Advances in understanding and managing water repellent soils.

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Abstract
Water repellency occurs in most irrigated soils, but is most pronounced in coarse sands and sandy soils due to accumulation of hydrophobic compounds on soil particles or to physiochemical changes in soil organic matter. As soils dry, hydrophobic compounds polymerize and water repellency increases. Once a critical moisture content is reached soils shift from wettable to non-wettable, impacting infiltration and unsaturated flow in affected soils, and consequently water use efficiency and turf quality. Surfactant formulations were evaluated on water repellent or susceptible soils at diverse test locations in the United States, the Netherlands and Australia. Treatments reduced water repellency (measured as water drop penetration time), shifted critical moisture content, improved temporal infiltration rate of applied irrigation water, and increased rootzone volumetric water content.

Introduction
Water repellent soil is found worldwide in diverse soils, crops, and cropping systems (Wallis and Horne, 1992) and is common in sandy soils supporting turf or pasture grasses. The phenomenon is most pronounced in coarse sands and sandy soils and is attributed to the accumulation of hydrophobic organic compounds as coatings on soil particles and aggregates, as well as, physiochemical changes that occur in decomposing soil organic matter of plant or microbial origin (Miller and Williamson, 1977; Hallett, 2001). The environmental consequence is decreased infiltration of irrigation water and precipitation, non-uniform wetting of soil profiles, increased run-off and evaporation, and increased leaching due to preferential flow (Dekker et al., 2001a).

Surfactants are well documented for the management of water repellency (hydrophobicity) in thatch and soils, and for the enhancement of soil hydration in managed turfgrass (Miller and Kostka, 1998; Cisar et al., 2000; Kostka, 2000; Karnok and Tucker, 2001). Leinauer et al. (2001) reported that different soil surfactants could influence the depth of water distribution in a sand rootzone mix, but not loamy soils under greenhouse conditions. The use of soil surfactants has been suggested as a tool to improve irrigation efficiency and water conservation, yet systematic studies to substantiate this hypothesis have not been published.

Maintenance of turf quality and simultaneous optimization of irrigation and conservation of water are goals of turfgrass managers, especially under drought conditions. Water may be conserved by maximizing input effectiveness (irrigation, precipitation) or minimizing output losses (transpiration, evaporation, runoff, and leaching or drainage below the rootzone) (Anon., 2002). The key to water conservation is maximizing the amount of water entering the turfgrass rootzone and it's storage and availability once in the rootzone. Management tactics include: reducing transpiration, reducing evaporation, increasing infiltration, reducing ponding, optimizing retention in the rootzone, and controlling water movement below the rootzone (leaching).

Materials and Methods

Two commercial surfactants, Primer®604 or Aqueduct® (Aquatrols Corporation of America, Cherry Hill, NJ), were evaluated at selected locations. Treatments were applied according to label recommendations to soils in replicated plots which exhibited symptoms of, or had a history of, soil water repellency. Plot size varied by test location ranging from 0.9 m^2 to 6 m^2, with the exception of the Netherlands where plots were 25m x 5 m. Aqueduct treatments were applied weekly (250 ml/100m^2) in a curative management strategy at sites in New Jersey and Arkansas. Primer was applied monthly in a program or preventative strategy at sites in Australia and the Netherlands. In Australia, the surfactant was evaluated at two rates (125 ml/100m^2 and 190 ml/100m^2), while in the Netherlands, the surfactant was tested at 190 ml/100m^2. Soils in New Jersey, Victoria (Australia), and Arkansas were putting greens built to USGA specifications (USGA, 1993). The Dutch test location was a fine sand with less than 3% clay.

Soil water repellency was assessed in soil cores extracted prior to application of treatments. A minimum of five cores were extracted from each plot on each sampling date, then transported to the laboratory and allowed to air dry prior to assessments. Water repellency was measured using water droplet penetration time (WDPT) (Letey, 1969). WDPT was measured in soil cores beginning at the thatch-air interface then proceeding at 1 cm intervals to a depth of 4-6 cm. WDPT was measured to the nearest second. Trials were conducted as randomized complete block designs with four replications. Temporal infiltration rate in the Arkansas trial was measured by placing 5 ml of distilled water on the surface of untreated or surfactant treated plots and measuring the time for the applied water to infiltrate (Thomas and Karcher, 2000).

