Surfactants and soil water repellency in golf course soils – water use and environmental implications.

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ABSTRACT

Golf courses are highly conspicuous consumers of surface and ground waters for irrigation purposes. As such, golf courses receive considerable public scrutiny on water use as well as on the impacts of management practices on surface and groundwater quality. Soil water repellency is a well established phenomenon in all soils supporting highly managed turfgrass stands. The objective of this presentation is to use recent findings from research conducted on irrigated, water repellent soils (with and without surfactant treatments) to illustrate the effects of soil water repellency on distribution uniformity and irrigation efficiency and its influence on maximization of irrigation inputs and minimization of losses from evaporation, runoff (overland flow), and leaching below the rootzone. Cost-benefit analyses will be presented for management of soil water repellency and the concomitant potential for water conservation.

INTRODUCTION

Water repellent soils are found worldwide under a range of crops and cropping systems (Wallis and Horne, 1992) and are common in sandy soils supporting turf or pasture grasses. The phenomenon is most pronounced in coarse sands 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., 2001).

Golf courses are highly conspicuous consumers of surface and ground waters for irrigation purposes. As such, they receive considerable public scrutiny on water use as well as on the impacts of management practices on surface and groundwater quality. Estimated annual water irrigation water consumption by U.S. golf courses is 1.8 x 10^9 m^3 (475 billion gallons). The amount of water consumed by individual golf courses ranges widely based on the region of the country. On a Rhode Island golf course, water consumption is estimated at approximately 7.5 x 10^4 m^3 $year^{-1}$ (20 million gal) (Rottenberg, 2003). In more arid states like Texas consumption rises further to 4.2×10^5 m^3 (110 million gal)(Grigory, 2003). In Arizona, that number reaches 6.8×10^5 m^3 (180 million gal) annually)(Shimokusa, 2004). In California, average golf course water consumption varies between 4.3×10^5 to 8.5×10^5 m^3 (110-220 million gal) depending on location within the state (Green, 2005).

Soil water repellency (SWR) is a well established phenomenon in all soils supporting highly managed turfgrass stands (Karnok and Tucker, 2002a, 2002b). On newly constructed golf courses, this phenomenon develops rapidly (usually within three years) with visible symptoms occurring seasonally under periods of high evaporative demand. Symptoms include turf wilting and development of dry areas, often impervious to water. These water repellent areas (referred to as localized dry spots or dry patch) are associated with degrading organic matter of plant or microbial origin (including basidiomycete fungi that cause fairy rings). Recently, Hallett et al. (2004) suggested that reduced water infiltration may be linked to small scale microbial and/or chemical processes that cause subcritical water repellency.

Management strategies have traditionally focused on alleviation of dry spot symptoms or control of fairy rings in order to improve localized turf quality and performance. With the worldwide realization of the fragility of water supplies and the occurrences of several prolonged regional droughts, the golf course industry has recognized that options must be developed to more effectively utilize available water resources. While SWR is a recognized problem in turfgrass culture, its hydrological impact and influence on irrigation efficiency is poorly understood.

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). Irrigation practices also influence nitrogen leaching (Barton and Colmer, 2004) be that water does not move beyond the effective rootzone (Snyder et al., 1984) or that preferential flow is mitigated or not established (Bauters et al., 1998). Surfactants have been suggested as a strategy to remediate fingered flow (a form of preferential flow) associated with water repellent soils (Barton and Colmer, 2004).

The key to water conservation is maximizing the amount of water entering the turfgrass rootzone and its storage and availability once in the rootzone (Carrow et al., 2005). Management tactics include: reducing transpiration, reducing evaporation, increasing infiltration, reducing ponding, optimizing retention in the rootzone, and controlling water movement below the rootzone (leaching).

