), and its presence increases solid–liquid contact angle and hence SWR even at low concentrations (Franco et al., 1995; Meggie and Posner, 1980). In laboratory, extraction or redistribution of POM often involves intensive physical procedures, such as ultrasonic dispersion and high speed centrifugation followed by extensive water flushing (Franco et al., 1995; Oorts et al., 2005). As a result, removal of POM even at a relatively low quantity by simple management
practices, such as wetting agent application with sequential flushes, can be desirable for mitigating SWR.

After combining all forms of OC outputs recovered from leachates, the cumulative organic carbon (COC) showed a similar trend as found in total DOC and POC (Table 3). Compared with control, both ABP and PoAP resulted in significant OC yield in leachates. Cumulative OC output from NIS– and water-treated sand columns were statistically the same, indicating minimum influence of NIS on soil OC. It is intriguing that ABP–treated sand columns produced the greatest amount of COC in leachates, which was within 1% variation compared to its OC input of 1765 mg. However, PoAP–treated columns yielded only 53% of the OC introduced to the sand system. This again, demonstrated a strong sorption effect of PoAP compared to ABP as discussed above.

Effects of Surfactant on Sand SOC and SWR

After wetting agent application and sequential wash events, SOC content in the sand systems showed a very different pattern among treatments (Fig. 1). Compared with the untreated sand, water only treatment resulted in no statistical difference in SOC. In contrast, application of PoAP led to 27% additional accumulation of SOC, while application of NIS reduced SOC by 16%, compared with the untreated sands. Following ABP application, however, the amount of SOC after treatment was similar to the untreated sands.

Hydrophobicity levels of the treated sands following three washes also showed diverse effects among wetting agents (Fig. 2). Compared with the untreated sand, application with water resulted in elevated MED above 3 M, similar to NIS-treated sands. At this level, the hydrophobicity of the sand is categorized as severe, based on a report by King (1981) who found that air-dried sand generating a MED of 3 M also produced a contact angle of 97° and a steady infiltration rate of 0.09 mm min⁻¹ for water. The author did not report the result for water droplet penetration test (WDPT), another commonly used test for determining soil water repellency. In the present study, application of ABP or PoAP reduced SWR to none or minimum, respectively. These results indicated a reversal of SWR following application of ABP or PoAP, despite the two wetting agents having distinctly different effects on SOC (Fig. 1).

The contrasting effects of ABP and PoAP on sand SOC content are likely related to their chemical properties. Although published information that specifically discusses the sorption of different nonionic surfactants on soil organic matter is limited, it is suggested that polyoxyalkylene block copolymer sorption on soil organic matter occurs due to strong lipophilicity of the copolymers (Nace, 1996). A high log octanol–water partition coefficient (K_{ow}) value was observed for a polyoxyalkylene block copolymer, suggesting strong potential for copolymer sorption to soil organic matter (Nace, 1996). These properties of polyoxyalkylene in PoAP likely explain the extended residual effect of this product on water retention (Table 1), relatively smaller amount of DOC in leachates (Tables 2 and 3), and greater amount of SOC in treated sands (Fig. 1), compared with sand columns treated with ABP. For ABP, however, the actual chemistry of alkyl block polymer remains unpublished, thus inadequate information is available to thoroughly elucidate its impact on hydrophobic sand. Nevertheless, our data suggested that application of ABP resulted in a removal of POC and a total reverse of SWR while maintaining SOC at pre-treatment levels, which collectively points to the hypothesis that ABP could replace at least a portion of organic coatings on the sand surface with surfactant molecules.