For tests conducted in the Netherlands, spatial and temporal variability in soil moisture content was evaluated eight times in vertical transects by intensive sampling of the treated and untreated plots. Soil samples were collected in stainless steel cylinders (5 cm dia) at six depths in 2.5 cm intervals beginning at the soil surface and to a depth 19 cm. A total of 35 samples were collected at each depth along a 1.8 m transect and 75 samples in a 15 x 5 grid in a horizontal fashion at each depth in adjacent soil blocks. Cylinders were placed in sealed plastic bags and transported to the laboratory. WDPT was measured in field moist and laboratory dried soil. Mean soil water content was measured gravimetrically and resistance to wetting was determined by subjecting soil samples to a constant pressure head of –2.5 cm of water applied to the sample surface according to methods described by Dekker (1998) and Dekker et al. (2001b).

Results and Discussion

In most cases, water repellent soils were confined to the upper 1-3 cm of the profile (data not presented). Notable exceptions occur, such as the Netherlands site where water repellency was detected to a depth of 50 cm under extremely dry conditions (data not presented). Both surfactants tested (Aqueduct and Primer) reduced soil water repellency in the upper regions of the soil profile over the duration of the study periods (Figure 1, Figure 2, Table 1). At one week post-application, Aqueduct significantly reduced water repellency in the thatch-soil interface (Figure 1). At the next depth interval, (cm 1), statistically significant differences became apparent by week three (Figure 2). These were the sole depths where WDPT indicated the presence of soil water repellency. While water repellency increased in the untreated soils, Aqueduct treatment either reduced water repellency or prevented it from increasing over the course of the three-week study period.

Monthly applications of the soil surfactant Primer significantly reduced soil water repellency (Table 1). Prior to treatment applications, water repellency (WDPT) was similar in all plots. Reductions in soil water repellency were observed after a single surfactant application with residual effectiveness lasting for at least one month. Subsequent monthly surfactant treatments maintained soil water repellency below that of the untreated control for the duration of the study. At the Victoria (Australia) test location, water repellency was confined to uppermost region of the soil profile, just below the soil surface, the region containing the highest organic matter content. Reductions in WDPT (as a measure of soil water repellency) were observed in trials conducted in the Netherlands (data not presented). Changes in WDPT were observed in the surface layer and to a depth of 5 cm after two treatment applications. Changes in water repellency were most pronounced in the upper regions of the soil profile, which contained the highest organic matter levels. These studies confirm that while soils and decomposing organic matter may differ, surfactants will consistently ameliorate water repellency in treated soils.

Dekker et al. (2001b) recently introduced the concept of critical soil water content; the nominal volumetric water content below which a soil becomes non-wettable in the field. Surfactant treatment shifted the mean critical soil water content in the top 15 cm of the rootzone (Figure 3). In the top 2.5 cm of the rootzone, untreated soils were wettable until volumetric water content dropped to 18 vol%, while surfactant treated soils were wettable to 11 vol%. At 5 cm, the surfactant-treated soil remained wettable until soil water content reached 6.4 vol%, while the untreated soil became non-wettable at 11 vol%. Between 7.5 cm and 15 cm, differences were still encountered between the treated and untreated soils, though not to the degree observed in the upper regions of the soil profile. The consequence of this shift in critical soil water content is that soils remain wettable and irrigation water or precipitation may more effectively infiltrate a surfactant treated soil under more edaphically stressed conditions (drought) than in untreated soil. Mean soil volumetric water content in field moist cores was greatest in the upper 10 cm of the profile (Figure 4). At all depths, Primer-treated soils tended to have volumetric soil water contents greater than the untreated controls. This trend was evident for the duration of the study and suggests that under field conditions, surfactant treatment may increase mean soil water content in the region of the rootzone with the greatest root density and highest organic matter content.

