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Surfactant and irrigation impacts on soil water content and leachate of soils and greenhouse substrates

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Abstract

Water retentionx is considered an important characteristic for determining the efficiency and effectiveness of soils and greenhouse substrates. Surfactants have the potential to improve water infiltration and distribution uniformity throughout the soil profile. In addition, efficient irrigation can improve the wettability of soils. The objective of this study was to determine how surfactants and irrigation influence soil water content (SWC), leachate volume, and pH in soils and greenhouse substrates. This study was conducted at Clemson University, SC, on two soils (sandy loam and sand) and two substrates (Fafard 3B-SURF and 80% sand, 20% peat). Four surfactants (a) 10% oleic acid esters of block copolymers (OAC), (b) 30% alkoxylated polyols and 21% glucoethers (APG), (c) 50% nonionic polyols and 5% 1,2-propanediol (NIPP), and (d) water control (CNT) with two irrigation regimes (ONCE and SPLIT) were applied to PVC columns. Based on the leachate results, applying irrigation volume as SPLIT in conjunction with using a surfactant reduced leachate up to 75%. The soils retained more water when OAC and NIPP surfactants were applied. When the soil was left to dry out, the SWC was 5 and 9% higher from SPLIT irrigation compared with ONCE irrigation in the sand–peat and the sand soils, respectively. Surfactants can increase SWC, and combining split irrigation with surfactants can play an important role in reducing leaching from soils and greenhouse substrates, resulting in water quality and quantity conservation, and an economic advantage to the grower.

1 | INTRODUCTION

Drought has a significant impact on crop production and ultimately food security (Fahad et al., 2017). For example, crop losses in the United States as a result of the 2007 drought were estimated to be more than US$1.3 billion (USDA-NASS, 2014). This situation can be more critical for soil types having a low water holding capacity and rapid infiltration (Brady & Weil, 2008). In addition, warm temperate climates cause soils to become water repellent (Barton et al., 2020). With prolonged dry periods, organic matter from plant root exudates dry out and coat soil particles, resulting in a large number of nonpolar sites on soil particle surfaces (Ellerbrock et al., 2005; Graber et al., 2009; Hallett et al., 2006; Ruthrof et al., 2019). This can cause the soil to expel the irrigated water (Blackwell, 2000; Rye & Smettem, 2017; Zheng et al., 2016), thus reducing the efficiency of irrigation water.

Abbreviations: APG, 30% alkoxylated polyols and 21% of glucoethers; CNT, water control; NIPP, 50% nonionic polyols and 5% 1,2-propanediol; OAC, 10% oleic acid esters of block copolymers; ONCE, irrigate on Tuesdays; SPLIT, irrigate on Tuesdays and Thursdays; SWC, soil water content.

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To increase production, growing food crops in shade and greenhouses has become more wide-spread over the past decade (Anderson et al, 2011; Case et al., 2005; Nafiye & Gubbuk, 2015; USDA-NASS, 2014). For best productivity, artificial and soilless growing substrates composed of various components including peat moss, bark, compost, vermiculite, and perlite are used (Asaduzzaman et al., 2015; Gizas & Savvas, 2007; Shaw et al., 2004). These soilless substrates are considered to be essentially free of diseases, insects, and weed seeds (Alsmairat et al., 2018; Anderson et al, 2011) and, therefore, result in increased yields per unit area (Lopez-Medina et al., 2004). Although using substrates has its advantages (Michael & Lieth, 2007; Neocleous & Ntatsi, 2018), water management can be problematic (Caron et al., 2015) because they are primarily composed of organic matter (Fields, 2013; Horowitz & Elmore, 1991. When these organic materials such as waxes (Hallett et al., 2006), alkanes (Mainwaring et al., 2004), and fatty acids (Graber et al., 2009) dry out, a large number of nonpolar sites on the surface of the soil particles are formed (Ellerbrock et al., 2005; Wallis & Horne, 1992), causing a reduction in substrate wettability (Greco, 2002; Zheng et al., 2016).

One of the potential management practices for enhancing the ability of soil to capture and retain water is the use of soil surfactants, commonly called wetting agents (Bilderback & Lorscheider, 1997; Czarnota & Thomas, 2006; Fields et al., 2014). Because these surfactants have an affinity for the surface of hydrophobic soil particles and adsorb at the soil surface, they reduce the surface tension of the water, letting it infiltrate soils and distribute uniformly throughout the soil profile (Hallett, 2006; Song et al., 2018). Thus, combining these surfactants with irrigation may improve both irrigation efficiency and crop quality and yields. For example, the application of the surfactant 10% alkyl polyglycoside, 7% ethylene oxide/propylene oxide block copolymer with irrigation water has been found to increase the vertical movement of the water compared with a control, resulting in increasing irrigation efficiency and plant yield (Chaichi et al., 2015). Applying a modified alkylated polyol surfactant (Aamlid et al., 2009) and a methyl-capped triblock copolymer surfactant (Dekker et al., 2019) has been found to increase the soil water content (SWC) of sand rootzones of grass, leading to enhanced turfgrass performance. The application of alkylphenol ethoxylate surfactant with irrigation to a bark–peat–perlite (equal volume) substrate increased its SWC (Blodgett et al., 1993). In addition, alkyl phenol ethoxylate surfactant decreased substrate leaching the amount of substrate leaching and increased the wettability rate for bark substrate (Michael et al., 2008). Similar results were found when a non-ionic ether poly-ethylene-glycol none-phenol soil surfactant was applied to coconut coir substrate (Urrestarazu et al., 2008).

