A Mineral Oil Plant Protection Product Improves Turfgrass Quality of Deficit Irrigated Bermudagrass

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Keywords. Civitas™, *Cynodon* spp., drought, NDVI, soil moisture, volumetric water content

Abstract. **Managing turfgrass in arid and semiarid areas of the southern United States is becoming increasingly challenging due to prolonged drought and diminishing water resources. Turfgrass managers have been seeking products that control pests while promoting drought resistance. Civitas™ Turf Defense is a new petroleum-derived spray oil (PDSO) mixed with green pigment. Like other traditional PDSO products, Civitas is reported to have positive effects on turfgrass pest control and management. However, limited information is available regarding its impact on water conservation in turfgrass. The objective of this study was to evaluate the effects of Civitas on bermudagrass (*Cynodon* spp.) under deficit irrigation conditions. A 2-year study was conducted in Riverside, CA, USA, to evaluate the effect of Civitas on bermudagrass irrigated at 55% or 65% of reference evapotranspiration (ET_o), which represented a 20% or 10% savings in water, respectively. Civitas was applied at 4.5 or 8.5 oz/1000 ft^2 every two weeks (2019–20), and 8.5 oz/1000 ft^2 every 3 weeks (2019 only), compared with an untreated control. Results show that Civitas improved bermudagrass quality under deficit irrigation at both rates, but the 3-week application interval was less effective compared with the 2-week application interval at either rate. Civitas applied at 8.5 oz/1000 ft^2 every 2 weeks resulted in better turfgrass quality than the 4.5 oz/1000 ft^2 rate in the first year only. Results suggest that using Civitas on bermudagrass can save up to 20% water while maintaining desirable turf quality.**

Petroleum-derived spray oils (PDSOs) have been used in horticulture and agronomy for pest control since the 1800s (Agnello 2002). Civitas (Suncor Energy, Mississauga, Canada) is a spray oil made from food-graded isoparaffins and is offered in two forms: Civitas™ Turf Defense Ready-2-Mix, a two-pack system that allows for on-site mixing of mineral oil and green pigment (Harmonizer™), and Civitas Turf Defense Pre-M1xed, a single premixed formulation containing 88.8% (w/w) mineral oil. Unlike the traditional PDSOs, Civitas is a new approach to turfgrass pest management by trigging plant defense mechanisms (Cortes-Barco et al. 2010). Van Dyke and Johnson (2017) reported the effectiveness of Civitas on snow mold (*Typhula* sp. not specified) disease control. Similarly, Aamlid et al. (2018) and Stricker et al. (2017) demonstrated positive effects of Civitas on Microdochium Patch (*Microdochium nivale*) disease control. Civitas has also shown variable impacts on spring green-up, likely influenced by species-specific responses, snow cover duration, and winter temperatures. For example, Civitas improved spring green-up in Utah, USA (Van Dyke and Johnson 2017) but inhibited it in Europe (Aamlid et al. 2018). However, some studies have documented adverse effects of Civitas application. Reduced turfgrass quality was observed when Civitas was combined with rolling on an annual bluegrass (*Poa annua* L.) putting green (Mattox 2015). Additionally, leaf chlorosis appeared on a creeping bentgrass (*Agrostis stolonifera* L.)/annual bluegrass putting green within hours of Civitas application (Kreuser and Rossi, 2014), but it was partially masked by the Harmonizer, the pigment product. The pigment has also demonstrated effects in reducing dollar spot (*Clarireedia* sp.) by inhibiting fungal radial growth (Nash 2011) and increasing canopy temperature (Aamlid et al. 2018; Braun et al. 2016). However, few studies have focused on evaluating the effect of Civitas on turfgrass water conservation.

Many southwestern US states are experiencing severe drought, especially in the summer months. When precipitation is limited or absent, supplemental irrigation is needed for plant growth. However, replacing full evapotranspiration (ET) for plants growth is not practical or possible in most situations; therefore, deficit irrigation has been introduced by researchers and turfgrass managers. Deficit irrigation, defined as replacing water less than full crop-water requirements, has been identified as a feasible practice for water conservation (Feldhake et al. 1984). The aim of deficit irrigation on turfgrass is to use the least amount of water to obtain an acceptable quality, and therefore to conserve water (Gibeault et al. 1985; Kneebone et al. 1992). Several studies have focused on combining other water conservation strategies with deficit irrigation to achieve the most water-conservative strategies, including using plant growth regulators, wetting agents, and effective fertility management programs (Schiavon et al. 2014, 2019; Serena et al. 2018, 2020). However, the impact of Civitas, a mineral oil product, on water conservation has yet to be investigated.

Materials and methods

The experiment was conducted at the University of California, Riverside turfgrass research facility (Riverside, CA, USA; USDA plant hardiness zone 9b; 310 m elevation) during 2019–20. Research was performed on 'Princess 77' bermudagrass [*Cynodon dactylon* (L.) Pers.] from May to

Received for publication 5 Nov 2024. Accepted for publication 18 Dec 2024.

