2025-04-28

Hybrid Bermudagrass Drought Tolerance in a Cool-Season Climate

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

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Kentucky bluegrass (*Poa pratensis* L.) (KBG) is the most commonly grown cool-season C3 turfgrass. However, as global temperatures rise, KBG struggles to tolerate higher temperatures, leading to increased irrigation demands—a growing concern in arid and semi-arid regions facing escalating drought conditions. In contrast, hybrid bermudagrass (HBG; *Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy), a warm-season C4 grass, has demonstrated promising adaptability in traditionally cool-season climates. Since 2008, HBG has been successfully grown with minimal winterkill in Provo, UT, USA, and is now being considered for broader adoption in similar climates. Two separate studies were conducted to evaluate the drought tolerance of HBG compared to KBG. The first study assessed two HBG cultivars, 'Latitude 36' (L36) and 'Tahoma 31' (T31), against a blend of KBG cultivars grown in a sand soil in a full factorial design with severe, mild, and no drought stress during the 2023 and 2024 growing seasons. As expected, KBG exhibited significant declines in NDVI, canopy cover, and visual turf quality under drought stress, with complete mortality occurring after ~six weeks of severe drought. In contrast, HBG maintained high performance under mild drought stress and showed only minor impacts under severe drought conditions by the third to sixth week. This suggests that HBG can sustain severe drought while maintaining acceptable turf quality. The second study expanded the evaluation by comparing KBG, six HBG cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1163' [O63], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31])with its genetic parents, Common Bermudagrass (*Cynodon dactylon* [L.] Pers.) (CBG), African bermudagrass (*Cynodon transvaalensis* Burtt Davy) (AFB) in a loam soil. A single drought treatment of no irrigation was applied to all species and varieties, with four dry-down cycles across the 2023 and 2024 growing seasons. In the first year, KBG and CBG showed the poorest performance in NDVI, canopy cover, and visual turf quality ratings. HBG cultivars consistently ranked highest of all species across all measurements, but there was not much significant difference between cultivars. The HBG cultivars demonstrated strong drought tolerance and recovery compared to KBG and CBG. Findings from both studies suggest that HBG cultivars offer a promising, water-efficient alternative to KBG in semi-arid, cool-season regions experiencing increasing water scarcity.

Keywords: turfgrass, water conservation, sustainable landscape, water-wise

ACKNOWLEDGEMENTS

Thank you, Dr. Bryan Hopkins, Glenl Wear, Dr. Neil Hansen, Dr. Brad Geary, Alexis Beazer (mom), and Brent Beazer (dad). I wanted to complete a master's degree, and you all helped me do it! I feel very blessed to have you in my life. I am grateful for your guidance and support. Thank you to my friends in the lab, especially Shannon Nelson, Caden Seely, and Clarissa Peterson. You all encourage me and make my life so full! Additional thanks to Adam Russell from MVP Genetics and to West Coast Turf for donating grass for our research.

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CHAPTER 1

Cool-Season Hybrid Bermudagrass and Kentucky Bluegrass Drought Tolerance When Grown in a Sand Root Zone

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ABSTRACT

Kentucky bluegrass (*Poa pratensis* L.) (KBG) is the most commonly grown cool-season C3 grass. As average global temperatures rise, these grasses that prefer a more moderate climate (22-26ºC) struggle to tolerate higher temperatures. This results in an escalation in irrigation water demand, which is an increasingly scarce resource in arid zones under escalating drought conditions. The triploid interspecific hybrid bermudagrass (HBG; *Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) is a warm-season C4 grass that may be increasingly suited for northern ecosystems traditionally classified as transitional or cool-season climates. This species has been successfully grown, with virtually no winterkill, since 2008 in Provo, UT, USA. It has also recently been grown in other traditionally cool-season zones and is being considered for more widespread use in these regions. The objective of this study is to compare HBG 'Latitude 36' (L36) and 'Tahoma 31' (T31) to a blend of KBG cultivars in a full factorial design with two cycles of severe, mild, and no drought stress in each of the 2023 and 2024 growing seasons. As expected, the severe drought stress in KBG resulted in significantly lower NDVI, percent cover, and visual turf quality ratings than the mild stress, with both significantly lower than no drought stress in 2023. Mild drought stress KBG sometimes performed better than optimally irrigated turfgrass in the second year (2024), perhaps due to drought induced adaptation. The first six-week cycle of severe drought stress killed the KBG completely in the first year. In stark contrast, mild drought stress in HBG resulted in no differences with the fully irrigated grass compared to drought stress through ~six weeks of no irrigation. Similar results were observed in 2024, however the second dry-down period of 2024 lasted ~11 weeks. The HBG performed well with no irrigation from 30 July 2024 until the irrigation systems were winterized on 14 October 2024. Both HBG cultivars were consistently statistically different from KBG across NDVI, percent cover, and visual quality ratings, but not statistically different from each other. Root depth, and root biomass of KBG were significantly less than either HBG cultivar, but the interaction between treatment (irrigation level) and grass type was not significant. The data suggest that irrigation needs will be less for HBG than KBG and that HBG could provide a water-saving turfgrass alternative to KBG in semi-arid, cool-season regions with increasing water scarcity.

INTRODUCTION

As urban environments expand, turfgrass is the largest irrigated crop in the USA. It is estimated to cover ~163,800 km2, occupying roughly 2% of the surface of the continental United States (Milesi et al., 2005). Turfgrass provides many environmental, economic, and psychological/social benefits to society. Turfgrass supports environmental processes by: sequestering carbon, respiring oxygen, reducing nutrient pollution, minimizing soil erosion, improving soil health, reducing fire hazards, cleaning atmospheric pollutants, and lowering temperatures and noise pollution in urban areas (Li et al., 2011; Monteiro, 2017; Zirkle et al., 2011). The turfgrass industry makes a significant impact on the economy, generating billions of dollars of revenue and creating nearly a million jobs (Haydu et al., 2006). Increased aesthetic value, sports, recreation, and reduced crime rates are also benefits associated with maintained turfgrass in a community (Brosnan et al., 2020;Troy et al., 2016).