These and a wide range of other surfactant chemistries on the market and under development today claim to help soil retain moisture efficiently (Curtis & Thomas et al., 2016; Zontek & Kostka, 2012). Further claims that some soil surfactants decrease leaching are being promoted to farmers with minimal scientific support. Moreover, little is known about the combined effect of surfactants and irrigation management on leachate pH and volume and the SWC of the soils and soilless growing substrates. We hypothesize that different surfactants affect leachate pH and volume and SWC differently depending on their chemistry and on irrigation management. Thus, the objective of this study was to evaluate the effect of various surfactant chemistries on these three factors under different irrigation management regimes.

Core Ideas

- In most cases, integrating surfactants with irrigation resulted in more optimal rootzone moisture environment for plant growth, which can be economically advantageous to the grower.
- Applying 2.54 cm water volume split over two irrigation events per week in conjunction with using certain surfactant chemistries reduced leachate up to 75%.
- More water was retained when soil surfactants were applied.
- The water content at different soil depths was influenced by surfactant chemistry and growth medium.

2 | MATERIALS AND METHODS

2.1 | Site description and leaching columns preparation

An experiment was conducted at Clemson University's Research Greenhouse Complex (Clemson, SC; 34°40′8″ N, 82°50′40″ W) from 2 Sept. to 13 Nov. 2014 and repeated from 3 Feb. to 16 Apr. 2015 to evaluate how surfactants and irrigation affect the SWC and leachate volume and pH. This experiment involved a split plot experimental design with four replicates per treatment, with irrigation regime as the main plot factor, soil as the sub-plot factor, and surfactant treatments randomized within soils. Leaching columns (total of 128) 7.6 cm in diameter by 30 cm in length were constructed from polyvinyl chloride pipe. A screen was laid over the bottom of each column to retain soil followed by a slip cap with a 1.9-cm hole bored in the bottom to allow the columns to drain. Four slits were cut horizontally into each column at 5, 10, 15, and 25 cm from the top lip (Figure 1a) to measure the SWC.

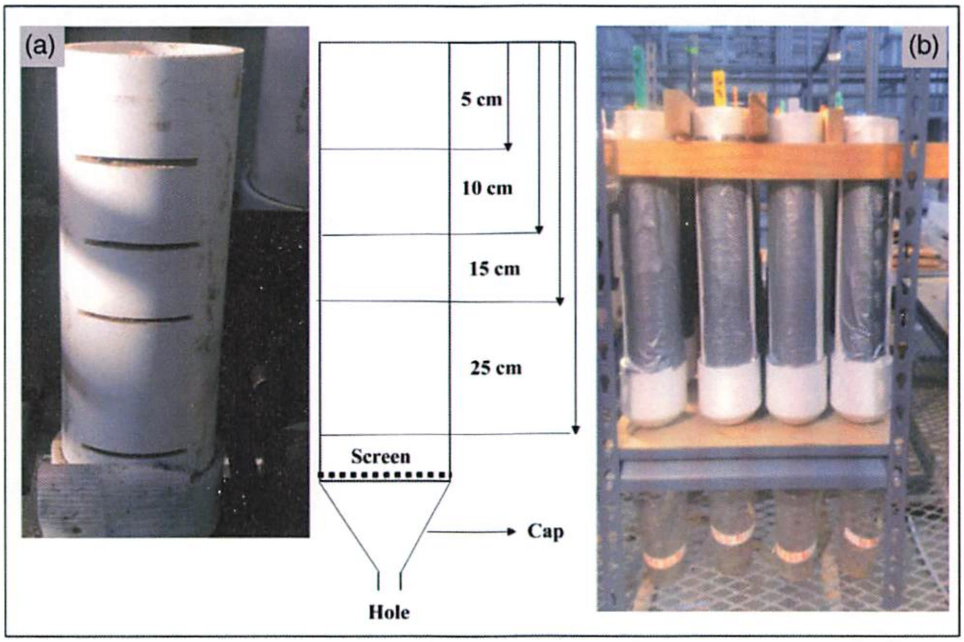

FIGURE 1 Photograph and diagram of the leaching column (a) used in the study made of polyvinyl chloride pipe with a length of 37 cm and an inner diameter of 7.6 cm showing the cap with the hole to collect the leachate water. Photograph of the shelving unit (b) that was used to vertically hold the columns of each soil

TABLE 1 Chemical properties of the sand, sandy loam, 80:20 sand/peat, and Fafard 3B-SURF used this study

	Sand	Sandy loam	Sand–peat	Fafard3B-SURF
pH	7.3	6.2	7.8	5.6
P, kg ha^{-1}	6	50	3	2
K, kg ha^{-1}	8	202	212	110
Mg, kg ha^{-1}	16	235	109	71
Ca, kg ha^{-1}	1,536	766	299	56

2.2 | Soil packing

One-fourth (32) of the columns were filled with Goldsboro series (fine-loamy, siliceous, subactive, thermic Aquic Paleudults) sandy loam, a layer from 0 to 10 cm obtained from the Pee Dee Research and Education Center (PDREC) in Florence, SC, one of the significant agriculture areas of South Carolina. Another 32 columns were filled with commercial sand used as a control. The soils were dried and screened through a 2-mm sieve before filling. An additional 32 columns were filled with 80:20 sand/peat rootzone mix (Clemson University Sport Maintenance Facility), and the remaining one-fourth with a Fafard 3B without the standard surfactant (Fafard 3B-SURF) (Sun Gro Horticulture). Subsamples of all soils were sent to Clemson University Agricultural Services Laboratory, Clemson, SC, for pH analysis (1:1 soil/water method), and P, K, Mg, and Ca (by Mehlich-1 extraction and inductively coupled plasma, ICP) (Table 1). All columns in each experiment were packed with each soil to a height of 28.5 cm by uniformly tapping using a wooden rod to achieve a uniform packing at the same bulk density (Jalali & Ostovarzadeh, 2009). Eight shelving units (each shelf holding 16 columns) approximately 7.6 cm above the floor were used to vertically hold all the columns containing the soils (Figure 1b).