Preliminary studies demonstrated that blends of alkyl polyglycoside (APG) and ethylene oxide-propylene oxide (EO/PO) block copolymer surfactants improved the hydrophilization and infiltration of water into water repellent soils (Kostka and Bially, 2005a; Kostka and Bially, 2005b). The synergistic wetting interactions associated with APG-EO/PO block copolymer blends were produced by blends even when one or both components alone had limited effect on infiltration. When the APG-EO/PO block copolymer surfactant blend was mixed with urea ammonium nitrate (UAN 32) and applied via injection to *Cynodon sp.* growing in a clay soil, rootzone nitrogen and leaf nitrogen were increased in plots receiving the surfactant plus fertilizer treatment over that of the plots receiving the fertilizer alone (Moore et al., 2004) suggesting that application of the APG-EO/PO block copolymer surfactant blend also reduced N leaching.

It is the objective of this paper to review recently published research conducted on irrigated soils (with and without surfactant treatments) to illustrate the effects of soil water repellency on distribution uniformity and irrigation efficiency and its influence on maximization of irrigation inputs and minimization of losses from evaporation, runoff (overland flow), and leaching below the rootzone. Cost-benefit analyses will be presented for management of soil water repellency and the concomitant potential for water conservation.

CASE STUDIES

<u>Case Study 1 - California</u>

A two-year study was conducted at the Center for Turf Irrigation and Landscape Technology (C-TILT) at the California State Polytechnic University, Pomona (Mitra, 2005; Mitra et al., 2005). Twenty-four plots (each 9 m^3) of bermudagrass (*Cynodon sp.* 'GN-1'), growing in a clay loam soil and maintained under golf-course fairway management conditions, were laid out in a split-plot design. Irrigation-water quality (potable or recycled) was the primary factor with surfactant treatments as the secondary factor. Surfactants included, ACA1853, an EO/PO block copolymer formulation (20% ai), applied at 1.753 L ha^{-1} every two weeks and ACA 1848, an APG-EO/PO block copolymer blend (17% ai) applied weekly at 0.877 L ha^{-1}. Surfactant treatments were compared to an untreated control. Each treatment combination was replicated three times. The plots were irrigated at 100% of the reference cumulative monthly evapotranspiration (ETo) demand in May and were reduced to 70% ETo in June, followed by a further reduction to 30% ETo in July and finally 10% ETo in August. Soil volumetric water content was monitored through out the experiment using time domain reflectrometry (TDR) and time domain transmission (TDT) (Aquaflex Sensors, Streat Instruments, New Zealand).

Based on TDR, all the wetting agents treatments helped in retaining higher moisture levels in the soil compared to the control (Table 1). Similar results were obtained with TDT (data not shown). In a clay loam soil under high evaporative demand and irrigated at 100%, 70%, 30% or 10% ETo, ACA1848, the APG-EO/PO block copolymer, maintained higher soil moisture between irrigation cycles compared to plots treated with an EO/PO block copolymer alone (ACA1851) or the untreated control (Table 1). The treatment effect was more pronounced under moisture stress (30% and 10% of ETo). Similar results were obtained whether the plots were irrigated with potable or recycled water. On this fine textured soil, bermudagrass was maintained under optimum conditions with irrigation reduced by 50-70%

Table 1. Effect of surfactants on volumetric soil moisture (VMC) (%) content in soils. Data from the 15th of each month was used for the analysis. The means followed by the same letter do not significantly differ. (P = 0.05 Duncan's New Multiple Range Test).

Treatments	Volumetric Soil Water Content (%)							
	100% ET		70% ET		30% ET		10% ET	
	Potable	Recycled	Potable	Recycled	Potable	Recycled	Potable	Recycled
ACA1851	50 b	49 c	30 b	29 c	20 c	27 b	20 b	23 b
ACA1848	56 a	58 a	36 a	35 a	29 a	32 a	28 a	27 a
Untreated	46 c	40 c	28 c	28 c	18 d	22 c	16 c	17 c