Despite its benefits, turfgrass is frequently scrutinized due to the following and other reasons: large tracts of monoculture, pesticide and fertilizer pollution, maintenance related carbon emissions, and water consumption (Robbins & Sharp, 2003; Whitney, 2010). It is especially under fire in semi-arid regions because of its water consumption (*Principles of Water Wise Landscaping*, n.d.). Increasing water scarcity is a major concern in many regions of the world, including the western USA. For example, the potential drying up of the Great Salt Lake poses significant risks to the ecosystem, potential future water restrictions, agriculture, and the economy (Abbott et al., 2023; Steed, 2024). Lake Mead faces a similar fate with potentially serious impacts on the environment and communities to which its water is distributed. Availability of hydroelectric power, agricultural irrigation, and municipal water supply for several states is a major concern (Edalat & Stephen, 2019).

It is vital to find solutions that minimize water consumption while maintaining the essential services provided by turfgrass in urban ecosystems. Efficient irrigation systems should be considered to conserve water. Many systems are inefficient and have poor distribution uniformity (DU; Kruse, 1978) measures of only 40-50% (Baum et al., 2005). Proper design and installation with continual maintenance to repair leaks, replace broken or improperly sized sprinklers/nozzles, adjust spray patterns, and installation of smart controllers (Evans et al., 2022) will increase DU and irrigation system efficiency for water savings (*Principles of Water Wise Landscaping*, n.d.). Reducing non-practical lawn space is also a possible solution to conserve water and maintain many of the benefits of turfgrass in the urban environment. For example, “park strips”, between sidewalks and roads, are small areas of turfgrass that don’t serve much of a purpose and are especially wasteful of water (Martini et al., 2025). The responsible and sustainable use of turfgrass is one approach that allows us to be better stewards of the earth.

Another option for improving water conservation is utilization of water-conserving species and cultivars. Kentucky bluegrass (KBG; *Poa pratensis* L.) is the most commonly grown turfgrass species because it has many excellent properties (Christians et al., 2016), but it is generally not considered a water-conserving species. Some cultivars require less water than others with, for example, drought tolerance ranging from 3.8-7.5 on a 1-9 scale where 9 represented no wilting under drought conditions (*NTEP 2017 National Kentucky Bluegrass Test*, 2017). These cultivars employ varying drought escape ability as it slides into dormancy under severe water and/or temperature stress, but KBG has an outstanding ability to stay alive during dormancy and recover efficiently (Bonos et al., 2008; Jiang & Huang, 2000). However, turfgrass managers generally want green grass and KBG requires more than 10 mm d^{-1} to stay out of dormancy and thrive (Beard & Beard, 2005; Huang, 2008). As such, KBG is generally classified as having moderate to low drought resistance (Abraham et al., 2004; Aronson et al., 1987).

Many other turfgrass species have lower water requirements. For example, another cool-season species is tall fescue [*Lolium arundinaceum* (Schreb.) S.J. Darbyshire], but it has been shown to use ~10% less water than KBG (Ervin & Koski, 1998). Furthermore, warm-season grasses typically need less water than cool-season grasses with evapotranspiration (ET) rates 1-6 mm d^{-1} lower (Christians et al., 2016; Huang, 2008). For example, hybrid bermudagrass (HBG; *Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy), the most commonly grown turfgrass in warm-season climates, is very water efficient (Beard & Beard, 2005) (Pinnix & Miller, 2019). The HBG ET rates are 6-7 mm d^{-1} (Beard & Beard, 2005; Council for Agricultural

Science and Technology, 2006). Some cultivars display acceptable turf quality after receiving irrigation at 10-15% of ET (Wherley et al., 2014), and others are so drought-tolerant that they can recover in less than 2 weeks from a 55 or 90 d drought (Steinke et al., 2011). Burgin et al. (2022) found that HBG grew well with 30-50% less irrigation water applied than KBG. Proposed mechanisms for HBG water efficiency include the use of a deep, dense, efficient root system (Carrow, 1996; Fu et al., 2004; Garrot Jnr & Mancino, 1994; Husmoen et al., 2012; Zhou et al., 2013; Burgin et al., 2021), bulliform cells (Bizhani & Salehi, 2014; Iqbal et al., 2022; Tufail et al., 2023), metabolite accumulation (namely sugars, sugar alcohols, organic acids, and amino acids) (Du et al., 2011), and closing wax-protected stomata quickly in dry periods (Kim, 1987; Romero & Dukes, 2009; Zhou et al., 2013).

As a result, HBG and other warm-season grasses are a great option to provide the ecosystem services provided by grass while also conserving water in these regions. Droughts are also very common in northern climates (Abbott et al., 2023), but warm-season grasses are not generally an option as they die out in cold winters. Although HBG is a warm-season grass, it is adapted to cold weather better than most other C4 species.

As the climate warms (*State Climate Summaries 2022 - Utah*, 2022), the use of HBG is moving northward into transition and cool-season climates (Burgin et al., 2021). Notable examples of this trend include successful use of HBG ('Iron Cutter') in 2022/2023 at the Northwestern University football field in Illinois (Simons, 2024), establishment and production of HBG sod (e.g., Green Valley Turf Company, Platteville, CO, USA; Green Belt Turf Farm, Colorado Springs, CO, USA; NoCo Sod, Gill, CO, USA), and the practice fields and playing field for the Philadelphia Eagles since 2013 (Tony Leonard, personal communication). The Eagles did have some winterkill initially with the 'Latitude 36' cultivar, but then successfully switched to 'NorthBridge' and 'Tahoma 31' cultivars. Some researchers are using daily light integral measures to estimate the potential for success of HBG in cool-season climates (Simons, 2024).

As global climate change continues to alter temperature and precipitation patterns, it is essential that landscaping practices are adapted to maintain the ecosystem services provided by turfgrass—such as erosion control, heat mitigation, carbon sequestration, and improved water infiltration (Li et al., 2011; Monteiro, 2017; Zirkle et al., 2011). Turfgrass plays a vital role in urban and suburban environments, and by incorporating more resilient species like HBG in regions that were once too cold, benefits of turfgrass can be preserved while reducing water use and improving drought tolerance.