Published online 7 Feb 2025.

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Funds to support this research were provided by the California Agricultural Experiment Station and the National Institute of Food and Agriculture, US Department of Agriculture, under award number CA-R-BPS-5066-H and Hatch Project 1019739. We also thank Intelligro/Suncor Energy Inc. and the California Turfgrass and Landscape Foundation (CTLF) for financial support.

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https://doi.org/10.21273/HORTTECH05568-24

Table 1. Weather data of monthly reference evapotranspiration (ET_o), precipitation, average air temperatures, and soil temperature, near the study site during the study period in 2019 and 2020, Riverside, CA, USA. Data were recorded from an on-site weather station and downloaded from the California Irrigation Management Information System, station 44.

Year	Month	Total ET_o (inch)	Total precipitation (inch)	Avg max air temp (°F)	Avg min air temp (°F)	Avg air temp (°F)	Avg soil temp (°F)
2019	May	5.0	1.0	71.2	52.5	60.8	66.9
	Jun	6.5	0.0	83.1	60.1	69.6	73.4
	Jul	8.0	0.0	72.2	62.8	75.7	74.8
	Aug	7.7	0.0	93.4	62.4	76.6	74.3
	Sep	5.7	0.0	73.2	62.1	73.8	74.5
	Oct	5.1	0.0	82.9	52.9	66.9	64.0
2020	May	5.6	0.3	74.2	54.7	63.7	68.5
	Jun	7.6	0.0	86.4	58.8	71.1	73.9
	Jul	8.0	0.0	75.2	67.6	80.8	78.8
	Aug	7.4	0.0	92.8	66.4	78.3	77.7
	Sep	5.9	0.0	76.2	60.8	73.6	73.8
	Oct	4.3	0.9	80.2	56.7	67.5	68.2

October in 2019 and on 'Tifway II' bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy] from Jun to Oct 2020. For both years, soil was a Hanford fine sandy loam (70.4% sand, 19.8% silt, 9.8% clay; superactive, nonacid, thermic Typic Xerorthents) with 0.6% organic matter. Turf was mowed at 0.5 inches (12.7 mm) three times per week with a reel mower (Toro Reelmaster 3100-D, Bloomington, MN, USA), and clippings were returned. Each April, verticutting was performed to reduce organic matter. Monthly fertilization from 21–7–14 (Yara International ASA, Oslo, Norway) was applied at 0.5 lbs N/1000 ft^2 (23 $kg{\cdot}ha^{-1}$ N) from April to November for both years.

During the study period, climate data were recorded from an on-site weather station [(California Irrigation Management Information System (CIMIS), station 44)], which is presented in Table 1. From 23 May to 31 Oct 2019 and 3 Jun to 31 Oct 2020, irrigation treatments were applied by hand-watering three times per week to replace either 55 or 65% of previous week's reference evapotranspiration (ET_o) based on CIMIS data. For reference, bermudagrass in Riverside typically requires 75% ET_o during the summer months to maintain acceptable turf quality. Nonlimiting irrigation was applied using sprinklers from 1 Nov 2019 to 2 Jun 2020 unless precipitation occurred. The irrigation water had a pH of 7.8, electrical conductivity of 0.72 dS/m, and sodium adsorption ratio of 3.2.

The study was a split-plot in a randomized complete block design with four replicates, with individual plots measuring 4 × 6 ft. The whole-plot factor consisted of irrigation treatments, with either 55% or 65% ET_o replacements. The subplot factor included application rates and frequencies of Civitas Turf Defense Pre-M1xed (hereafter referred to as Civitas). Subplot treatments involved Civitas applied at 4.5 oz/1000 ft^2 biweekly, 8.5 oz/1000 ft^2 biweekly, and 8.5 oz/1000 ft^2 every 3 weeks, compared with an untreated control with no applications. These rates and frequencies were selected based on the lower end of the labeled rate, half of this rate, and varying application intervals to evaluate cost-saving options. Applications were made using a CO_2 backpack sprayer calibrated to deliver 2 gal/1000 ft^2. In 2019, Civitas applied at 8.5 oz/1000 ft^2 every 3 weeks showed minimal effects on enhancing turfgrass drought resistance compared with the biweekly treatments, leading to the discontinuation of this treatment in 2020.

Data collection and analysis

Data were collected biweekly for turf quality, color, normalized difference vegetation index (NDVI), soil volumetric water content (VWC), soil moisture variability (SMV), percent green coverage (PGC), and dark green color index (DGCI). Turf quality was

Table 2. Results of analysis of variance testing the effects of Civitas application rate and frequency, irrigation replacement based on reference evapotranspiration (ET_o), sampling month, and their interactions on turf quality, color, normalized difference vegetation index (NDVI), volumetric water content (VWC), soil moisture variability (SMV), percentage green cover (PGC), and dark green color index (DGCI) of mature 'Princess 77' bermudagrass in 2019 and mature 'Tifway II' bermudagrass in 2020.