2.3 | Soil surfactant and irrigation application

At the beginning of the experiment, distilled water was applied to the 128 columns to thoroughly wet the profiles. The next day, the experiment began with the application of the soil surfactants and irrigation treatments. Two irrigation treatments were applied in this study: (a) irrigating with 2.54 cm of water on Tuesdays (ONCE) or (b) irrigating with 1.27 cm of water on Tuesdays and Thursdays (SPLIT). Surfactants were mixed with irrigation and applied on Tuesdays only. Surfactants were applied once each week and irrigation was applied twice a week over the study period. The four surfactant treatments were (a) 10% oleic acid esters of block copolymers (OAC, applied at a rate 1.12 kg ha^{-1}), (b) 30% alkoxylated polyols and 21% of glucoethers (APG, applied at a rate 0.56 kg ha^{-1}), (c) 50% nonionic polyols and 5% 1,2-propanediol (NIPP, applied at a rate 0.56 kg ha^{-1}), and (d) water without surfactant (CNT) (Table 2). All surfactants

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TABLE 2 Soil surfactant abbreviations, chemistries, manufacturers, and rate used in this study

Abbreviation	Active ingredient	Manufacturer	Rate
			kg ha^{-1}
OAC[a]	10% oleic acid esters of block copolymers	Agstone, LLC, Greenville, SC	1.12
APG	30% alkoxylated polyols and 21% of glucoethers	Aquatrols Corporation of America, Paulsboro, NJ	0.56
NIPP	50% nonionic polyols and 5% 1,2-propanediol	Aquatrols Corporation of America, Paulsboro, NJ	0.56
CNT	Water control		

[a]A new surfactant chemistry.

do not contain N. These surfactants are specifically made of carbon atoms bonded together into long chain. Irrigation and surfactants were hand applied using a calibrated syringe at experiment initiation and continued for 10 wk.

2.4 | Measurements

After each irrigation and surfactant application, leachate was collected into cups that were placed under each column; leachate volume was measured using a graduated cylinder and pH determined (VWR International Model SB70P). One hour after irrigation, the SWC at the 5-, 10-, 15-, and 25-cm depths of the columns was measured using a hand-held time domain reflectometry device (Dynamax, Inc.). The SWC measurements were taken three times a week: first on the day that surfactants and irrigation applications were applied (Tuesdays); second on the day of second irrigation associated with the split irrigation treatment (Thursdays); and third after 6 d from the first measurement to investigate the effect of the surfactants on a longer period (Mondays). For ease of discussion, these measurement days will be referred to as Tuesdays, Thursdays, and Mondays in the rest of the article. This experiment continued for 10 wk, at which time the soils were removed from the leaching columns, which were cleaned before being repacked with new soils to repeat the experiment.

2.5 | Statistical analysis

Before analysis, normality and homogeneity were tested using the Shapiro–Wilk test and Levene's test, respectively. Data within each year were normal and variance homogeneous for all variables. Year, which was the factor first tested in each experiment, was found not significant for all metrics; therefore, it was considered as a random variable. To analyze how soil surfactants and irrigation affect SWC and leachate pH and volume for each soil, a mixed model was used with surfactant, irrigation, depth, day, and their interactions being considered as fixed variables and replication as a random variable. If interactions are significant, main effects are not discussed. Treatment means were separated using Fisher's LSD test. All significance tests were performed with a significant level (α) equal to .05, and all calculations were performed using JMP Pro 12.0.1 software (SAS Institute Inc.).

3 | RESULTS

3.1 | Leachate pH and total volume

Leachate pH values for the soils were not significantly influenced by the surfactant or irrigation regime (Table 3). The interactions between surfactant and irrigation for each soil were significant for total leachate (Table 3). Applying SPLIT irrigation resulted in 44–70% less percolate compared with ONCE irrigation for all soils (Figure 2). Regardless of the surfactant treatments, more water leached from the sand than the sandy loam (71% under ONCE irrigation and 63% under SPLIT irrigation) and more water leached from the sand–peat than the Fafard 3B-SURF (48% under ONCE irrigation and 31% under SPLIT irrigation). The significant surfactant by irrigation interaction for ONCE irrigation identified no differences for total leachate volume among treatments for the sand soil. However, when the SPLIT irrigation was applied to the sand, applying the OAC and NIPP both resulted in 61% less leachate volume than the APG, and 52 and 53% less leachate volume, respectively, compared with the CNT (Figure 2). For the sandy loam under ONCE irrigation, applying the OAC resulted in 18, 19, and 21% less total volume leached than NIPP, APG, and CNT, respectively. Applying NIPP recorded 34% less total leachate volume compared with the CNT for the sandy loam under the SPLIT irrigation regime (Figure 2).