HBG has been grown continuously in the cool-season, semi-arid zone of Provo, UT, USA since 2008 without any significant winter kill (Bryan G. Hopkins, personal communication). This region in the Inter-Mountain West (IMW) of the USA has had dramatic increases in average temperatures. As evidence of this, the average annual temperatures in Salt Lake City, Utah, USA show an overall upward trend over the last four decades, with greater incidences of drought (Carter et al., 2010; Simon Wang & R., 2012). These observations led to studies with common bermudagrass [CBG; *Cynodon dactylon* (L.) Pers.], African bermudagrass [ABG; *Cynodon transvaalensis* Burtt Davy] and six HBG cultivars, with no winterkill in any of these studies over nearly a decade and with significant evidence of reduced water requirements (Burgin et al., 2021; Burgin et al., 2022).

Building on these previous studies, we hypothesize that HBG will be able to thrive with no irrigation for significantly longer than KBG under mild and extreme drought conditions. The objectives of this study are to determine the impact of mild and severe drought stress on plant health of KBG and two HBG cultivars when grown in sandy soil by evaluating verdure, normalized difference vegetation index (NDVI), canopy density, evapotranspiration (ET), volumetric water content (VWC), and gravimetric water content.

MATERIALS AND METHODS

Establishment and Management

A field study was conducted at Brigham Young University in Provo, UT (40° 14′ 43″ N, 111° 38′ 29″ W, 1406 m above mean sea level). The study area is semi-arid with a cool-season climate, although daytime high temperatures during the summer typically ranged 30 to 40°C. Winter nighttime low temperatures during the study period typically ranged -1 to -11°C. This area falls under the USDA Hardiness Zone 7a (U.S. Department of Agriculture, 2023). The study was established on an existing KBG field established in 2016 as sod laid over a constructed soil (0.05 m of soil over a compacted subsoil base) from locally sourced quarry sand. The soil was a calcareous sandy loam soil (Table 1). The HBG was established in randomized blocks in two-thirds of the study area by killing the KBG with two applications of glyphosate herbicide, following label directions, in the late spring of 2020. The HBG cultivars were established in early summer as 'OKC 1119' ('Latitude 36'™), hereafter referred to as L36, in one-third of the plots, and 'OKC 1131' ('Tahoma 31'™), hereafter referred to as 'T31 ', in one-third of the plots amidst the other one-third of the plots with the established blend of KBG cultivars ('Arrowhead' 40%, 'Rubio' 40%, and 'Blue Note' 20%). The HBG cultivars were planted vegetatively. The L36 was obtained as 2.5 cm plugs, which were spaced 30 cm apart and planted to the depth of their roots on 10 June. The T31 was obtained as sod which was cut into strips ~8 cm long and ~2 cm wide, spaced 31 cm apart, and planted to the depth of their roots on 10 July. The plots were 3 m x 3 m with grass types separated from the next with a 0.2 m barrier of bare soil maintained with glyphosate.

Best Management Practices were followed for soil, nutrient, water, pest, and cultural management between establishment and the beginning of the study. The grass was mowed at approximately 5 cm during establishment every ~7 d with a rotary mower. The mowing height was gradually transitioned to a lower level using a reel mower 30 d before the beginning of the trial. During this phase, the grass was mowed twice weekly at a height of 4 cm. Clippings were recycled in place during mowing. Fertilizer was added at a rate of 49 kg N ha^{-1} during establishment on each of the following dates: 15 November 2019 ammonium sulfate 20-0-0-24(S), 16 July 2020 (Pro Prills 12-8-16-17[S]-3[Fe]; Simplot, Boise, ID, USA), 23 September 2020 (Pro Prills), and 20 April 2021 (25-5-10-3[Fe]-3[S]-0.03[Mn]-0.12[Zn]). GameOn™ (Corteva Agriscience, Wilmington, DE, USA) and SpeedZone® Southern (PBI/Gordon Corporation, Kansas City, MO) herbicides were applied at labeled rates on 22 July and 6 August 2021, respectively. Other than a few weeds, there were no notable pest or pathogen pressure problems in the plot area. The grass was watered every day during the first month of establishment and then decreased to once every second day. Plots were subjected to irrigation studies in 2021 and 2022, as described by Burgin (2021), and then recovered fully by fall 2021. Weather during the study time frame was mostly typical for this semi-arid region with low humidity (average ~20-30% relative humidity) and hot days and cool nights with minimal precipitation (Burgin et al., 2021) (Supplementary Figures 1 and 2).

Table 1. Soil properties for two studies prior to fertilization				
	Irrigation Trial		**Variety Trial**	
Property	**Method**	**Value**	**Method**	**Value**
VWC at field capacity, %	Volumetric	23	Gravimetric	?
Texture	Hydrometer[1]	Sandy loam	Hydrometer	Sandy loam
Sand, %		67.4		75.4
Clay, %		11.8		9.8
Silt, %		20.7		14.7
Bulk density, g cm-3	Gravimetric[2]	1.3	Gravimetric	1.62
pH	Saturated Paste[2]	7.5	Saturated Paste	7.7
EC, dS m-1	" "	0.5	EC Meter	0.5
OM, %	Walkley-Black Method[2]	1.5	Dichromate Oxidation	1.3
NO3-N, ppm	KCl 2M[2]	5	Lachat	4
P, ppm	Olsen Bicarbonate[2]	16	Olsen	13
K, ppm	" "	93	" "	92
Zn, ppm	DTPA Extraction[2]	3.7	DTPA	2.2
Mn, ppm	" "	6	" "	4.3
Fe, ppm	" "	38.6	" "	20.0
Cu, ppm	" "	1.3	" "	0.7

[1] (Gavlak et al., 2000)

During the experiment the plots were mowed 2-3x weekly at a height of 3.8 cm using a reel mower. Best management practices were followed for fertility and pest management. Fertilizer was added at a rate of 98 kg N ha^{-1} (urea; 46-0-0), 49 kg P_2O_5 ha^{-1} (monoammonium phosphate; 11-52-0), 49 kg K_2O ha^{-1} (potassium chloride; 0-0-60), 0.49 kg H_3BO_3 ha^{-1} (boric acid) on 28 July 2023. An additional 98 kg N ha^{-1} (urea 46-0-0) TSF-1 was applied on 24 October 2023. GameOn™ (Corteva Agriscience, Wilmington, DE, USA) was applied on 9 August 2023 and WeedBGone™ (Scotts Miracle-Gro Company, Marysville, OH, USA) was applied on 8 September 2023. Plots were dethatched with a Classen TR-20HD Power Rake on 17 April 2024 and fertilized with 98 kg N ha^{-1} (urea; 46-0-0) on 10 May 2024. GameOn and glyphosate were used to spot spray broadleaf weeds as needed. 294 kg K2O ha^{-1} (potassium chloride; 0-0-60) was applied 28 August 2024.