	Turf quality		Color		NDVI		VWC		SMV		PGC		DGCI	
Effect	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
ET_o	NS	**	NS	*	*	***	***	*	***	NS	NS	*	*	NS
Civitas treatment	***	**	***	*	NS	NS	NS	NS	NS	NS	***	NS	***	*
Civitas treatment × ET_o	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Month	***	***	***	***	***	***	***	***	***	***	***	***	***	***
ET_o × month	NS	***	*	***	***	***	***	**	***	NS	*	**	NS	**
Civitas treatment × month	***	NS	***	NS	NS	NS	NS	NS	NS	NS	***	NS	***	NS
Civitas treatment × ET_o × Month	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

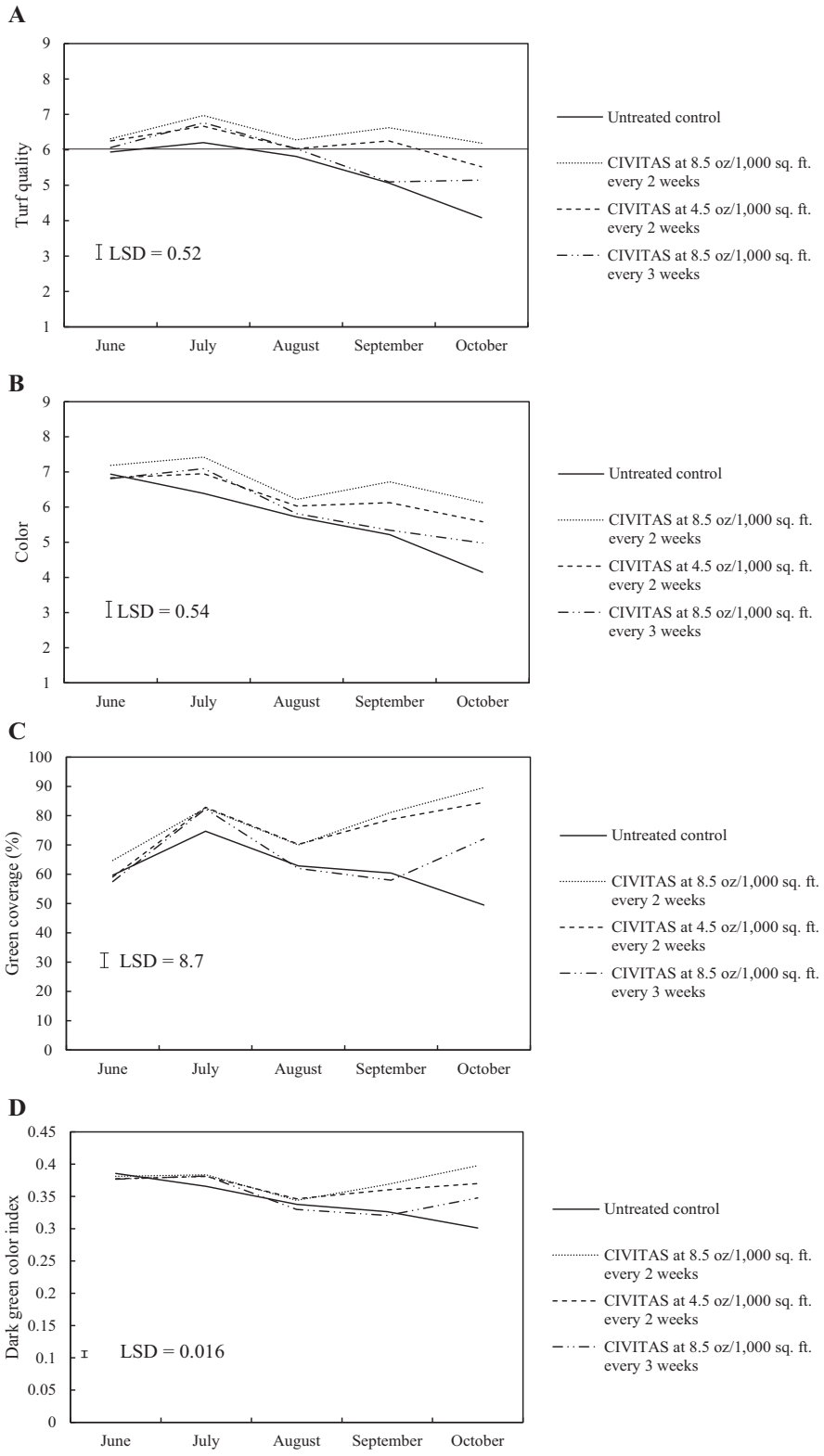

Fig. 1. Turf quality (A), color (B), percent green cover (C), and dark green color index (D) of 'Princess 77' bermudagrass treated with Civitas in 2019, Riverside, CA. Results are pooled across two evapotranspiration irrigation replacements and four replicates. 1 oz/1000 ft^2 = 0.000318 L/m^2. LSD = least significant difference.

rated visually on a 1 to 9 scale, where 1 = brown turf, 6 = minimal acceptable quality, and 9 = dense, dark green, uniform turf (Morris and Shearman 1999). Color was also rated visually on a 1 to 9 scale, where 1 = straw color and 9 = dark green color. Normalized difference vegetation index was recorded by a GreenSeeker NDVI handheld crop sensor (Trimble, Sunnyvale, CA, USA) to quantify stress (Park et al. 2004).

