Title:	**Surfactants for water conservation and their impact on soil health**
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Objectives:

i. To evaluate the effects of natural and market available chemical surfactants on the physical, chemical and biological soil health indicators in turfgrass under both sufficient and deficit irrigation in an arid environment

ii. To identify suitable minimum data set (a suite of soil measurements) that can be used for turfgrass soil health assessment and to develop soil health indexes from these measurements that will be related to turfgrass performance for bermudagrass and Kentucky bluegrass

iii. To assess the effects of natural and market available chemical surfactants on turfgrass quality under deficit irrigation

iv. Incorporate our findings into best turfgrass management practices

Start Date:	2019
Project Duration:	2 years (2019 – 2020)
Total Funding:	$29,290.00

Summary Points:

1) Soil surfactants did not affect soil biological parameters Total Biomass, Arbuscular Mycorrhizal Biomass, Total Bacteria Biomass, Total Fungi Biomass, Fungi Bacteria Ratio, and Diversity Index for both Kentucky bluegrass and bermudagrass.
2) Soil biological parameters did not correlate with turfgrass performance parameters such as visual quality, percent coverage, or DGCI and NDVI.
3) Surfactants did not affect soil moisture, turfgrass quality, and soil moisture uniformity of Kentucky bluegrass.
4) When data were averaged over all sampling dates and ET replacement levels, Bermudagrass plots treated with Revolution had highest quality.
5) Bermudagrass plots treated with Dispatch or Revolution and irrigated at 45% ET replacement level showed similar quality than untreated plots irrigated at 75% ET.
6) Bermudagrass plots that received Revolution exhibited the most uniform soil moisture distribution.

Soil surfactants have been used in regular turfgrass maintenance programs to increase irrigation efficiency, because their use has been shown to increase uniformity and improve the moisture retention in the root zones (Alvarez et al., 2016; Kostka and Bially, 2005; Leinauer et al., 2001; Leinauer et al., 2010; Leinauer and Devitt, 2013; Mitra et al., 2005). Due to their ability to weaken the surface tension, wetting agents permit the penetration of water not only into repellent rootzone areas but also into the meso and micropores of soils. Thus, in addition to offering remediation of LDS and hydrophobic soil conditions, soil surfactants may also help to reduce irrigation requirements by improving water use efficiency. Several studies have documented improved turfgrass performance under drought or decreased irrigation when soil surfactants were applied (Alvarez et al., 2017; Cisar et al., 2000; Kostka, 2005; Kostka et al., 2007). Currently, 94% of golf courses in the United States have incorporated soil surfactants into their regular maintenance protocols (Gelernter et al., 2015).

While the benefits of surfactants in combating LDS and soil hydrophobicity have been well documented, the effects of long-term use of surfactants on overall soil health have not been studied. Golf course superintendents have started to report changes in the soil physical properties after long-term application of surfactants, such as decreased drainage, increasing anaerobic soil conditions, and lower turf quality.

Soil health or soil quality is “the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health” (Doran & Parkin, 1996). To fulfill these requirements, healthy soils usually integrate physical, chemical, and biological attributes of the soil (Idowu et al., 2008). The interactions of soil chemical, physical, and biological properties often determine how effectively the soil functions in areas of nutrient retention and release, partitioning of rainfall into runoff and infiltration, moisture retention and release, resistance to environmental degradation, and buffering environmental pollutants (Karlen et al. 1997). The assessment of soil health is not based on the magnitude of any single soil parameter, but rather relies on selected soil measurements (soil health indicators) to quantify management-induced changes (Arshad & Coen, 1992; Doran & Parkin, 1994). A suite of soil measurements that best describe changes in response to management practices constitutes the minimum data set (MDS), and the MDS vary with soil health management goals (Andrews et al., 2002). Currently, there is no documentation on the MDS that can be used to holistically assess soil health of turfgrass in arid environments. Most of the previous studies have only focused on specific soil aspects, without any integration of the physical, chemical and biological attributes of the soil. Due to environmental concerns, chemicals applied to turfgrass systems are receiving increased scrutiny, and the impacts of these chemical need to be related to soil health.

Study

A study was conducted at New Mexico State University in Las Cruces, New Mexico from 2019 to 2020 to investigate the effects of repeated applications of commonly available chemical and natural soil surfactants on soil health, irrigation water requirement, and turfgrass quality (Figure 1). The study was initiated in 2018 and included four non-ionic wetting agents which were compared against an untreated control on ‘Princess 77’ bermudagrass (*Cynodon dactylon* L.) and ‘SR 2100’ Kentucky bluegrass (*Poa pratensis* L.).

Figure 1. Study area at New Mexico State University. Soil sampling on Kentucky bluegrass site (left), Bermudagrass plots (right).