Treatments

Treatments consisted of all combinations of the three grass types with three irrigation rates replicated three times and arranged in a randomized complete block, full factorial design (Table 2; Supplementary Figure 3). Grass treatments were HBG L36, HBG T31, and KBG blend. Irrigation treatments included optimal irrigation (no drought stress), mild stress, and severe stress. For the moisture stress treatments, the irrigation water was turned off completely until visible signs of stress were present. The treatments began on 31 May 2023. The mild stress treatment was not irrigated until the KBG showed signs of stress seven days later on 7 June 2023. The severe stress treatment was irrigated when the HBG showed similar stress on 14 July 2023. The end of each dry down period was determined by a drop of ~0.1 NDVI and/or with visual symptoms (grass color had a gray hue and did not return to an erect form when stepped on due to being flaccid). After irrigation was turned back on, the plots were brought back to near optimal health and then stressed again for a second repetition of the experiment between 8 August 2023 and 21 August 2023, except for the KBG plots in the severe stress treatment which did not recover. These plots were replaced and established with sod in October 2023 before 2024 evaluations began. The establishment was successful with fully mature sod, including normal rooting depth, by June 2024.

In 2024 the plots were irrigated optimally for several weeks to prepare for the experiment. The mild and severe stress zones were shut off on 3 June 2024. The mild stress treatment zone was not irrigated until 8 June when the KBG showed visual signs of stress. The severe stress treatment zone remained shut off until 26 June 2024 when HBG showed visual signs of stress. The second dry down period of 2024 was from 30 July to 14 October, with the mild stress treatment only going until 14 August 2024.

Table 2. Treatments for a field study (2023-2024) with a blend of Kentucky bluegrass (KBG) cultivars compared to 'Tahoma 31' (T31) and 'Latitude 36' (L36) hybrid bermudagrass irrigated at Severe or Mild drought stress compared to Optimal irrigation.

Trt #	Grass Type	Irrigation
1	KBG	Severe
2	KBG	Mild
3	KBG	Optimal
4	T31	Severe
5	T31	Mild
6	T31	Optimal
7	L36	Severe
8	L36	Mild
9	L36	Optimal

The evaluated treatment periods were 31 May 2023 to 14 July 2023, 8 August 2023 to 21 August 2023, 3 June 2024 to 26 June 2024, and 30 July 2024 to 14 October 2024 with ample irrigation for nearly full plant health recovery in between. In the optimal irrigation treatment, the irrigation levels were adjusted regularly based on average ET_o (reference ET) according to an on-site weather station (ATMOS 41, METER Group, Pullman, WA, USA).

Irrigation was supplied via a buried PVC pipe system at 400 kPa pressure with a controller (ESP-Modular, Rain Bird, Azusa, CA, USA). The sprinkler heads (Pro-Spray PRS40, Hunter Industries, San Marcos, CA, USA) were located at each corner of each plot. Each sprinkler head was calibrated to do a quarter turn and throw the length of the plot (3 m) to ensure minimal overlap with adjacent plots. Measurements were taken from the near center of each plot to avoid any irrigation contamination from adjacent plots. This system allows each plot to receive a unique irrigation rate.

Measurements

Soil VWC and temperature were constantly monitored with in-situ sensors (GS3; METER Group, Pullman, WA, USA) installed 6 cm deep underneath every plot before establishing the KBG. Soil water potential (θ) was constantly monitored with sensors (MPS-6; METER Group, Pullman, WA, USA) installed at 6, 15, and 30 cm deep intervals underneath select plots before KBG establishment. These data were collected every 1 h (EM50G Remote Loggers; Meter Group, Pullman, WA, USA). Soil mass water content, soil VWC, grass NDVI, percent cover, and visual grass health ratings were all measured at the beginning and end of each dry down period of the study 31 May 2023, 14 July 2023, 8 August 2023, 21 September 2023, on 3 June 2024, 26 June 2024, 30 July 2024, 14 October 2024.

The NDVI measurements were taken every ~7 d in each plot with a handheld sensor passed directly above at 1 m height mid-day (Trimble Handheld GreenSeeker, Trimble Agriculture, Sunnyvale, CA, USA). Canopy cover percentage was evaluated ~7 d in every plot with a smartphone app using a camera passed directly overhead of every plot midday, avoiding shadows (Canopeo, Oklahoma State University, Department of Plant and Soil Sciences, Stillwater, OK, USA). Visual turf quality ratings (verdure) were evaluated every ~7 days on a scale from 1-9, with 9 healthy green full canopy and 1 unhealthy tan/brown canopy.

These same measures, as well as root depth and root biomass, were measured at the end of the study on 21 September 2023 and 14 October 2024. Root and thatch biomass were determined after air drying until the biomass reached a constant weight.

Average daily ET was calculated by determining total ET for each dry down period and dividing by the number of days in the dry down. The total ET for each plot was calculated using the following water balance equation:

$$ET = I + P - D - R - \Delta\theta$$

where *ET* is total evapotranspiration for the dry down period, *I* is total irrigation, *P* is total precipitation, *D* is total drainage, *R* is runoff, and $\Delta\theta$ is the change in soil water depth within the 0.46 m deep soil profile, calculated between the soil sampling at the start and the end of the dry downs. Drainage was assumed to be zero because irrigation rates were at or below daily ET. Runoff was assumed to be zero.