Soil volumetric water content at 3.0 inches (76.2 mm) soil depth was determined using a time domain reflectometer (FieldScout TDR300 Soil Moisture Meter; Spectrum 223 Technologies Inc., Aurora, IL, USA). The average soil VWC was calculated by averaging the means of five random spots within each plot. Furthermore, SMV was determined by calculating the standard deviation of the VWC among the five data points (Xiang et al. 2021), where a higher value indicates lower soil uniformity.

Percent green coverage and DGCI were determined from digital image analysis (Karcher and Richardson 2005; Richardson et al. 2001) using Turf Analyzer (Karcher et al. 2017). Digital images representing 3.2 ft^2 (0.3 m^2) of each plot were taken with a digital camera (PowerShot G15, Canon USA Inc., Melville, NY, USA), mounted inside an enclosed light box. The light box provided a consistent light source with four light-emitting diode lightbulbs. The threshold for digital image analysis was set with a hue of 60/300, saturation of 0/100, and brightness of 10/80.

For both years, data were averaged as monthly data to improve clarity of data representation. Due to the elimination of the Civitas treatment at the 3-week interval in 2020, data were analyzed for each year separately. Data were subjected to analysis of variance (ANOVA) using SAS PROC MIXED with repeated measures (version 9.4; SAS Institute, Cary, NC, USA). For any given parameter, when appropriate, multiple comparisons of means were separated using Fisher's protected least significant difference test at $P \leq 0.05$.

Results

In 2019, Civitas treatment × month interaction was highly significant for turf quality, color, PGC, and DGCI (Table 2). Therefore, data were averaged over ET_o and replicates. Additionally, ET_o × month interaction was highly significant for color, NDVI, VWC, SMV, and PGC. For those parameters, data were averaged over Civitas treatment and replicates. In 2020,