Turfgrass irrigation strategies deliver water uniformly to the soil surface in finite irrigation cycles (10-60 minutes). Irrigation efficiency may be influenced not only by the degree of water repellency (or wettability) of the top 1-2 cm of the soil profile, but also, the depth of water repellency in the soil profile and hence how effectively water can infiltrate into the soil under unsaturated flow conditions. A single surfactant treatment applied to a water repellent, localized dry spot on an Arkansas bentgrass green increased the initial infiltration rate from 40 ml/min (untreated) to 150 ml/min (surfactant-treated) (Figure 5). Infiltration was increased 3-fold to 7.5-fold in the surfactant treated plots. In a second study in which two surfactant applications were made, infiltration was increased 1.5-fold to 30-fold over the control (data not presented). These results were corroborated in a Dutch trial on a water repellent fine sand soil that received a monthly surfactant treatment and a simulated 60-minute irrigation cycle (Figure 6). After one surfactant treatment, no differences in infiltration were observed at the 0-2.5 cm depth. By June (two surfactant applications), soil volumetric water content after a 60-minute simulated irrigation was only marginally higher in surfactant treated soils than in untreated soils (47 vol% versus 40 vol%). In surfactant treated soils, infiltration rate and increase in volumetric water content approached plateau levels within the first 10-20 minutes of simulated irrigation. On subsequent sampling dates, volumetric water content in surfactant treated soils was 2-fold to 5-fold greater than in the controls. Infiltration rate and the rate of change in soil volumetric water content increased asymptotically in treated soils, while it was generally linear in the untreated controls. On two dates (27 July and 2 September), both the surfactant treated soils and the untreated soils had volumetric water contents below 10 vol%. After 60 minutes of simulated irrigation, volumetric soil water content did not increase in the controls, indicating that these soils were below the critical soil water content and would be susceptible to severe runoff and ponding. Conversely, the surfactant treated soils, though at the same initial soil water content, remained wettable. After the 60 minute simulated irrigation cycle, approximately 10 mm of water infiltrated the surfactant treated soil and volumetric water contents approached 40 vol%.

This study confirms that surfactants reduce soil water repellency in sandy soils regardless of the origin of the soil, the nature of the organic matter, or the local environment. While this conclusion was anticipated, these trials also provide substantiation that surfactants influence irrigation efficiency and enhance water conservation in turfgrass systems on water repellent soils. We have demonstrated that surfactants as a consequence of managing soil water repellency will:

- modify critical soil water content so that soils remain wettable even under periods of limited irrigation and high evaporative demand.
- increase the infiltration rate of applied water, so that less water is lost to evaporation and runoff.
- rapidly increase soil volumetric water content upon irrigation, improving water reserves in the rootzone.
- limit deep percolation of water and hence losses to leaching.

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Table 1. Effect of surfactant treatment on soil water repellency as measured by water drop penetration time (in sec) in the water repellent 0-1 cm zone of a soil core (Melbourne, Victoria, Australia).

Treatment	**0 MAT**	**1 MAT**	**2 MAT**	**3 MAT**
Primer (125 ml $100m^{-2}$)	312	53	173	92
Primer (190 ml $100m^{-2}$)	311	58	120	82
Control	229	150	426	203
LSD (p<0.05)	ns[z]	29	92	79

[z] ns = not significantly different

Figure 1. Effect of surfactant treatment on soil water repellency in the 0 cm zone (* = p<0.05) (New Brunswick, NJ)