Analysis of Variance was used to determine statistical significance for each measurement with mean separation by the Tukey method (JMP statistical software version 18.0.2, SAS, Cary, NC, USA).

RESULTS

In general, weather conditions during this study were hot and dry. Between 30 May 2023 and 21 September 2023 total precipitation was equal to 53 mm and the average temperature was 22.7ºC. Between 5 June 2024 and 14 October 2024 the site received 49 mm of precipitation, and the average temperature was 23.1ºC (Supplementary Figures 1 and 2). Generally, grass type and irrigation treatments and their interactions had highly significant effects on all measured parameters (Table 3) with the exception of root growth (Table 4). Root biomass and depth were much greater for HBG compared to KBG, but there were no differences among irrigation treatments (Table 4). The HBG cultivars behaved statistically identical for most parameters and, thus, were combined for analysis for all measurements except VWC. Statistical comparisons were made within a species to compare mild and severe drought stress to the optimal.

Table 3. Statistical output for surface volumetric water content (VWC) measured with a handheld sensor, verdure (visual ratings), Normalized Difference Vegetation Index (NDVI), and cover percentage for a study comparing Grass Types (G) and Irrigation Treatments (I) across several Dates (D) and their interactions over two growing seasons.

	VWC		Verdure		NDVI		Cover	
Source	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**
2023								
G	0.1	0.8869	181.6	<.0001	366.4	<.0001	93.5	<.0001
I	87.5	<.0001	410.6	<.0001	491.1	<.0001	36.2	<.0001
D	329.3	<.0001	108.2	<.0001	249.9	<.0001	107.7	<.0001
G*I	3.3	0.0121	299.3	<.0001	394.8	<.0001	24.9	<.0001
G*D	1.8	0.0089	11.5	<.0001	26.0	<.0001	8.8	<.0001
I*D	11.5	<.0001	8.8	<.0001	14.9	<.0001	12.8	<.0001
G*I*D	1.2	0.1819	5.5	<.0001	8.2	<.0001	5.2	<.0001
2024								
G	237.1	<.0001	155.7	<.0001	233.1	<.0001	366.3	<.0001
I	862	<.0001	230.9	<.0001	411.8	<.0001	256.2	<.0001
D	23.9	<.0001	147.8	<.0001	276.0	<.0001	225	<.0001
G*I	22.9	<.0001	166.0	<.0001	277.2	<.0001	163	<.0001
G*D	5.7	<.0001	67.4	<.0001	114.8	<.0001	67.4	<.0001
I*D	23.2	<.0001	9.7	<.0001	11.3	<.0001	8.5	<.0001
G*I*D	1.2	0.1088	5.9	<.0001	10	<.0001	5.5	<.0001

Table 4. Statistical output for root depths (mean and maximum) and root biomass for a study comparing Grass Types (G) and Irrigation Treatments (I) and their interactions over two growing seasons.

	Max Root Depth		**Mean Root Depth**		**Root Biomass**	
Source	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**
2023						
G	78.5	<.0001	67	<.0001	9.4	0.0016
I	2.0	0.1573	2.6	0.1005	0.2	0.7912
G*I	1.1	0.4003	1.7	0.19	0.7	0.6227
2024						
G	52	<.0001	84.4	<.0001	4.4	0.0285
I	1.9	0.1769	1.7	0.2054	0.7	0.5227
G*I	1.3	0.2947	1.9	0.1489	1.9	0.1561

Normalized Difference Vegetation Index

In 2023, the HBG maintained similar NDVI under both severe and mild drought stress compared to optimal irrigation (Figure 1A; Supplementary Table 1). Results were similar in 2024 with no significant differences between drought-stressed and optimally irrigated plots, except on two dates in June when severe drought stress led to lower NDVI (Figure 1B). Similarly, KBG subjected to mild drought stress showed no significant difference in NDVI compared to optimal irrigation in 2023. However, severe drought-stressed KBG exhibited significantly lower NDVI beginning 7 June 2023 (Figure 1A). In 2024, severe drought-stressed KBG had reduced NDVI compared to optimally irrigated plots for much of the summer after 20 June (Figure 1B). It is interesting to note that in the first part of summer 2024 (until the first week of August) mild drought stressed KBG performed as well as or better than the optimally irrigated KBG and mild drought stressed HBG (Figure 1B). This could be a result of turfgrass adaptation to drought after the 2023 induced mild drought stress. For example, conditioning the plant to use less water or form deeper roots.