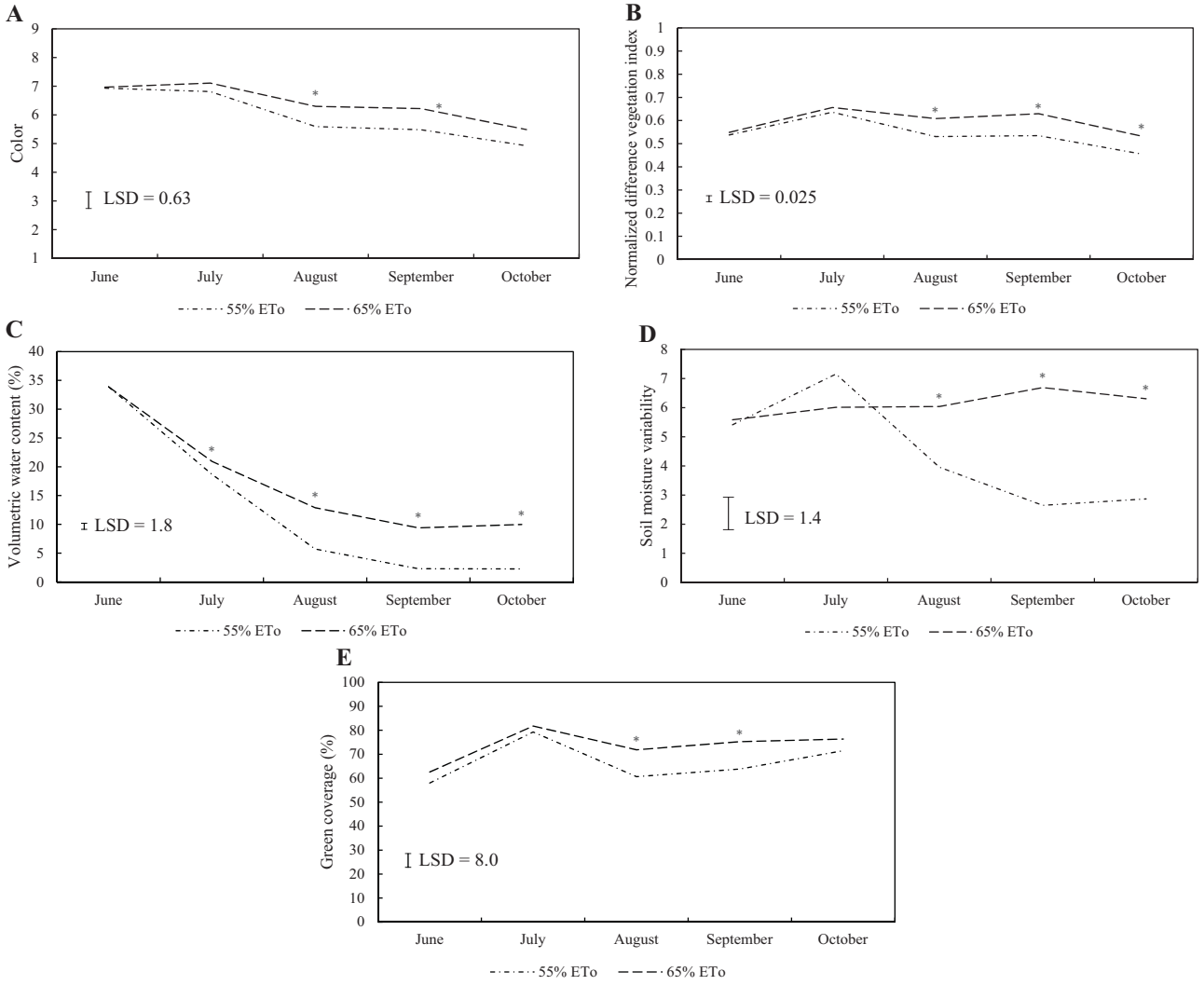

Fig. 2. Color (A), normalized difference vegetation index (B), volumetric water content (C), soil moisture variability (D), and percent green cover (E) of 'Princess 77' bermudagrass irrigated at either 55% or 65% reference evapotranspiration (ET_o) replacements in 2019, Riverside, CA, USA. Results are pooled across three Civitas treatments and the untreated control. Asterisks (*) above the treatments indicate significant differences among the means. LSD = least significant difference.

Civitas treatment was significant for turf quality, color, and DGCI. The interaction between ET_o and month was highly significant for turf quality, color, NDVI, VWC, PGC, and DGCI (Table 2).

Turf quality and color

In 2019, plots treated with Civitas at 8.5 oz/1000 ft^2 at both 2- and 3-week application frequencies exhibited higher quality than the untreated control in July when averaged over ET_o irrigation replacements (Fig. 1A). In September, regardless of application rate, Civitas sprayed at a 2-week application interval resulted in higher quality than the 3-week application frequency and the untreated control. In October, the best turf quality was observed on plots treated with Civitas at 8.5 oz/1000 ft^2 every 2 weeks. Treating bermudagrass with Civitas at 8.5 oz/1000 ft^2 every 2 weeks resulted in acceptable quality for 5 months when data were averaged over ET_o irrigation replacement. Differences in turf quality of bermudagrass were only observed in October when comparing application rates at the 2-week application frequency. The two irrigation replacements (55% vs. 65% ET_o) exhibited no effects on turf quality (Table 2).

Civitas treatments in 2019 also improved turf color. In July, Civitas improved turf color across all application rates and frequencies compared with the untreated control (Fig. 1B). By September, biweekly applications of Civitas at 8.5 oz/1000 ft^2 enhanced turf color compared with the 4.5 oz/1000 ft^2 rate, and both rates outperformed the untreated control. However, applying Civitas every 3 weeks at 8.5 oz/1000 ft^2 had no effect on color compared to the untreated control. In October, Civitas applied biweekly at 8.5 oz/1000 ft^2 resulted in the best turf color, followed by 4.5 oz/1000 ft^2 applied biweekly. The 3-week application frequency with 8.5 oz/1000 ft^2 was less effective than biweekly applications but still outperformed the untreated control. Across all Civitas treatments, the higher irrigation replacement (65% ET_o) improved turf color in August and September (Fig. 2A).

In 2020, turf quality was comparable between biweekly applications of Civitas at 8.5 oz and 4.5 oz/1000 ft^2 and was significantly higher than the untreated control when averaged