Case Study #2 – Florida

A three-year study was conducted on replicated bermudagrass (*Cynodon dactylon* X *Cynodon transvaalensis* 'Tifdwarf") growing in a sand rootzone at the University of Florida, (Fort Lauderdale Research and Education Center, Fort Lauderdale). Each plot (4m x 4m) had a dedicated irrigation system with an injection system designed to deliver precise volumes of treatment solutions to each plot. Surfactant treatments (ACA1848 at 1.75 L ha^{-1}) were injected monthly in 2002. In 2003, ACA1848 was applied at 1.75 L ha^{-1} monthly or 0.89 L ha^{-1} weekly). In 2004, ACA1848 was applied at 0.89 L ha^{-1} weekly. Controls did not receive any surfactant treatment. Each treatment was replicated three times. Plots were exposed to a dry-down period after treatment applications, and allowed to recover between dry-down/declines with irrigation applied on a daily schedule until monthly surfactant treatments were re-applied. Turfgrass quality (scale of 1-10 with 10=dark green turf, 1=dead/brown turf and 6=minimally acceptable turf), volumetric water content (Theta Probe, Delta-T Devices, Cambridge, England, UK), and localized dry spot (percent), when evident, were taken for the duration of the experiment.

2003-2003 - Turfgrass quality and localized dry spot was significantly improved by addition of surfactant treatments during many rating dates as the dry season study period progressed in intensity from late winter through spring and early summer, with weekly applications producing more consistent quality (Park et al., 2004). Generally, surfactant treatments outperformed untreated controls. The weekly surfactant treatment maintained higher turf quality than the control throughout the test period (Fig. 1). Soil moisture content (VWC) in soils receiving weekly surfactant application was higher than in the controls (Fig. 2). These results suggest that improved turfgrass quality in the surfactant treated plots was a consequence of improved rootzone moisture status and availability.

During a dry six-week period of 2002, evapotranspiration replacement rates were evaluated. During this period, 198 mm of water were lost through evapotranspiration, with only 81 mm of water being replaced by rainfall and irrigation combined. Turf quality was maintained with a net water deficit of 117 mm; a 41% replacement of water lost through evapotranspiration. When this study was repeated in 2003 (March and April), combined irrigation and rainfall was approximately 143 mm, 86 mm less then the predicted ET of approximately 229 mm for that time period. Despite the water deficit, turfgrass quality was improved by surfactant treatment compared to the control. Even under such severe stress conditions, surfactant maintained acceptable turf quality ratings well above that of the control. This was achieved at 41% ET replacement in 2002 and 62% ET replacement in 2003.

2004 – In year three, turf performance was monitored in three separate trials conducted as drydown studies during periods of high evaporative demand (30 April – 02 May, 05 May – 06 May, 16 May – 18 May) (Park et al, 2005). Plots were arrange in a randomized complete block design with each plot receiving one of three treatments: irrigated daily to replace potential ET (irrigated control), no irrigation (non-irrigated control), and surfactant treated (0.89 L ha^{-1}) upon initiation of each drydown period (Table 2). Turfgrass quality and localized dry spot symptoms were monitored visually (as described above) and with an experimental active infrared/red sensor (LICOR, Lincoln, NE, USA).

Table 2. Total water applied to each test plot in each trial period (Fort Lauderdale, FL, 2004).

	Total irrigation applied (mm)		
Treatments	**Trial 1**	**Trial 2**	**Trial 3**
Non-irrigated	4.75	4.50	4.00
Irrigated	14.00	9.00	13.75
Surfactant treated	4.75	4.50	4.00

Surfactant treated plots, while receiving the same limited irrigation as the "non-irrigated" control, had significantly higher visual quality ratings in each trial (Table 3). Visual quality ratings in the surfactant treated plots (irrigated at 50% or less ET replacement) were statistically equal to the irrigated plots that received 100% ET replacement. Reductions in localized dry spots were observed in surfactant-treated and irrigated plots (Table 4). Improved turf physiological status was confirmed using the experimental active infrared/red sensor (Figure 3). The sensor also demonstrated small scale differences that developed between the non-irrigated control and the surfactant-treated and irrigated turfgrass. Surfactant treatment maintained turf quality in each of the three trials while reducing the irrigation requirement between 50% and 71%.

Table 3. Treatment effect on pooled trial mean daily visual quality ratings (1-10, 1 = dead, 6 = minimally acceptable, 10 = high quality) (from Park et al, 2005). Means in columns followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P=0.05.