The study included the following surfactants:
1) a modified methyl capped block co-polymer (trade name Revolution)
2) an alkyl polyglycoside (trade name Dispatch)
3) a natural wetting agent derived from *Yucca schidigera* (trade name Therm X-70) and
4) a rhamnolipid biosurfactant (trade name ZONIX). Rhamnolipids are glycolipids (two rhamnoses conjugated to fatty acid chains) produced by *Pseudomonas aeruginosa*. Their high surface activity has been reported not only for emulsifiers and detergents but also when applied to agricultural and horticultural soils (Ali et al., 2017; Renfro, 2013; Yang, 2008).

Turfgrass performance was evaluated twice per month by means of visual quality ratings, Digital Image Analysis (Coverage, Hue, Saturation, Brightness, and Dark Green Color Index), and Normalized Difference Vegetation Indices (NDVI) by means of a Greenseeker and subsequently averaged over sampling month. Soil biological indicators included the permanganate oxidizable carbon (Weil et al., 2003), soil organic matter using the Walkley-Black method (Nelson and Sommers, 1982) and the soil microbial community using the phospholipid fatty acid (PLFA) analysis (Buyer and Sasser, 2012). Phospholipid fatty acid analysis provides information on the amount of gram positive and gram negative bacteria; the amount of arbuscular mycorrhiza fungi and the total fungi; and the amount of anaerobes and actinomycetes. Soil physical measurements included saturated hydraulic conductivity, bulk density, dry aggregate size distribution, wet aggregate stability, and soil moisture retention characteristics.

Plots were mowed three times per week at a height of 1.2 cm (1/2") by means of a reel mower with clippings returned. A pre-emergence herbicide, Barricade 4L (Prodiamine @ 21 oz/A) was applied in mid-March and in mid-June. The insecticide Acelepryin (Chorantraniliprole @ 12oz/A) was applied in mid-June for white grub control. Fertilization consisted of a total of 20 g N, 4 g P_2O_5, and 8 g K_2O m^{-2} for both grasses. Fertilizer was applied monthly from April to September on bermudagrass and in March, April, May, August, September, and October on Kentucky bluegrass. Iron fertilization was applied 3 times during the growing season by means of Six Iron™ (12-0-0) which was added to the spray tank at 6oz/1000sqft during July and August.

The field experiment was laid out in a completely randomized block design with two levels of irrigation (75% and 45% ETos on bermudagrass and 90% and 65% ETos on Kentucky bluegrass) as the block treatment and surfactants at the plot level. Each treatment combination was replicated four times.

Results

Bermudagrass

Analysis of variance revealed that the interaction between surfactants and sampling months had a significant effect on DGCI, soil moisture, NDVI, and quality (Table 1). Moreover, quality was also affected by the interaction between surfactants and irrigation level (Table 1). Surfactants as a main effect influenced soil moisture uniformity (Table 1). When data were averaged over both irrigation levels and all sampling months bermudagrass plots treated with Revolution had highest quality and highest soil moisture content. Bermudagrass plots treated with Revolution also exhibited the most uniform soil moisture distribution. However, surfactants did not affect soil biological parameters Total Biomass, Arbuscular Mycorrhizal Biomass, Total Bacteria Biomass, Total Fungi Biomass, Fungi Bacteria Ratio, and Diversity Index.

Kentucky Bluegrass

Analysis of variance revealed that the interaction between surfactants, ET, and sampling months had a significant effect on NDVI (Table 1). Similar to bermudagrass, ANOVA also revealed that the interaction between surfactants and sampling months had a significant effect on DGCI (Table 1). Soil surfactants did not affect cover, visual quality, soil moisture and moisture uniformity, neither as main effect nor as interactions with ET and sampling months. Similar to bermudagrass, surfactants also did not affect soil biological parameters.

Conclusion

Surfactant treatments had no effect on soil biological parameters measured for either Kentucky bluegrass or bermudagrass. Results indicate that surfactants do not positively or negatively influence the soil microbial community, regardless of the type of surfactant applied (organic or synthetic). However, longer term investigations should be conducted to verify if this trend holds if surfactants are applied over several years.

Table 1. Probability values obtained from ANOVA, testing the effects of surfactants, irrigation replacement based on evapotranspiration for short grass (ET), sampling month (Date), and their interactions on percent green cover (Cover), Dark Green Color Index (DGCI) (both parameters determined by means of digital image analysis), volumetric soil water content (moisture), Normalized Difference Vegetation Index (NDVI), visual turfgrass quality (Quality), and soil moisture uniformity of ‘Princess 77’ bermudagrass (*Cynodon dactylon* L.) and ‘SR 2100’ Kentucky Bluegrass (*Poa pratensis* L.).