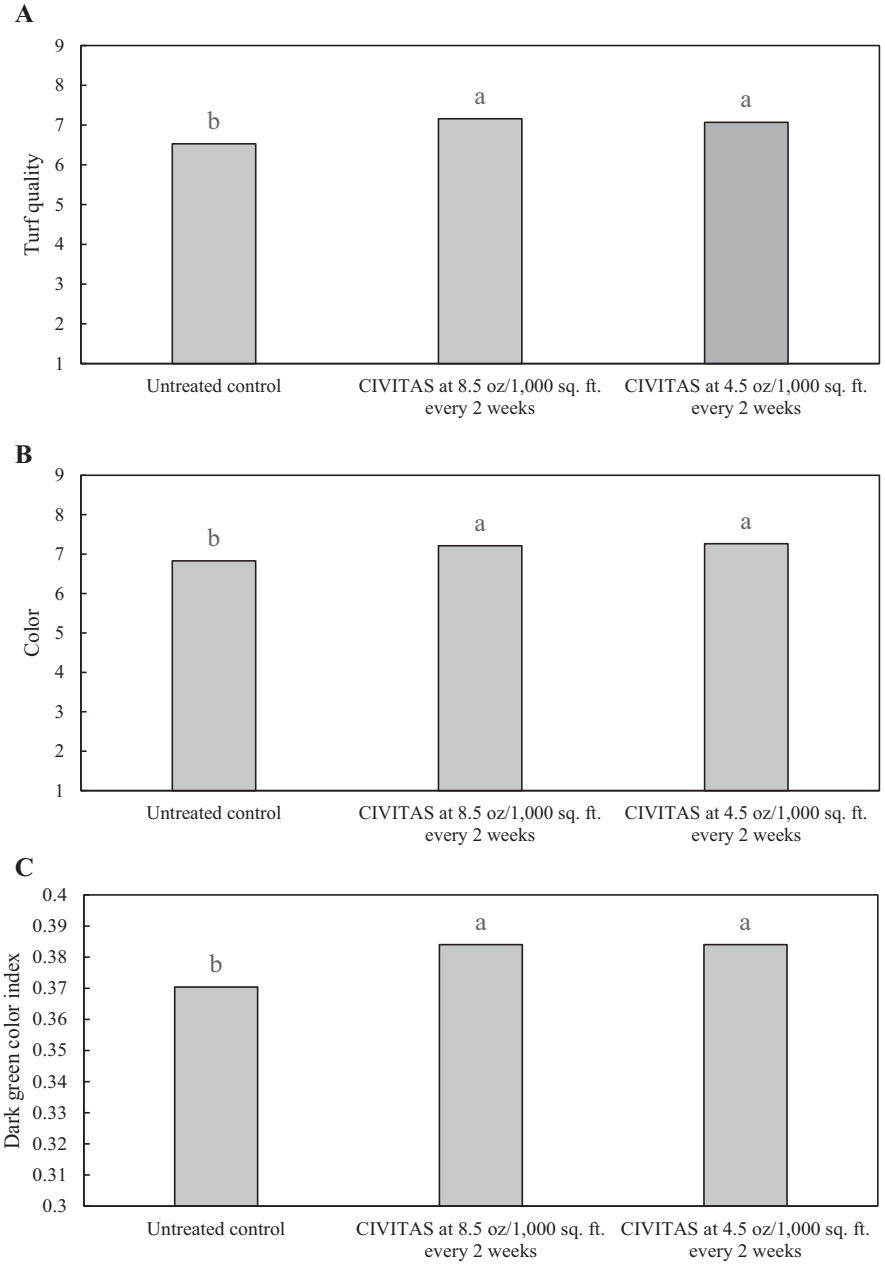

Fig. 3. Turf quality (A), color (B), and dark green color index (C) of 'Tifway II' bermudagrass treated with Civitas at different rates and frequencies in 2020, Riverside, CA, USA. Results are pooled across two evapotranspiration irrigation replacements, five months, and four replicates. 1oz/1000 ft^2 = 0.000318 L/m^2.

across ET_o level, months, and replicates (Fig. 3A). Additionally, turf quality was consistently higher in August, September, and October under the 65% ET_o replacement compared with the 55% ET_o replacement (Fig. 4A). In terms of turf color, both Civitas treatments (8.5 and 4.5 oz/1000 ft^2) applied biweekly significantly improved color compared with the untreated control in 2020, regardless of irrigation replacement or month (Fig. 3B). The higher irrigation replacement (65% ET_o) also enhanced turf color in August, September, and October (Fig. 4B).

NDVI, VWC, and SMV

Regardless of ET_o irrigation replacement, Civitas treatment exhibited no effect on NDVI in both years. Irrigation replacement at 65% ET_o improved NDVI ratings in August, September, and October in both years (Figs. 2B and 4C). Similar to NDVI, Civitas treatment did not affect VWC in either years. The higher ET_o irrigation replacement improved VWC from July to October in both years (Figs. 2C and 4D). In 2019, the higher ET_o irrigation replacement increased SMV from August to October regardless of the Civitas treatment (Fig. 2D), whereas the ET_o irrigation replacement had no impact on SMV in 2020 (data not shown).

PGC

In 2019, when averaging PGC over ET_o, Civitas applied every 2 weeks at either rate enhanced PGC compared with the untreated control in September (Fig. 1C). In October, the 2-week application frequency at both rates of Civitas treatments exhibited higher PGC followed by the 3-week application frequency, with all Civitas treatments outperforming the untreated control. In 2020, no differences were observed between any Civitas treatment and the untreated control (data not shown). Regardless of the Civitas treatment, the 65% ET_o irrigation replacement exhibited higher PGC in August and September in 2019 (Fig. 2E) and September and October in 2020 (Fig. 4E).