Treatments	**Day 1**	**Day 2**	**Day 3**
Non-irrigated	7.0 b	6.0 b	6.0 b
Irrigated	7.5 a	7.8 a	7.5 a
Surfactant-treated	7.4 a	7.3 a	7.4 a
Significance	**	***	***

** and *** = P<0.05 and P=<0.01 respectively.

Table 4. Treatment effect on pooled trial mean daily localized dry spot (%)(from Park et al, 2005). Means in columns followed by the same letter are not significantly different according to Duncan's Multiple Range Test at P=0.05.

Treatments	**Day 1**	**Day 2**	**Day 3**
Non-irrigated	10	36 a	58 a
Irrigated	3	9 b	13 b
Surfactant-treated	3	13 ab	14 b
Significance	Ns	*	***

ns, *, and *** = P>0.10, P<0.10, and P<0.01 respectively.

DISCUSSION

These results, based on multi-year evaluations in different environments and soils, provide science-based evidence that a specific group of surfactants, the APG-EO/PO block copolymer blends (Kostka and Bially, 2005a, 2005b) when incorporated systematically at low levels in irrigation water can improve infiltration into water repellent soils and increase soil rootzone moisture. This surfactant blend was more effective than the EO/PO block copolymer component alone. On a clay loam soil this surfactant blend maintained optimum turf quality when irrigation reduced by 50-70%. In a fine sand, bermudagrass performance was maintained under irrigation reductions of 38-71%. By delivering water more effectively, distribution uniformity was improved even under deficit irrigation conditions. Perhaps most striking is the ability of low level surfactant treatments to maintain turf quality and physiological status when irrigation was reduced by up to 71%.

What are the ramifications of this technology on water use and conservation on golf courses? As a basis for analysis, we use a fictitious California golf course using the minimum average consumption of 4.3 x 10^5 m^3 (110 million gal) $year^{-1}$ reported by Green (2005). Water cost estimates are based on pumping costs plus any fees to municipal providers. The two case studies reviewed substantiate that a 50% reduction in irrigation 2.15 x 10^5 m^3 (55 million) can be achieved realistically without reducing turfgrass performance. Based on the results from these studies and an estimate of surfactant cost reflecting application of the APG-EO/PO technology at 0.88 – 0.89 L ha^{-1}, the net annual savings, including the cost of surfactant, would range from $23,500 - $86,000, depending on water source and local cost structure.

	Water Cost (Estim.)	Surfactant Costs	Projected Savings
Ground or Surface Water	$57,000[a]	$5,000	$23,500
Municipal Water	$140,000[b]	$5,000	$65,000
Effluent Water	$170,000[b]	$5,000	$80,000

[a] Estimate of energy costs
[b] Includes energy costs

Currently, "best management practices (BMPs)" recommend a diversity of options for conserving potable water (Carrow et al, 2005). The surfactant technology evaluated in this study, provides a low cost strategy, high return strategy to a) reduce water requirements, b) conserve available water, b) maintain golfer and management expectations for quality turfgrass, and c) manage resources effectively.