Effect	Cover	DGCI	Moisture	NDVI	Quality	Uniformity
			Bermudagrass			
Surfactant	0.0850	0.0418	0.0027	0.0518	<.0001	0.0008
ET	0.0185	0.0157	0.0017	0.0039	0.0004	0.3771
ET*Surfactant	0.3483	0.3052	0.6677	0.7088	0.0286	0.0923
Month	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Surfactant*Month	0.0979	0.0112	0.0013	0.0223	0.0307	0.8578
ET*Month	0.0006	<.0001	<.0001	<.0001	<.0001	0.0004
ET*Surfactant*Month	0.5569	0.5860	0.1398	0.2820	0.9886	0.8952
			Kentucky Bluegrass			
Surfactant	0.3909	0.4988	0.2364	0.9810	0.0698	0.4749
ET	0.0053	0.0238	0.0662	0.0083	0.0027	0.5957
ET*Surfactant	0.2751	0.4403	0.7806	0.2388	0.1558	0.4436
Month	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Surfactant*Month	0.0554	0.0112	0.5959	0.0925	0.3804	0.6049
ET*Month	<.0001	<.0001	<.0001	<.0001	<.0001	0.0630
ET*Surfactant*Month	0.0798	0.4335	0.8815	0.0069	0.2971	0.8961

Table 2. Percent green cover (Cover), Dark Green Color Index (DGCI), soil moisture content (Moisture), Normalized Difference Vegetation Index (NDVI), and visual turfgrass quality (Quality) of ‘Princess 77’ bermudagrass as affected by different soil surfactants. Values are listed separately for each sampling month and averaged over two irrigation levels (45% and 75% of reference evapotranspiration for short grass).

Surfactant	May	June	July	August	September	October	November
Cover							
Control	96.9A	99.6A	99.7A	98.4A	98.3A	96.9A	96.6AB
Dispatch	94.0A	99.6A	99.7A	95.6A	94.4A	93.0A	93.5AB
Revolution	93.5A	99.7A	99.7A	97.9A	98.8A	98.8A	98.7A
Rhamnolipids	93.7A	99.3A	98.9A	93.5A	93.9A	89.8A	92.8AB
Yucca	92.6A	99.3A	98.7A	96.6A	93.4A	87.7A	86.8B
DGCI							
Control	0.4405A	0.5036A	0.5194A	0.4196A	0.4874AB	0.4826AB	0.4743AB
Dispatch	0.43A	0.5034A	0.5078A	0.4035A	0.4581B	0.4549AB	0.4509AB
Revolution	0.4286A	0.5012A	0.5179A	0.4332A	0.5056A	0.5049A	0.4921A
Rhamnolipids	0.429A	0.4992A	0.5154A	0.4082A	0.4637AB	0.4578AB	0.4637AB
Yucca	0.4254A	0.4937A	0.4946A	0.4092A	0.4509B	0.4404B	0.4363B
Moisture							
Control		21.1A	15AB	13.3AB	13.9AB	11.4AB	10.2AB
Dispatch		19.9A	14.0B	11.0B	11.8B	8.6C	8.3B
Revolution		19.9A	16.8A	16.0A	15.8A	12.7A	12A
Rhamnolipids		19.7A	14.8AB	12.1B	12.1B	9.2BC	8.6B
Yucca		18.0A	13.8B	10.9B	12.1B	8.6C	8.7B
NDVI							
Control	0.5994A	0.7434A	0.7471A	0.6546AB	0.6672AB	0.689AB	0.6515A
Dispatch	0.568AB	0.7375A	0.7346A	0.6327AB	0.6416AB	0.6822AB	0.6499A
Revolution	0.5689AB	0.7487A	0.7601A	0.6837A	0.7293A	0.7585A	0.7106A
Rhamnolipids	0.5552AB	0.723A	0.7418A	0.6269AB	0.6408AB	0.6895AB	0.6664A
Yucca	0.5347B	0.7135A	0.7153A	0.6186B	0.6363B	0.6546B	0.6284A
Quality							
Control	5.3B	6.9C	6.6B	6.1B	5.0B	4.8B	4.6B
Dispatch	5.8B	8AB	7.1B	6.4B	5.6B	5.1B	4.8B
Revolution	6.6A	8.4A	8.2A	7.8A	7.1A	7.1A	6.2A
Rhamnolipids	5.6B	7.6BC	6.8B	6.1B	5.2B	5.1B	5.1B
Yucca	5.2B	7.3C	6.6B	6.2B	4.9B	4.5B	4.5B

[¶] Values followed by the same letter in each column (separately for each output variable) are not significantly different according to simulated adjustment (0.05).