DGCI

In Jul 2019, plots treated with Civitas every 2 weeks at 8.5 oz/1000 ft^2 had higher DGCI compared with the untreated control (Fig. 1D). In August, Civitas applied at 4.5 oz/1000 ft^2 every 2 weeks exhibited superior DGCI than Civitas applied at 8.5 oz/1000 ft^2 every 3 weeks. In September, Civitas applied at the 2-week frequency at both rates resulted in higher DGCI compared with the other treatments. In October, the highest DGCI was observed in plots treated with Civitas at 8.5 oz/1000 ft^2 every 2 weeks, followed by those treated at 4.5 oz/1000 ft^2 every 2 weeks, and then by plots treated at 8.5 oz/1000 ft^2 every 3 weeks. All treatments were better than the untreated control. The irrigation replacement had no impact on DGCI in 2019 (data not shown). In 2020, regardless of irrigation replacement, Civitas applied every 2 weeks at 8.5 or 4.5 oz/1000 ft^2 enhanced DGCI, compared with the untreated control (Fig. 3C). Impacts of irrigation replacement only occurred in September, where 65% ET_o irrigation replacement enhanced DGCI (Fig. 4F).

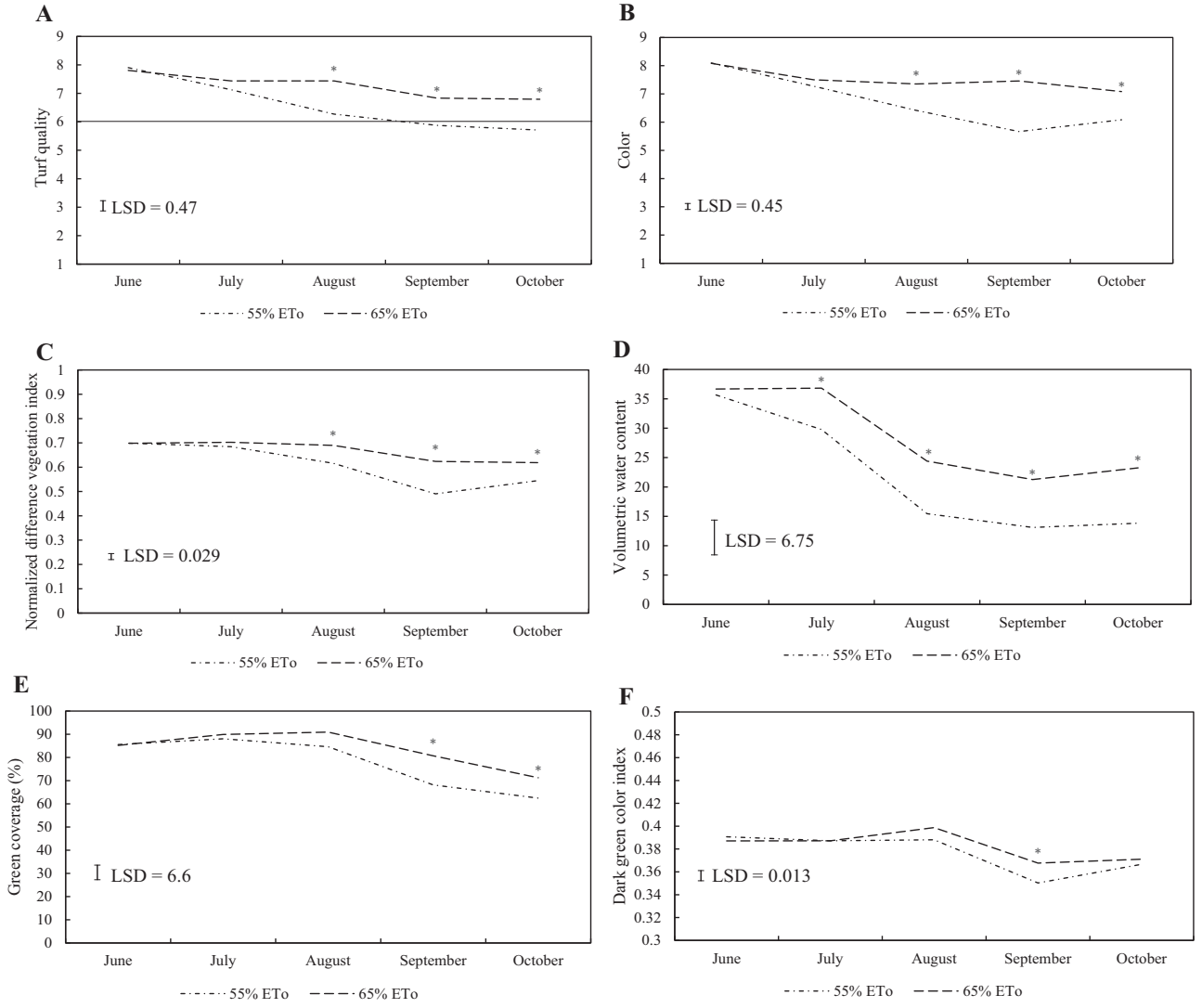

Fig. 4. Turf quality (A), color (B), normalized difference vegetation index (C), volumetric water content (D), percent green cover (E), and dark green color index (F) of 'Tifway II' bermudagrass irrigated at either 55% or 65% reference evapotranspiration (ET_o) replacements in 2020, Riverside, CA, USA. Results are pooled across three Civitas treatments, the untreated control, and four replicates. Asterisks (*) above the treatments indicate significant differences among the means. LSD = least significant difference.