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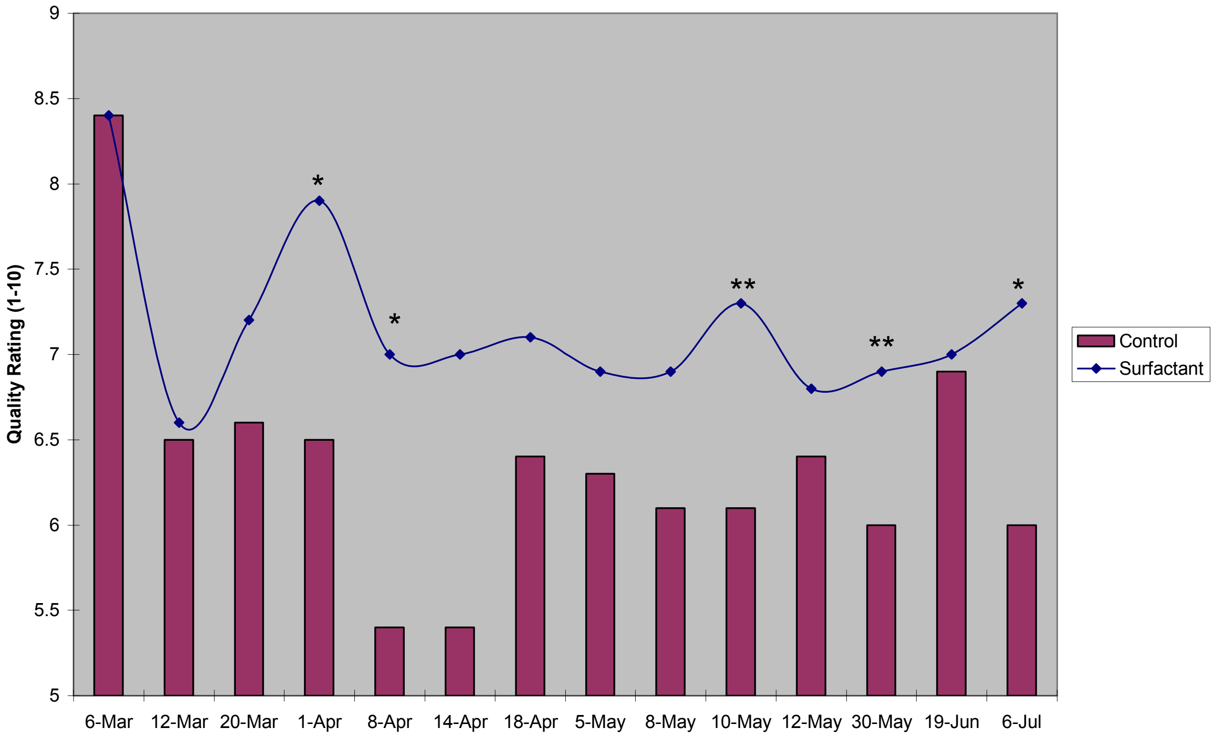

Figure 1. Effect of injected surfactant treatment on bermudagrass quality under Florida conditions (2003). The following indicate significant differences between means on an observation date: * and ** = P<0.05 and P<0.01 respectively.

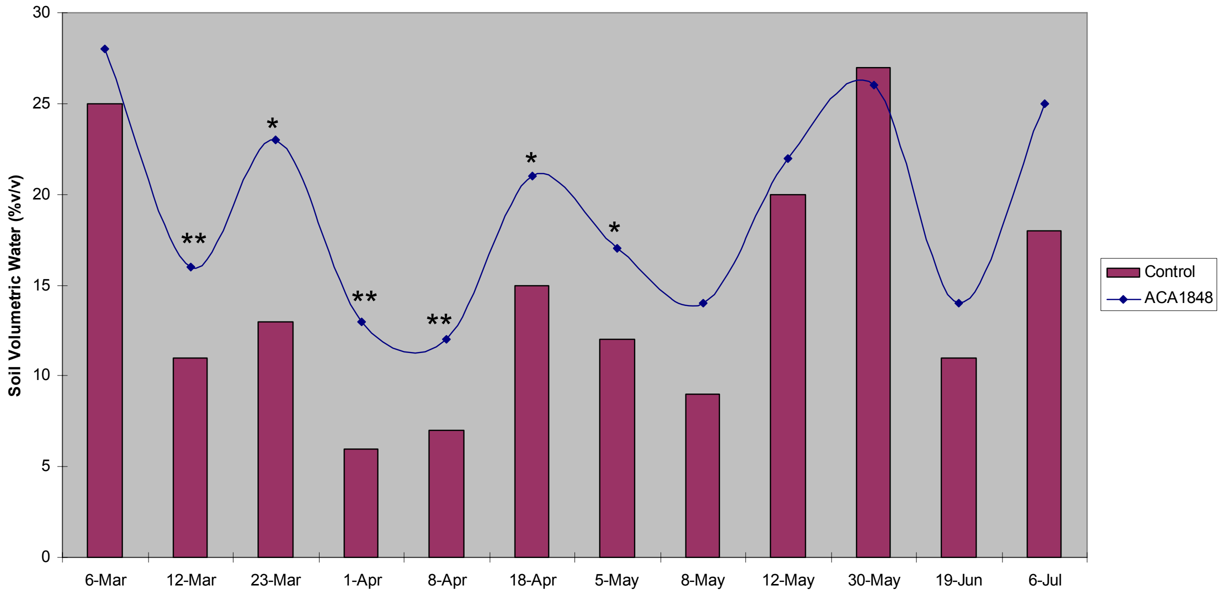

Figure 2. Effect of injected surfactant treatment on soil volumetric water content (vol:vol) in a fine sand soil under Florida conditions (2003). The following indicate significant differences between means on an observation date: * and ** = P<0.05 and P<0.01 respectively.