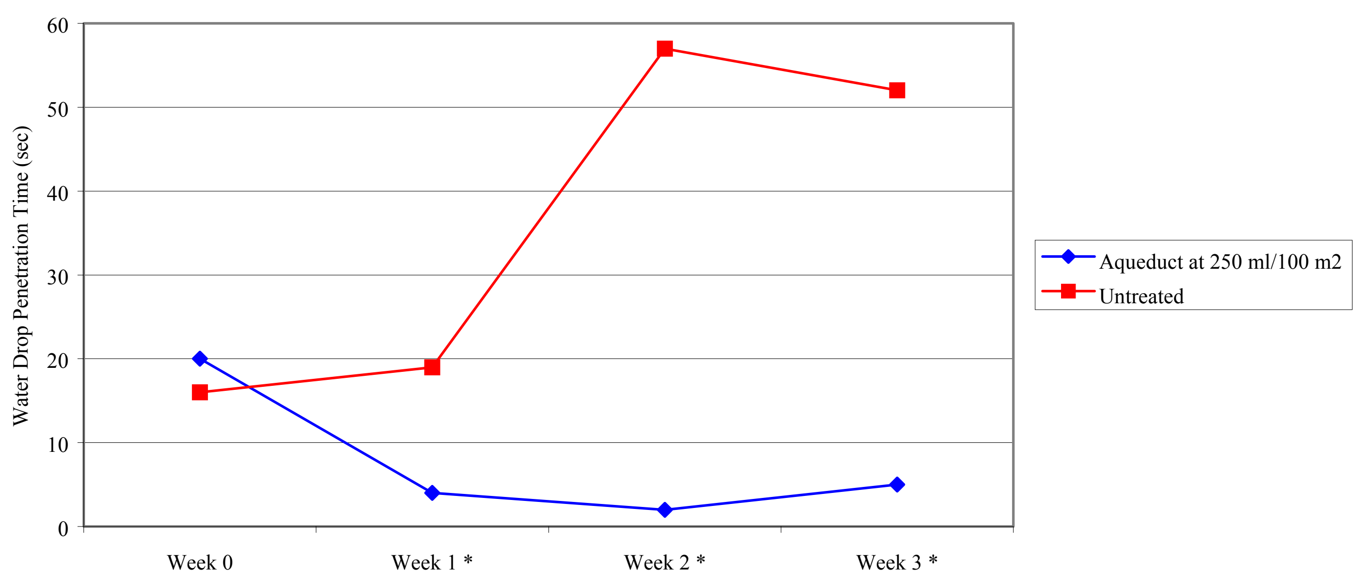

Figure 2. Effect of surfactant treatment on soil water repellency in the 1 cm zone ($* = p<0.05$)(New Brunswick, NJ)

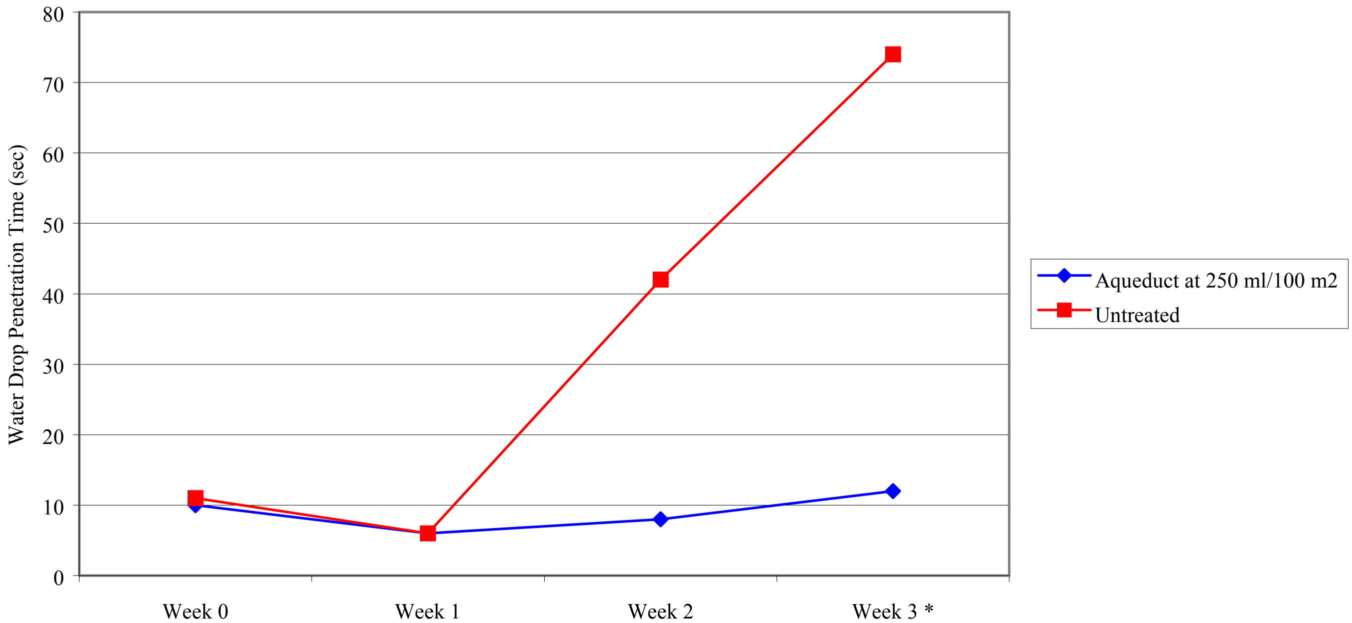

Figure 3. Critical soil water content curves - surfactant treated (Primer 604) and untreated control (Alterra, The Netherlands)