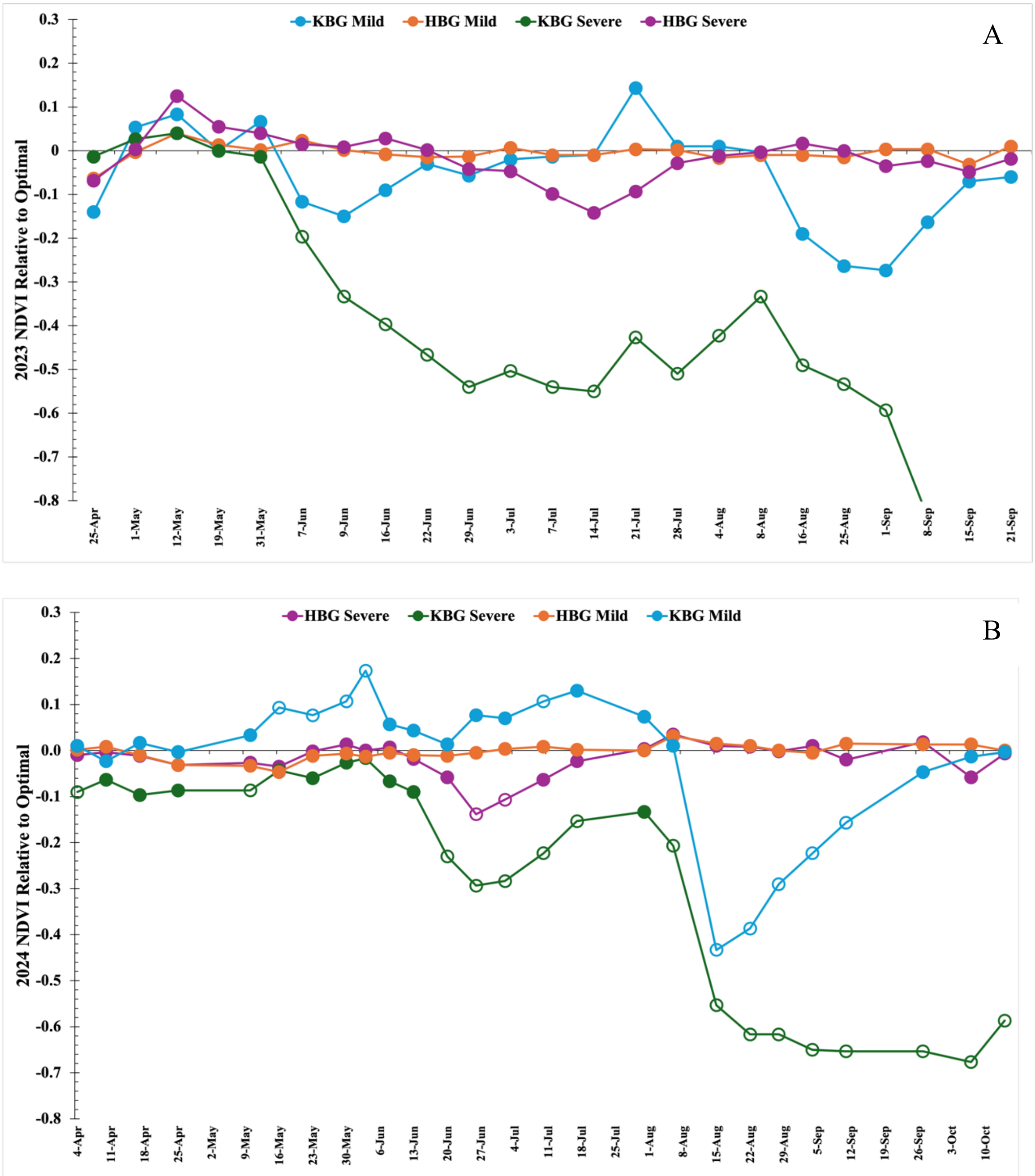

Figure 1. Normalized Difference Vegetation Index (NDVI), a measure of canopy health, for Mild or Severe drought-stressed Kentucky bluegrass (KBG) and hybrid bermudagrass (HBG; averaged across two hybrids, Tahoma 31 and Latitude 36) relative to fully irrigated optimal grasses during summer 2023 (A) and 2024 (B). Severe drought indicates no irrigation applied during the dry down period until HBG showed visual signs of stress. Mild drought indicates no irrigation applied until KBG showed visual signs of stress. Optimal irrigation indicates a 100% ET replacement. Open circle data points are significantly different from the optimal irrigation ($P < 0.05$).

Visual Ratings (Verdure)

Similar patterns were observed in visual turf quality ratings (Supplementary Table 2). In both years, HBG cultivars under mild and severe drought stress showed no visible differences compared to optimally irrigated plots. However, severe drought-stressed KBG consistently received lower visual ratings than the optimally irrigated control, with more pronounced declines in 2023 compared to 2024 (Figure 2A, Figure 2B).

Canopy cover percentage

The most notable differences in Canopy Cover were observed in severe drought-stressed KBG plots. In contrast, the HBG cultivars under mild and severe drought stress maintained canopy cover comparable to optimally irrigated plots during both years of the study (Figure 3A, Figure 3B, Supplementary Table 3).