Manufacturer labeling on NIS indicated that acidifying agents in the product are intended to manage the inorganic carbon fraction of soil (Ca and Mg carbonates), which consists of insoluble salts that can rapidly precipitate from the soil solution (Ogino et al., 1987). Recycled water or well water often contains excessive amount of carbonate that increases soil pH and forms a substantial amount of insoluble salts (Harivandi, 2004). With application of NIS, soil pH can be acidified to release Ca²⁺ and Mg²⁺ ions into solution through the dissolution of carbonates, hence reducing the amount of pore restriction caused by Ca and Mg carbonate deposits. Additionally, high sodium content in golf course water

![Fig. 1. Solid phase organic carbon (SOC) mass in columns by treatment. Bars labeled with the same letters were not significantly different based on Fisher's Protected LSD at P < 0.05. ABP, alkyl block polymer; DD water, distilled deionized water; NIS, nonionic surfactants+ acidifiers, and PoAP, polyoxyalkylene polymer.](image1)

![Fig. 2. Soil water repellency (SWR) determined by molarity of ethanol droplet (MED) test. Bars labeled with the same letter were not significantly different based on Fisher's Protected LSD at P < 0.05. ABP, alkyl block polymer; DD water, distilled deionized water; NIS, nonionic surfactants+ acidifiers, and PoAP, polyoxyalkylene polymer.](image2)
recycling irrigation systems has been a concern (Harivandi, 2004), because increased Na⁺ in the soil disrupts and disperses small soil aggregates that can block soil micropores (Duncan et al., 2000; Gupta et al., 1984). The enhanced solubility of carbonates and increased concentrations of Ca²⁺ and Mg²⁺ in soil solution can increase the overall soil electrolyte level and counteract this negative effect from excessive Na⁺, thus stabilizing soil structure (Beltrán, 1999). The sand-based USGA putting green soil system has less than 3% clay content and a 35 to 55% total porosity with 15 to 30% air-filled macropores (USGA, 2004); therefore, the influence from NIS on USGA putting greens was expected to be less significant than on native soil-based turf systems.

It is important to mention that the treated and washed sands were oven dried at 50 °C for two weeks to achieve constant weight before testing for SWR. Previous studies have indicated that oven-drying of moist water-repellent soil samples can lead to an increase of SWR (Dekker et al., 1998; Franco et al., 1995). Under field conditions, temperature at the soil surface can reach > 50 °C and thus stimulate SWR development (Rose, 1968) due to: i) mechanically forced release of hydrophobic particles from plant tissues during drying (Neinhuis and Barthlott, 1997); ii) heating and/or biological process-triggered release of organic substances from wax globules and/or hydrophobic coatings that were originally present within the soil matrix (Franco et al., 1995); iii) build-up of new hydrophobic substances from plants or microorganisms (Doerr and Thomas, 2000); and iv) a heating induced shift of organic compound forms from high-molecular-weight fatty acids and aliphatic species to shorter fatty acids (< C12) and aromatic compounds, leading to increased SWR (Atanassova and Doerr, 2011). As the treated sand was oven-dried at 50 °C, the main reason for increased SWR by the water control and NIS application could be the second or fourth mechanisms: heating triggered release, activation, and/or transformation of the hydrophobic compounds.

CONCLUSIONS

This laboratory study demonstrated that wetting agents such as ABP and PoAP can significantly improve water retention of water-repellent sand, with PoAP providing longer residual effect. The chemical properties of the applied wetting agents influenced their performance in interacting with organic coatings on sand, and data collected after single applications of ABP and PoAP wetting agents suggest that these properties contributed to the sorption and desorption effects, which facilitated increased surface wettability. The PoAP molecules exhibited strong sorption to the hydrophobic sand surfaces, thus causing substantial accumulation of OC in the sand system and minimum SWR following application. The ABP wetting agent removed a greater portion of POC from the sand system and totally reversed SWR, although the overall SOC content in the sand remained unchanged after treatment. Our data suggested a possible replacement of hydrophobic organic coatings by the wetting agent molecules in ABP. For field operations, our data suggest that deep irrigation is probably beneficial following ABP or PoAP applications, to alleviate the negative effects of hydrophobic organic coatings that cause LDS. Future studies need to clarify the mechanisms of different surfactants at the molecular level, elucidate chemical composition of displaced DOC and POC using spectroscopic tools [e.g., Fourier-transform infrared (FTIR) spectroscopy and nuclear magnetic resonance (NMR) spectroscopy], and the long-term effects of repeated surfactant applications. Field experiments are also desirable to evaluate wetting agent residual effects as influenced by product rates and irrigation regimes, and their effects on rootzone soil organic matter and microbial activity.

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