Differences in total leachate volume among surfactant treatments were observed at both irrigation levels in the soil substrates. Surfactant treatments resulted in similar leachate volumes for the sand–peat soil. Applying the OAC to the Fafard 3B-SURF resulted in 42, 55, and 41% less volume compared with NIPP, APG, and CNT, respectively (Figure 2). In the sand–peat under SPLIT irrigation, applying the OAC resulted

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TABLE 3 Significance values for main effects and main effect interactions for pH and total leachate volume (ml) for the sand, the sandy loam, the 80:20 sand/peat, and the Fafard 3B-SURF

	Sand	Sandy loam	Sand–peat	Fafard 3B-SURF
	Prob > F			
	Leachate pH			
Irrigation	.3321	.3123	.3412	.7743
Surfactant	.3210	.4312	.9321	.6821
Irrigation × Surfactant	.3321	.2123	.0912	.2130
	Total leachate volume			
Irrigation	<.0001	<.0001	<.0001	<.0001
Surfactant	.7306	.3212	.6998	.0761
Irrigation × Surfactant	.0088	.0389	.0155	.0032

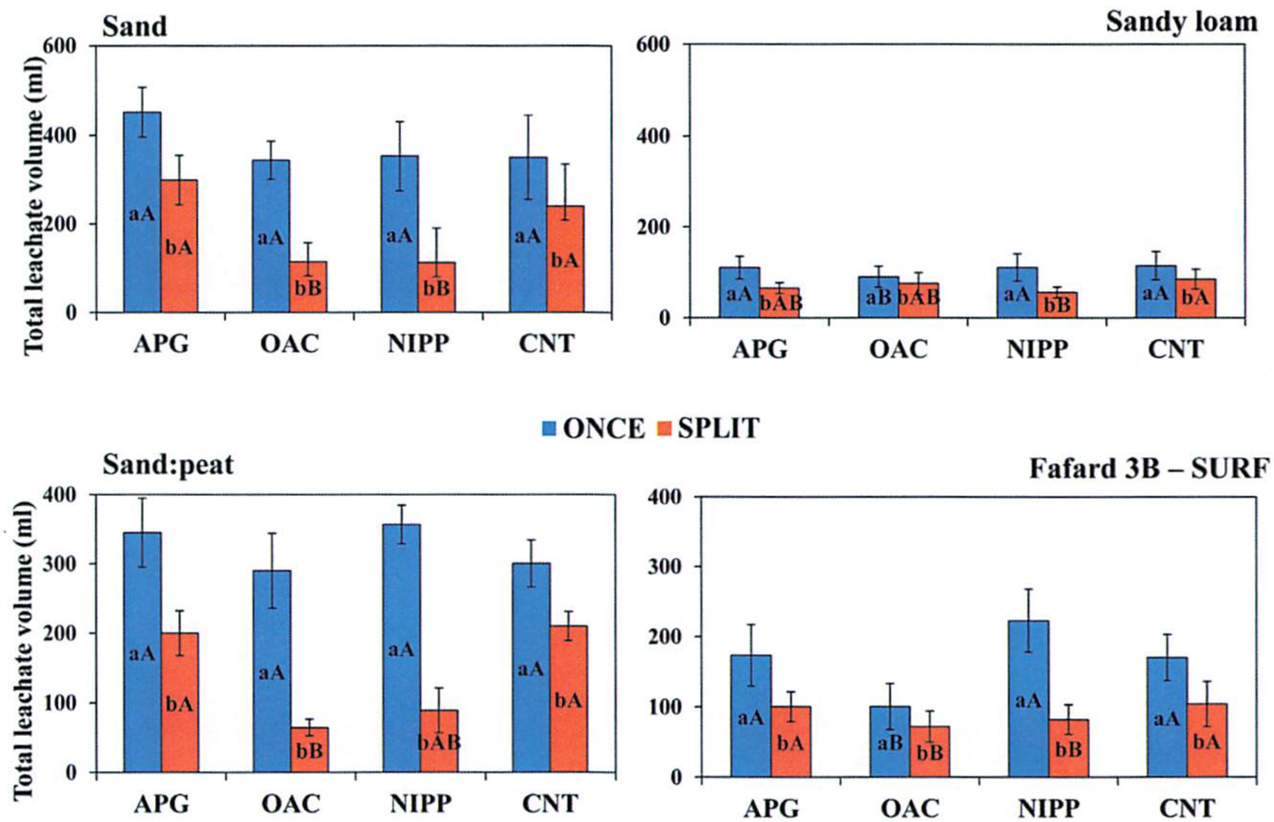

FIGURE 2 Total leachate volume (ml) for surfactant and irrigation interaction over the study period. Soils are sand, sandy loam, 80:20 sand/peat, and Fafard 3B-SURF. Lowercase letters indicate significance between the irrigation levels at each surfactant level and uppercase letters indicate significance among the surfactant levels at each irrigation level ($P < .05$). Vertical bars indicate standard errors of the means. OAC, 10% oleic acid esters of block copolymers; APG, 30% alkoxylated polyols and 21% glucoethers; NIPP, 50% nonionic polyols and 5% 1,2-propanediol; CNT, water control

in 68 and 69% less total leachate volume than the APG and the CNT, respectively; however, the OAC and NIPP recorded similar total leachate volumes. For the Fafard 3B-SURF under SPLIT irrigation, applying the OAC and NIPP resulted in 28 and 18% less total leachate volume, respectively, compared with the APG, and 31 and 21% less total leachate volume, respectively, compared with the CNT (Figure 2).