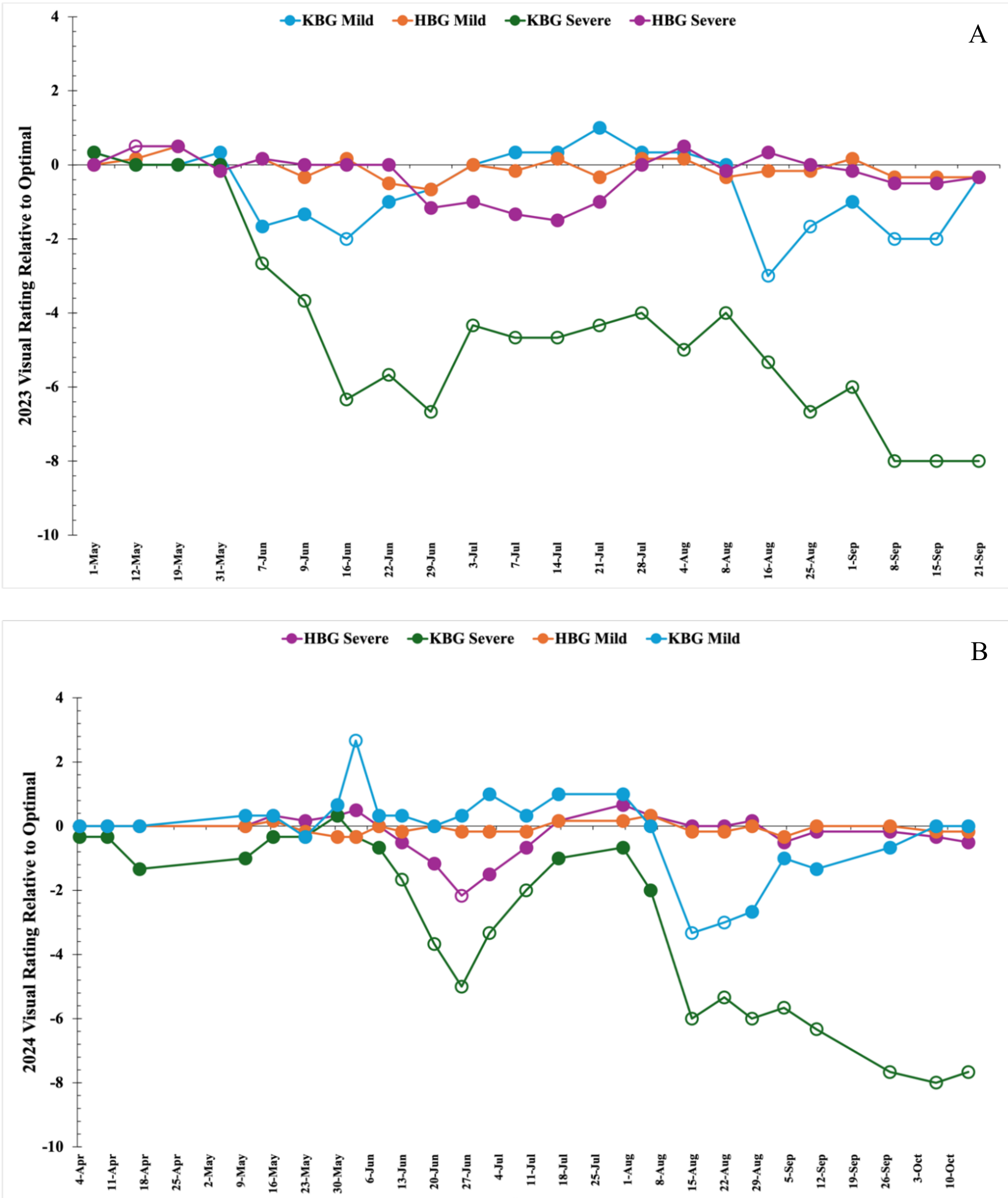

Figure 2. Visual turf quality rating, a measure of canopy health, for Mild or Severe drought-stressed Kentucky bluegrass (KBG) and hybrid bermudagrass (HBG; averaged across two hybrids, Tahoma 31 and Latitude 36) relative to fully irrigated optimal grasses during summer 2023 (A) and 2024 (B). Severe drought indicates no irrigation applied during the dry down period until HBG showed visual signs of stress. Mild drought indicates no irrigation applied until KBG showed visual signs of stress. Optimal irrigation indicates a 100% ET replacement. Open circle data points are significantly different from the optimal irrigation ($P < 0.05$).

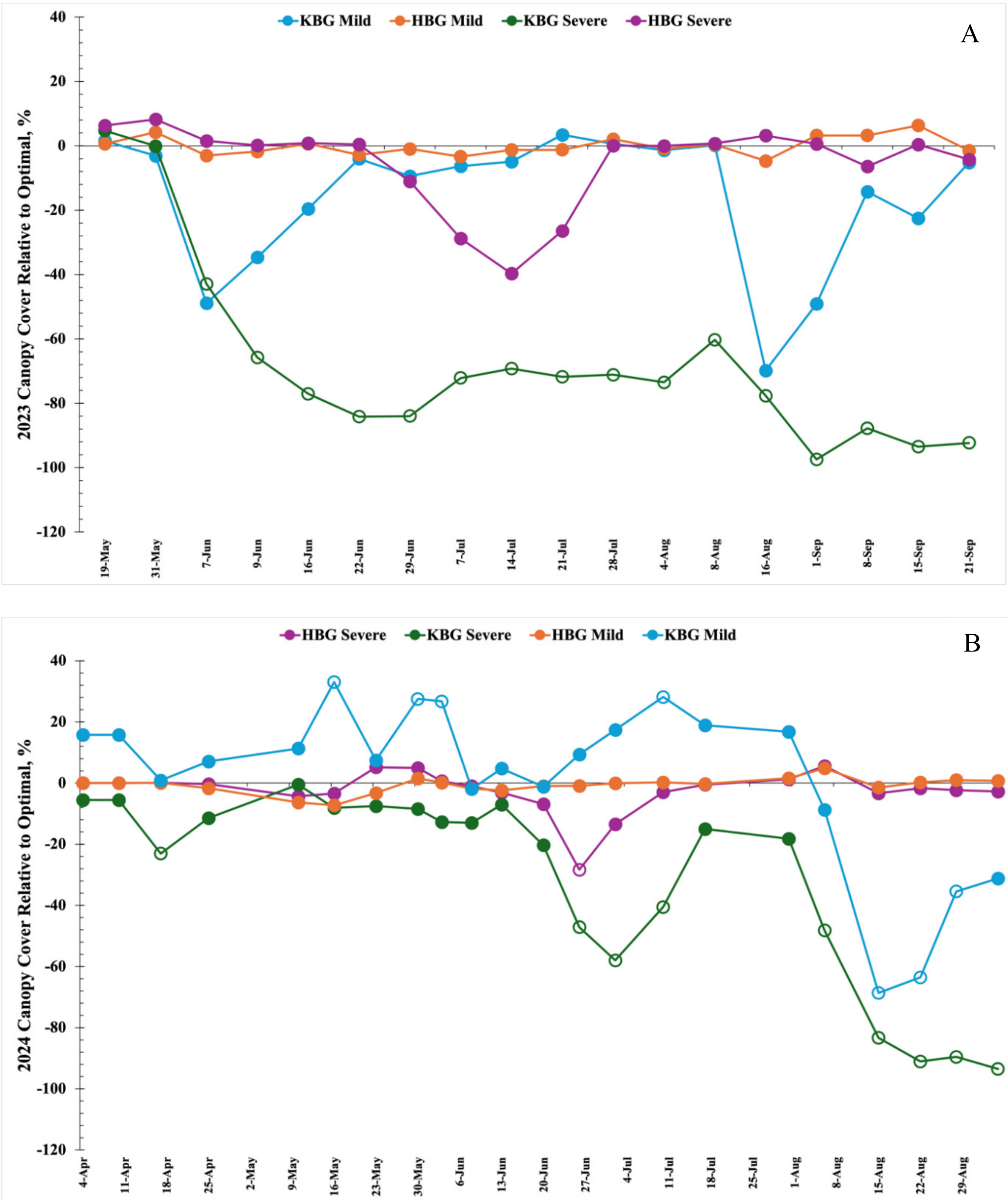

Figure 3. Canopy Cover for Mild or Severe drought-stressed Kentucky bluegrass (KBG) and hybrid bermudagrass (HBG; averaged across two hybrids, Tahoma 31 and Latitude 36) relative to fully irrigated optimal grasses during summer 2023 (A) and 2024 (B). Severe drought indicates no irrigation applied during the dry down period until HBG showed visual signs of stress. Mild drought indicates no irrigation applied until KBG showed visual signs of stress. Optimal irrigation indicates a 100% ET replacement. Open circle data points are significantly different from the optimal irrigation ($P < 0.05$).