Discussion

Drought conditions have increasingly posed challenges for turfgrass management by limiting irrigation availability. This study highlights the positive impact of Civitas in enhancing turfgrass quality in deficit-irrigated bermudagrass, demonstrating its potential as a valuable tool for maintaining healthy turf under water-limited conditions. The effects of Civitas on improving turf quality under drought conditions have also been observed in zoysiagrass (*Zoysia* spp.) and bermudagrass, particularly at low nitrogen levels (Diesburg et al. 2014). Similarly, Nissen et al. (2013) has reported that 'Palisades' zoysiagrass (*Zoysia japonica* Stued.) maintained acceptable quality and density at 36% ET_o throughout summer when treated with Civitas in Texas. In Europe, studies conducted on different putting greens showed up to 77% quality improvement with Civitas applied at 54 $L \cdot ha^{-1}$ (17 oz/1000 ft^2) (Aamlid et al. 2018). Although other research has reported phytotoxicity on cool-season turfgrass associated with Civitas (Kreuser and Rossi 2014), such effects were not observed in either year of this study.

The 3-week application interval tested in this study showed reduced efficacy on deficit-irrigated bermudagrass in 2019. This decline may have been attributed to the degradation of the mineral oil and/or the pigment or the pigment being removed through mowing. The highest overall efficacy of Civitas against drought in this study was observed at a rate of 8.5 oz/1000 ft^2 applied every 2 weeks. However, the differences between the 4.5 and 8.5 oz/1000 ft^2 were not significant. The average temperature in 2020 was higher than in 2019, which may have accelerated the degradation and volatilization of the mineral oil and/or pigment. This could explain the lack of significant differences between the two application rates during that year. Although the maximum label rate for this product is 17 oz/1000 ft^2, this study aimed to identify a cost-effective approach for product application.

Additionally, the 3-week application interval did not consistently align with the rating dates for Civitas applications. As the effects of the pigment gradually wane, earlier ratings often captured more favorable results. To

account for the potential influence of timing on both applications and ratings, we averaged the monthly data. However, the application schedules may still have affected the recorded outcomes.

In our study, Civitas improved turf color in both years. The application rate of 8.5 oz/1000 ft^2 demonstrated better overall turf color compared with the 4.5 oz/1000 ft^2 rate in one of the years. Aamlid et al. (2018) reported comparable results on several putting greens evaluated in November in Nordic countries. The pigment in Civitas, Harmonizer, is a polychlorinated copper II phthalocyanine pigment that produces a stable blue-green color (Nash 2011). This pigment has been associated with masking injury effects (Ervin et al. 2004), likely contributing to improved turf quality and color. The pigment may improve the aesthetics of yellowing turf under drought conditions. However, Civitas did not influence NDVI readings, indicating that the pigment does not alter the spectral response of the plants. Additionally, Civitas had no measurable impact on soil moisture levels at the first 3 inches of soil. Despite this, bermudagrass treated with Civitas showed improvements in green coverage percentage and DGCI in both years of the study.

Civitas improved quality under reduced water were promising: bermudagrass treated with Civitas maintained acceptable quality (6 or above) throughout most of the growing season while receiving 10% or 20% less water, particularly at the application rate of 8.5 oz/1000 ft^2 biweekly. This demonstrates that turfgrass managers could potentially save up to 20% on irrigation water compared with the average maximum consumptive water used by bermudagrass, as reported by Colmer and Barton (2017). The water-reducing benefits of Civitas were comparable to some of the top-performing wetting agents tested by Xiang et al. (2021). Additionally, Civitas offers further advantages, such as improved color and pest control.

Conclusion

In this study, the effects of Civitas on deficit-irrigated bermudagrass were assessed by determining turf quality, color, NDVI, VWC, SMV, PGC, and DGCI. Depending on the environmental conditions, we found that in 2019, the benefits of Civitas were reduced or eliminated due to chemical breakdown or pigment being mowed off before subsequent applications when applied every three weeks. In contrast, Civitas applied every 2 weeks, regardless of the rate, consistently demonstrated positive effects on deficit-irrigated bermudagrass in Riverside, CA, USA. Although Civitas applied at 8.5 oz/1000 ft^2 often promoted better turf characteristics than the 4.5 oz/1000 ft^2 rate in some instances, the overall differences were minimal. For turf managers operating on a limited budget, applying Civitas at 4.5 oz/1000 ft^2 may yield comparable results to the higher rate tested in this study. Future research should focus on understanding the mechanisms underlying Civitas' drought resistance, including its potential impact on root development, and should consider comparing a pigment-only treatment. At this stage, turfgrass managers may achieve multiple objectives by using Civitas, including enhancing turf quality and alleviating certain pest issues.

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