3.2 | Soil water content

Percentages of SWC (m^3 m^{-3}) each week for each surfactant treatment over the study period (10 wk) for the soils can be seen in Figure 3. The highest SWC in the sand, sandy loam, sand–peat, and Fafard 3B-SURF soils was recorded in the columns treated with the OAC (5 wk), the OAC

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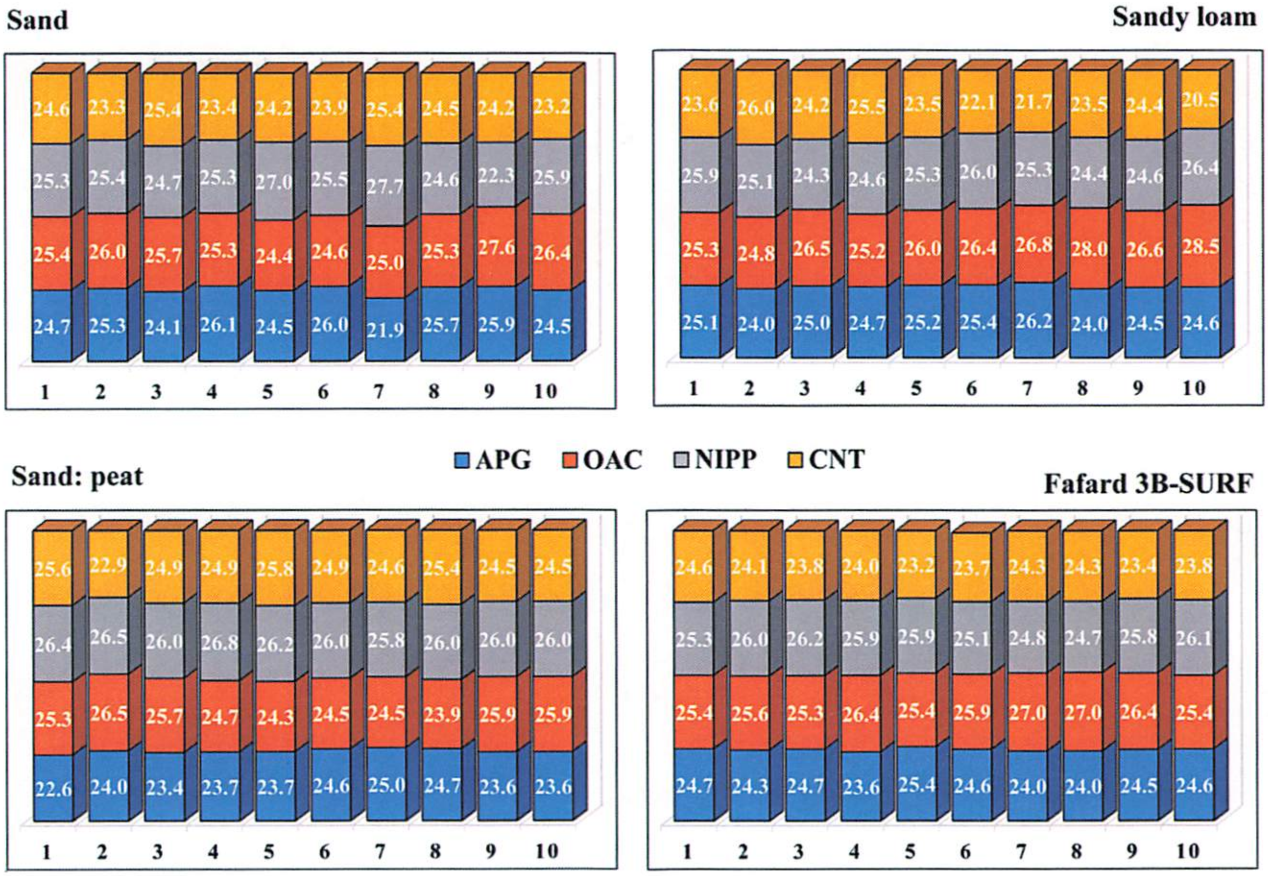

FIGURE 3 Percentages of soil water content (m^3 m^{-3}) under each surfactant treatment for each week over the experiment (10 wk). Soils are sand, sandy loam, 80:20 sand/peat, and Fafard 3B-SURF. OAC, 10% oleic acid esters of block copolymers; APG, 30% alkoxylated polyols and 21% glucoethers; NIPP, 50% nonionic polyols and 5% 1,2-propanediol; CNT, water control

(7 wk), the NIPP (10 wk), and the OAC (6 wk), respectively (Figure 3). No fourth and third order interactions were significant, and only second interactions were significant for all soils (Table 4). The second interactions (surfactant × depth and day × irrigation) will be discussed in this article.

3.3 | Interaction effects of surfactant and soil depth on the soil water content

The interaction between surfactant and depth for the soils can be seen in Figure 4. At the 5-cm depth, applying the OAC resulted in 60, 7, and 12% higher SWC compared with the APG, the NIPP, and the CNT, respectively, for the sand, and applying the NIPP resulted in 15, 11, and 22% higher SWC compared with the APG, OAC, and CNT, respectively, in the sandy loam (Figure 4). At the same depth, columns treated with the OAC and NIPP recorded 11 and 16% higher SWC, respectively, compared with columns that were treated with the APG, and 13 and 18% higher SWC, respectively, compared with the CNT in the sand–peat. In the Fafard 3B-SURF at the same depth, columns treated with the OAC and NIPP recorded 8 and 10% higher SWC, respectively, compared with columns treated with the APG, and 14 and 16% higher SWC, respectively, compared with the CNT treated columns (Figure 4).