Table 3. Percent green cover (Cover), Dark Green Color Index (DGCI), soil moisture content (Moisture), Normalized Difference Vegetation Index (NDVI), visual turfgrass quality (Quality), and soil moisture uniformity (Uniformity) of 'Princess 77' bermudagrass as affected by different soil surfactants. Values are averaged over seven sampling months and two irrigation levels (45% and 75% of reference evapotranspiration for short grass).

Surfactant	Cover	DGCI	Moisture	NDVI	Quality	Uniformity
Control	98.0A¶	0.4753AB	14.2AB	0.6789AB	5.6B	3.8A
Dispatch	95.7A	0.4584AB	12.3B	0.6638AB	6.1B	3.7A
Revolution	98.2A	0.4833A	15.5A	0.7086A	7.4A	2.5B
Rhamnolipids	94.6A	0.4624AB	12.8B	0.6634AB	5.9B	3.3AB
Yucca	93.6A	0.4501B	12.0B	0.643B	5.6B	3.6A

¶Values followed by the same letter in each column are not significantly different according to simulated adjustment (0.05)

Table 4. Visual turfgrass quality of 'Princess 77' bermudagrass as affected by different soil surfactants and reference evapotranspiration for short grass (ET). Values are averaged over seven sampling months.

Surfactant	45% ET	75% ET
Control	5.1D	6.1B
Dispatch	6.0BCD	6.2B
Revolution	6.7B	8.0A
Rhamnolipids	5.1CD	6.7B
Yucca	5.1CD	6.0BC

¶Values followed by the same letter are not significantly different according to simulated adjustment (0.05)

Table 5. Normalized Difference Vegetation Index (NDVI) of 'SR 2100' Kentucky bluegrass as affected by different soil surfactants, sampling months and irrigation levels based on 45% and 75% of reference evapotranspiration for short grass (ET).

Surfactant	May	June	July	August	September	October	November
				55% ET			
Control	0.7186A	0.7524A	0.7284A	0.6618A	0.6325BC	0.7234BC	0.7579C
Dispatch	0.6796AB	0.7325A	0.7411A	0.6711A	0.7006ABC	0.7714ABC	0.7962ABC
Revolution	0.6832AB	0.7178A	0.7161A	0.6702A	0.6796ABC	0.7479ABC	0.7849ABC
Rhamnolipids	0.7145A	0.7355A	0.7201A	0.6277A	0.6063C	0.6963C	0.7672BC
Yucca	0.6416B	0.73A	0.7363A	0.6675A	0.6939ABC	0.7799ABC	0.82AB
				85% ET			
Control	0.6854AB	0.7189A	0.7567A	0.7169A	0.7562AB	0.8157AB	0.8324A
Dispatch	0.6681AB	0.7316A	0.7512A	0.6802A	0.7224ABC	0.8041AB	0.838A
Revolution	0.6752AB	0.7078A	0.7332A	0.6984A	0.7496AB	0.8075AB	0.831A
Rhamnolipids	0.6932AB	0.7338A	0.7649A	0.7234A	0.7693A	0.8283A	0.8437A
Yucca	0.6734AB	0.7289A	0.7538A	0.7109A	0.7397AB	0.7972ABC	0.8209AB

¶Values followed by the same letter in each column (across both ET levels) are not significantly different according to simulated adjustment (0.05).

Table 6. Percent green cover (Cover) and Dark Green Color Index (DGCI) of ‘SR 2100’ Kentucky bluegrass as affected by different soil surfactants Values are listed separately for each sampling month and averaged over two irrigation levels (45% and 75% of reference evapotranspiration for short grass).

Surfactant	May	June	July	August	September	October	November
				Cover			
Control	97.4AB	98A	98.7A	95.4A	93.4A	97.2A	98.4A
Dispatch	97.2AB	98.3A	98.1A	94.2A	94.3A	95.9A	98.1A
Revolution	96.7AB	98.1A	97.3A	97.1A	97.3A	98.5A	98.9A
Rhamnolipids	97.8A	98.6A	98.8A	91.5A	91.3A	94.3A	97.3A
Yucca	95.8B	97.5A	98.4A	94.7A	95.7A	97.9A	99.1A
				DGCI			
Control	0.4843A	0.5028A	0.5281AB	0.4702A	0.5198A	0.5499A	0.5762A
Dispatch	0.4748A	0.5072A	0.5282AB	0.4693A	0.5141A	0.5467A	0.5777A
Revolution	0.4662A	0.4901A	0.5061B	0.4655A	0.5196A	0.5598A	0.5855A
Rhamnolipids	0.4856A	0.5092A	0.5293AB	0.4557A	0.5015A	0.5354A	0.5681A
Yucca	0.4671A	0.5095A	0.5357A	0.4777A	0.5293A	0.5712A	0.5981A

¶Values followed by the same letter in each column (separately for each output variable) are not significantly different according to simulated adjustment (0.05).

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