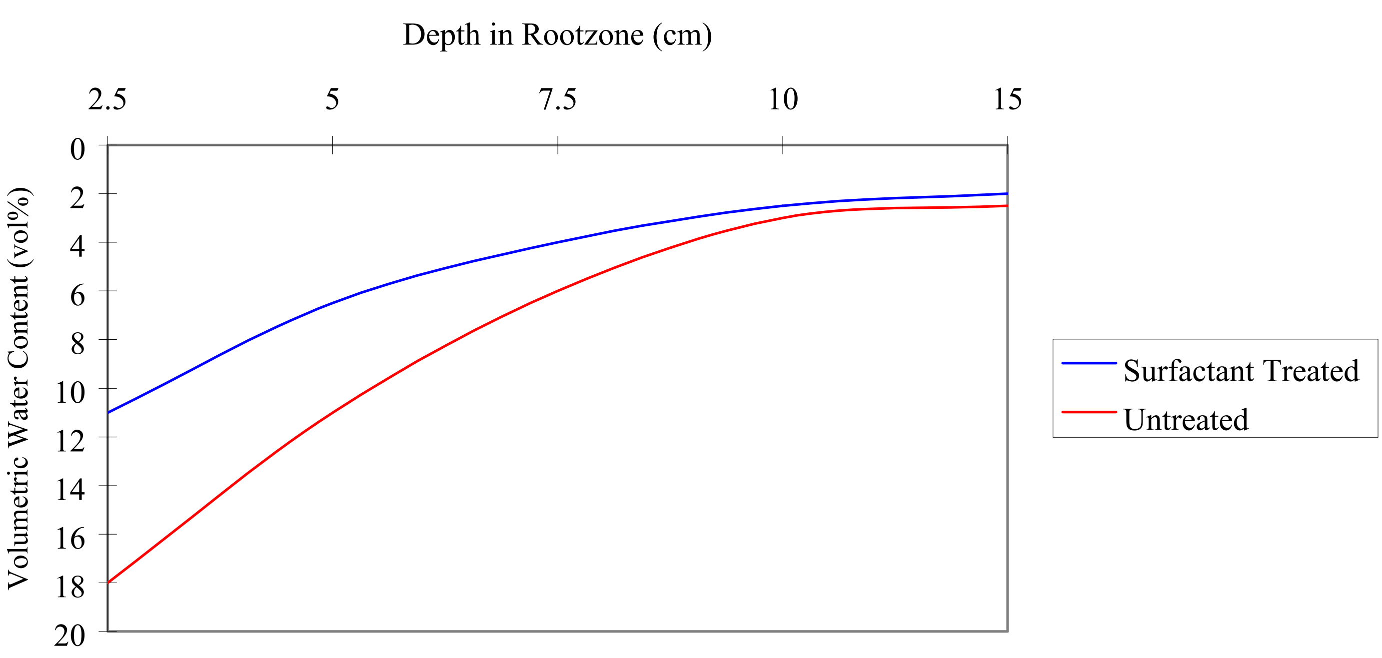

Figure 4. Comparison of volumetric water content (vol%) at different depths in the soil profile (Alterra, The Netherlands)