At the 10-cm depth, applying the NIPP resulted in higher SWC compared with the APG (11%), the OAC (14%), and the CNT (24%) for the sand and applying the OAC and the NIPP resulted in higher SWC compared with the APG (6% for OAC and 3% for NIPP) and the CNT (11% for OAC and 14% for NIPP) in the sandy loam (Figure 4). At the same depth, columns treated with the NIPP recorded higher SWC compared with CNT treated columns (12%) but similar to the columns treated with the other surfactants in the sand–peat and similar to the treatments in the Fafard 3B-SURF (Figure 4).

In the sand, similar SWC was recorded among surfactant treatments at the 15-cm depth. Columns treated with the OAC in the sandy loam had higher SWC compared with CNT treated columns (12%) but similar to the columns treated with the other surfactants at the 15-cm depth (Figure 4). Applying the OAC and the NIPP resulted in higher SWC compared with the APG (12% for OAC and 15% for NIPP) and the

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TABLE 4 Significance values for main effects and main effect interactions for soil water content for the sand, the sandy loam, the 80:20 sand/peat, and Fafard 3B-SURF

	Sand	Sandy loam	Sand–peat	Fafard 3B-SURF
	Prob > F			
Irrigation	.0002	.0001	.0077	<.0001
Surfactant	.0084	.0001	<.0001	<.0001
Depth	<.0001	.0001	<.0001	<.0001
Day	<.0001	.0011	.0005	<.0001
Irrigation × Surfactant	.4284	.0131	.8434	.1265
Irrigation × Depth	.3411	.1206	.0728	.0732
Irrigation × Day	.0073	.0047	.0413	.0821
Surfactant × Depth	<.0001	.0100	<.0001	.0015
Surfactant × Day	.4652	.1299	.9478	.0921
Depth × Day	<.0001	.0103	<.0001	<.0001
Irrigation × Surfactant × Depth	.9987	.5681	.3311	.5921
Irrigation × Surfactant × Day	.9561	.6995	.5498	.9211
Irrigation × Depth × Day	.3411	.7729	.1157	.8295
Surfactant × Depth × Day	.3387	.8748	.1486	.4223
Irrigation × Surfactant × Depth × Day	.9950	.9047	.9956	.6722

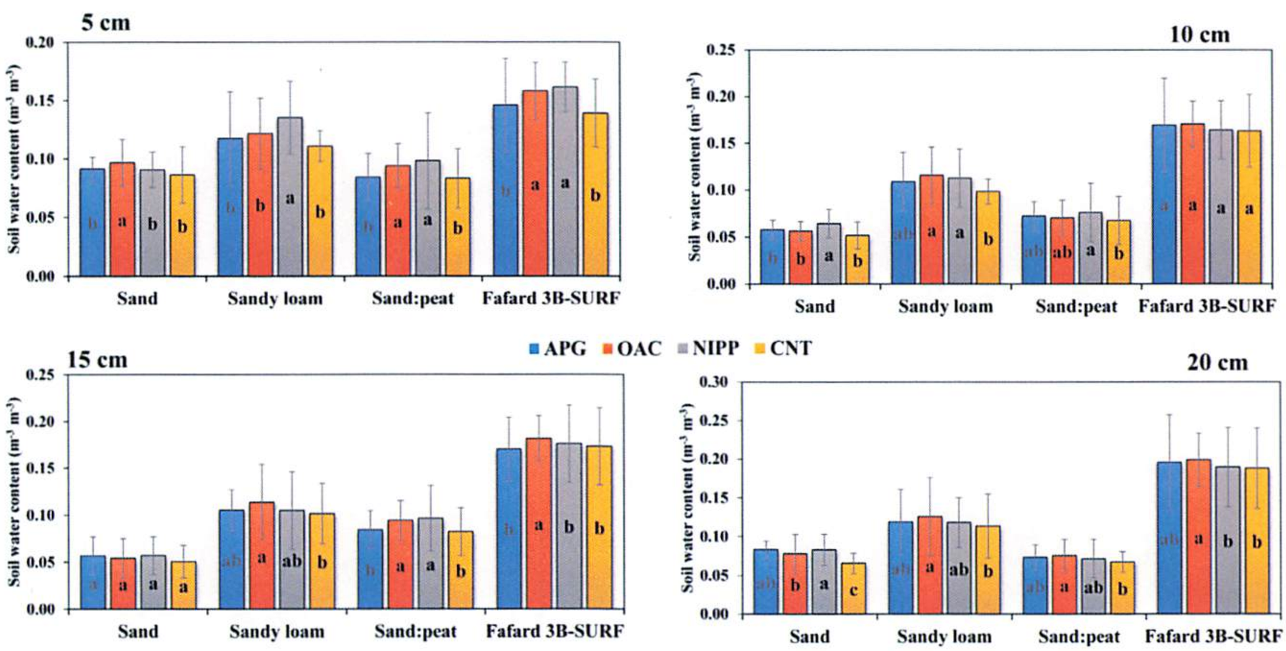

FIGURE 4 Soil water content (m^3 m^{-3}) for depth and surfactant interaction. Soils are sand, sandy loam, 80:20 sand/peat, and Fafard 3B-SURF. Lowercase letters indicate significance among surfactants at each depth ($P < .05$). OAC, 10% oleic acid esters of block copolymers; APG, 30% alkoxylated polyols and 21% glucoethers; NIPP, 50% nonionic polyols and 5% 1,2-propanediol; CNT, water control

CNT (14% for OAC and 17% for NIPP) in the sand–peat soil at 15 cm. Applying the OAC resulted in higher SWC compared with the APG (7%), the NIPP (3%), and the CNT (5%) in the Fafard 3B-SURF soil at 15 cm. At the 25-cm depth, all surfactants resulted in higher SWC than the CNT in the sand. In comparison to the CNT, only the OAC resulted in higher SWC in the sandy loam (11% higher), the sand–peat (12% higher), and the Fafard 3B-SURF (6% higher) (Figure 4).