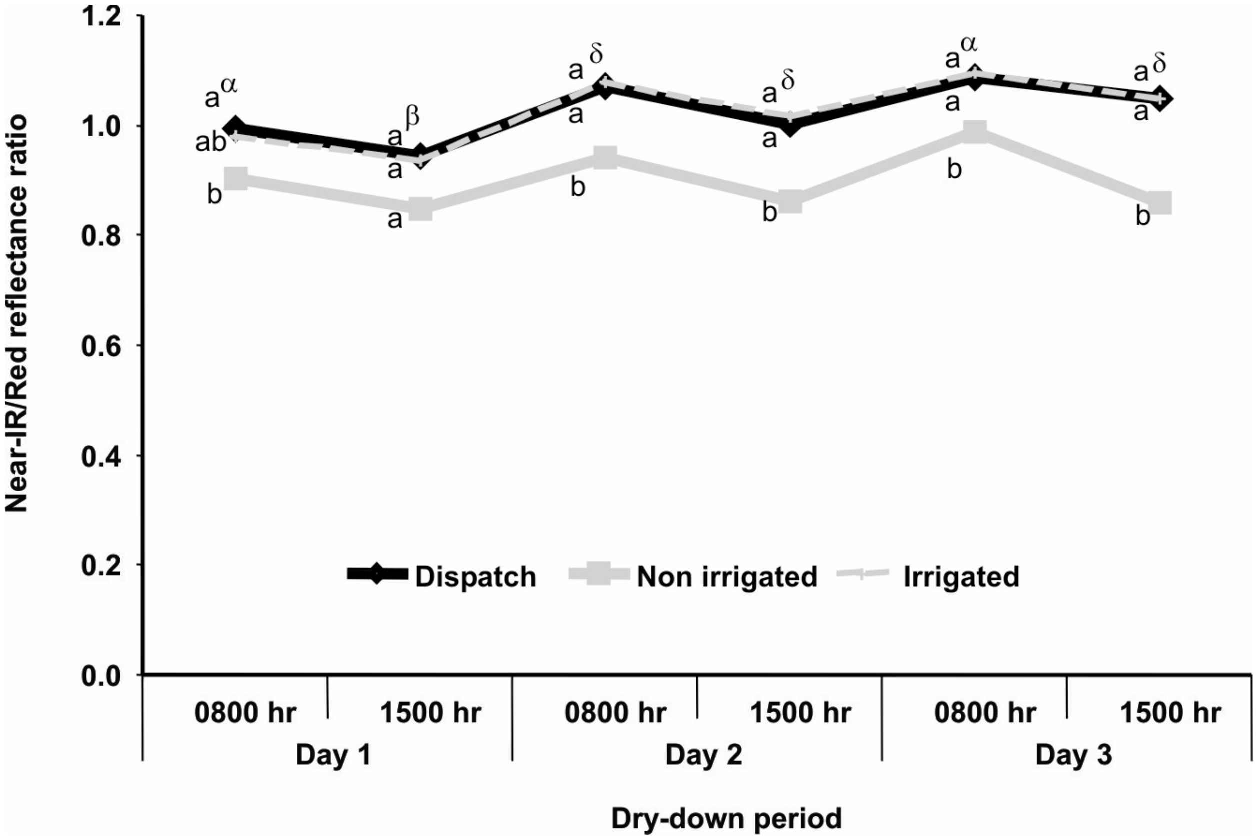

Figure 3. Mean morning and afternoon pooled trial near-IR/Red reflectance ratio (from Park et al, 2005). Means with the same letter within a column are not significantly different α, β, and δ = P<0.10, P<0.05, and P<0.01 respectively.