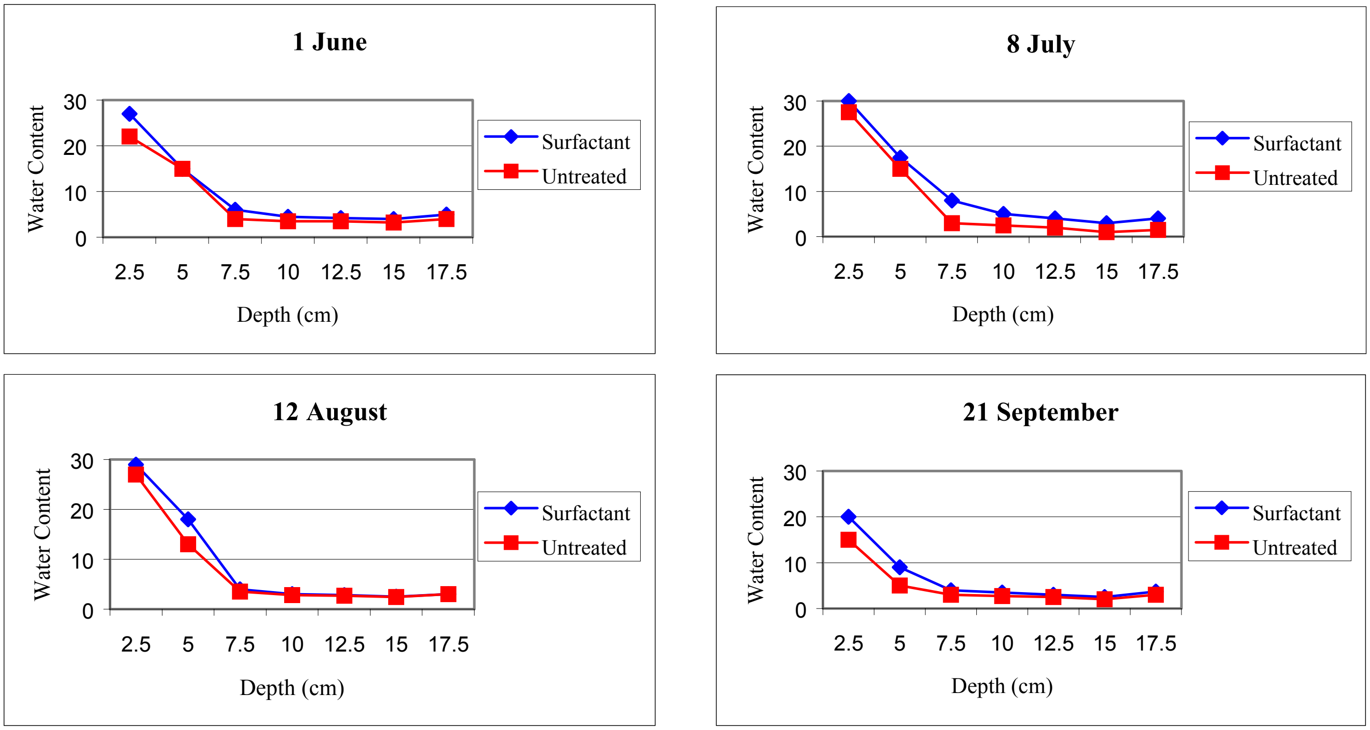

Figure 5. Effect of Aqueduct treatment on temporal infiltration rate (Fayetteville, AR)

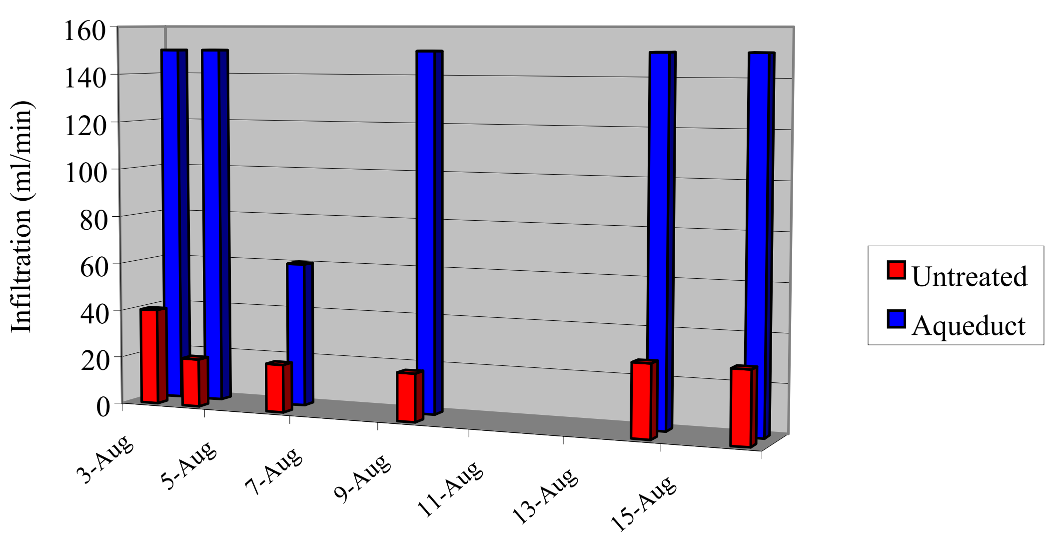

Figure 6. Effect of surfactant treatment on wetting of field moist samples of surfactant treated and untreated soil cores (0-2.5 cm) (Alterra, The Netherlands)