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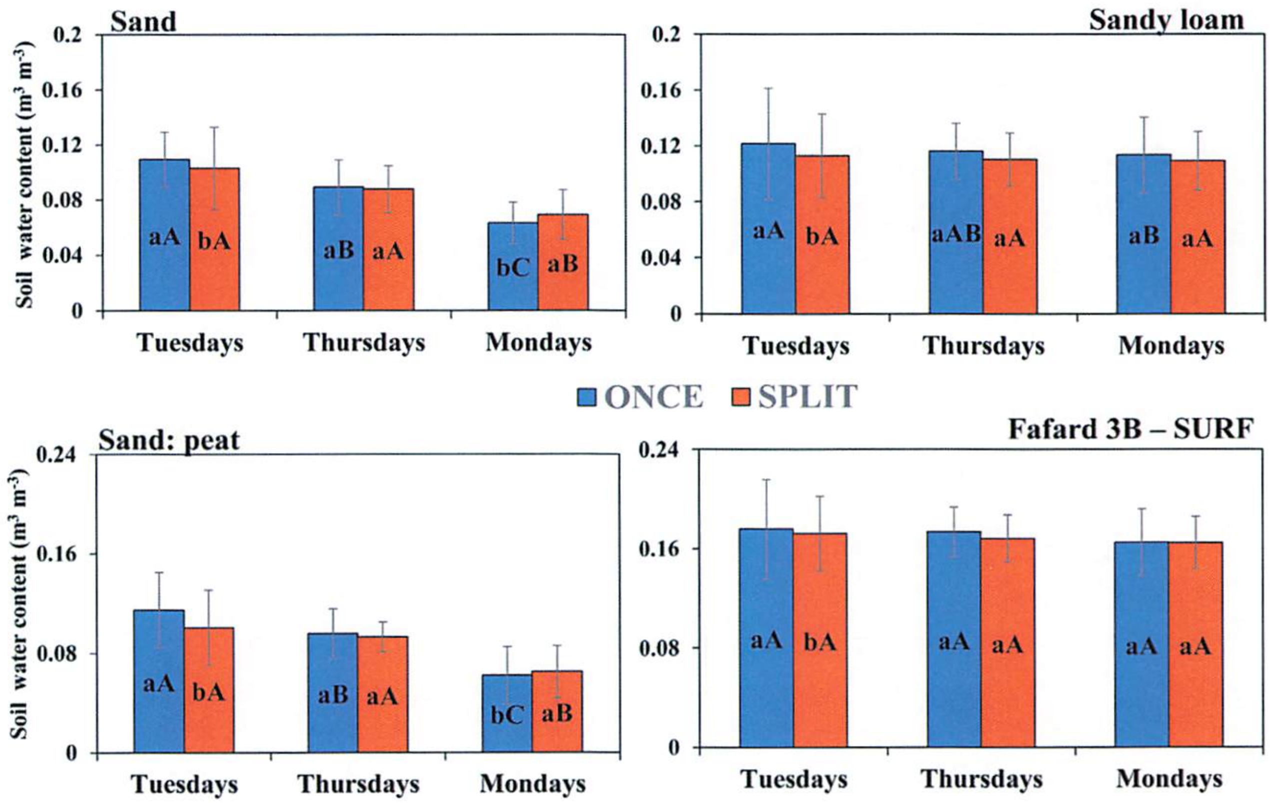

FIGURE 5 Soil water content (m^3 m^{-3}) for day and irrigation interaction. Soils are sand, sandy loam, 80:20 sand/peat, and Fafard 3B-SURF. Lowercase letters indicate significance between the irrigation levels at each day and uppercase letters indicate significance among the days at each irrigation level ($P < .05$). Vertical bars indicate standard errors of the means

3.4 | Interaction effects of day and irrigation on the soil water content

Soil water content for day and irrigation interaction for all soils can be seen in Figure 5. Generally, the SWC declined from Tuesdays to the following Mondays in the sand and sandy loam and in the sand–peat under ONCE irrigation (Figure 5). However, this trend was not as evident in the Fafard 3B-SURF (Figure 5). For SPLIT irrigation, the SWC was lower on Mondays compared with the other 2 d in the sand and sand–peat soils only. When the soil was left to dry out (from Thursdays to Mondays), the SWC was 5 and 9% higher under SPLIT irrigation compared with the ONCE irrigation in the sand–peat and the sand, respectively (Figure 5). Similar SWC were recorded between the irrigation regimes in the sandy loam and Fafard 3B-SURF soils (Figure 5).

4 | DISCUSSION

The ability to manage water more efficiently and effectively continues to receive much research attention, in part because new soil surfactant chemistries are being developed not only to address hydrophobicity but also to reduce leaching and enhance plant health and productivity (Blackstone & Welch, 2014; Curtis & Thomas, 2016). In addition, irrigation management may have an impact on the response of SWC to the surfactant application (Soldat et al., 2010).

4.1 | Leachate pH and total volume

Surfactant applications in this study did not affect leachate pH. Surfactant application (chemistries not disclosed) to sand soil did not affect nutrient losses compared with the control as reported by Chang et al. (2020). Guillen et al. (2005) reported similar results in which applying a surfactant with no phenol poly-ethylene glycol to a new coco fiber substrate growing a tomato crop (*Lycopersicon esculentum* Mill.) did not affect leachate pH compared with a control. Irrigation also can cause leaching of soil nutrients over time, affecting the pH of the leachate (Nunes et al., 2007); however, the amount of water applied in this study may not be enough to cause any changes in pH.

The results of the interactions between surfactant and irrigation for total leachate volume indicated that the effect of surfactants in reducing total leachate volume varied among soils and between irrigation regimes, supporting the results reported by Barton and Colmer (2011) and Chaichi et al. (2015). Although ONCE irrigation recorded higher total leachate volume than SPLIT irrigation for all soils, applying OAC and NIPP surfactants generally resulted in lower leachate volume compared with the APG and CNT except in ONCE irrigation for the sand and sand–peat soils. The results that under ONCE irrigation, more water leached from the sand than the sandy loam and from the sand–peat than the Fafard 3B-SURF suggest that surfactants may be leached out of the sand and sand–peat soils under this irrigation regime.

Differences in total leachate volume among soils may be attributed to the differences in their ability to hold water (Sadeghizadeh & Jalali, 2017). Clay particles in the sandy loam can help to retain the water in the soil (Osman, 2012), and more organic material in the Fafard 3B-SURF can increase soil water capacity (Minasny & McBratney, 2018; Moskal et al., 2001), subsequently resulting in the less leachate compared with the sand and sand–peat soils. Furthermore, surfactants can reduce the water surface tension allowing water to infiltrate into the spaces between soil pores, distribute uniformly, and decrease the leachate volume (Leinauer et al., 2001). Our previous study (data not shown) reported that applying OCA to a sandy loam soil grown used to grow Tifway 419 bermudagrass [*Cynodon dactylon* (L.) Pers.] resulted in less volume leached compared with a control under greenhouse conditions. Results from the leachate volume indicated that incorporating SPLIT irrigation applications and surfactants provides a more optimal root zone environment for plant growth and reduces the potential of water loss (and water constituents) to the surrounding environment.

4.2 | Soil water content

Surfactants have been widely used for improving water use efficiency and increasing soil water capacity (Chang et al., 2020; Dekker et al., 2019). Generally, applying NIPP and OAC surfactants to the soils increased the SWC for all soil depths, but their influence varied among the soils and the surfactant chemistry. Nonionic surfactants have the ability to stay longer in the soil profile (Park & Bielefeldt, 2003); therefore, they can remain active longer in increasing SWC. Both OAC and NIPP surfactants increased the SWC for all depths similarly. The lack of an effect of APG surfactant on SWC for all depths suggests that this surfactant may have been easily leached out of the soil profile. However, further research is necessary to evaluate the effectiveness of APG on SWC with a higher rate of application frequency. Other studies have reported either an increase (Soldat et al., 2010) or no effect (Schiavon et al., 2014) in SWC after APG application. Leinauer et al. (2001) and Alvarez et al. (2016) reported that the effectiveness of a surfactant in increasing SWC can vary depending on the application rate and weather conditions.

The general decline in SWC from Tuesdays to Mondays under both irrigation regimes (Figure 5), is logical since irrigation was applied on Tuesdays only under the ONCE irrigation regime and on Tuesdays and Thursdays under the SPLIT irrigation regime, with no water being applied on Mondays. The reason that this trend was clearer for the sand and sand–peat soils compared with the other soils may be due to the high clay or high organic material in the sandy loam and the Fafard 3B-SURF soils, a condition that may cause water to be held longer in the soil profile as discussed earlier.

The most significant finding from the irrigation results is that when the soil was left to dry out, SPLIT irrigation provided more water compared with ONCE irrigation in the sand and sand–peat soils but not in the sandy loam and Fafard 3B-SURF soils. This would suggest that SPLIT irrigation is the recommended practice for soil moisture conservation in sandy soils and soils with low organic material. Applying too much water can increase the potential for nutrients to leach out of these soils due to their rate of permeability (Alhammadi et al., 2013).

5 | CONCLUSIONS

Because drought can have a significant impact on crop production and water uses for human necessities, interest in practices that can help conserve moisture in the soils and greenhouse substrates has increased worldwide. Combining surfactants with irrigation regimes could potentially reduce leachate volumes and increase soil water content. This study was conducted in 2014 and 2015 to evaluate how soil surfactants and irrigation can affect soil water content, leach volume, and pH in soils and greenhouse substrates. Overall, applying surfactants to soils increased the SWC compared with the control, but their influence varied depending on the soil and the surfactant chemistry. Applying surfactants with SPLIT and ONCE irrigation reduced the amount of leachate compared with the control in soils and substrates. The results from this study indicated that the combining a surfactant with irrigation regimes can be used as a management approach to maximize irrigation efficiency and minimize water loss. Specifically, combining split irrigation with soil surfactants can play an important role in increasing soils and greenhouse substrate water holding capacity and, thus, conserve water and improve water availability for plants.

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AUTHOR CONTRIBUTIONS

Gandura Omar Abagandura: Data curation; Formal analysis; Methodology; Validation; Writing-original draft; Writing-review & editing; Dara Park: Conceptualization; Funding acquisition; Investigation; Methodology; Resources; Supervision; Validation; Writing-review & editing; William C. Bridges Jr: Formal analysis; Validation; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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