Volumetric Water Content (surface)

Across both years of the study, the three-way interaction involving time was not significant (Table 3). In 2023, VWC did not differ between species within the same treatment; however, grasses under severe drought stress had significantly lower VWC than those under mild drought stress or optimal irrigation (Figure 4A). In 2024, greater variation in VWC was observed (Figure 4B). The HBG cultivars showed no significant differences in VWC except under severe drought stress. In contrast, KBG consistently exhibited lower VWC than either HBG cultivar across all irrigation treatments (Supplementary Table 4). In 2024 there were also significant differences between T31 and L36 in the severe drought treatment with T31 exhibiting higher water content. Interestingly, this same trend was observed in 2023, though not statistically significant. In ground VWC sensor means across the four dry down periods are also reported (Supplementary Table 5), however, a data logger malfunction produced gaps in data so that no statistical analysis was run.

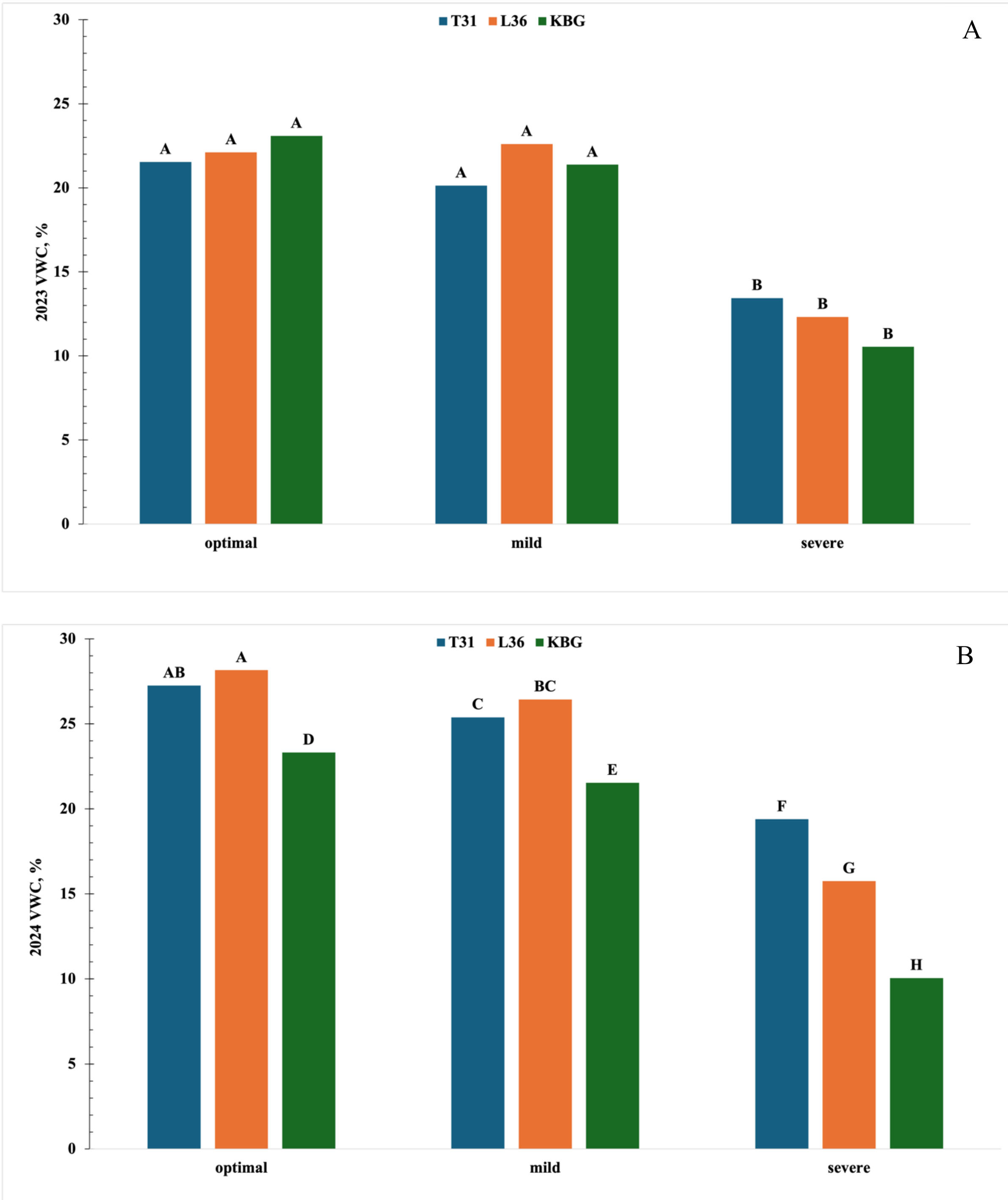

Figure 4. Soil volumetric water content (VWC) for Mild or Severe drought-stressed Kentucky bluegrass (KBG) and hybrid bermudagrass (HBG; averaged across two hybrids, Tahoma 31 and Latitude 36) relative to fully irrigated optimal grasses during summer 2023 (A) and 2024 (B). Severe drought indicates no irrigation applied during the dry down period until HBG showed visual signs of stress. Mild drought indicates no irrigation applied until KBG showed visual signs of stress. Optimal irrigation indicates a 100% ET replacement. Bars that share the same letter are statistically the same ($P < 0.05$).

Root Biomass and Root Depth

There were statistically significant differences observed in root biomass, mean root depth, and max root depth between grass types with HBG roots being deeper than KBG roots and HBG root biomass being greater than KBG root biomass (Table 4). However, there were no significant differences observed in the interaction between grass type and irrigation treatment, or irrigation treatment on its own (Supplementary Table 6).

Average Daily ET

Difference in daily ET between irrigation treatments was significant in all repetitions of the study (Supplementary Table 7). However, difference in daily ET between grass types was not significant. Additionally, across both years of the study, average daily ET was not statistically significant in a two-way interaction between irrigation treatment and grass type (Table 5). The average daily ET for L36 Severe, Mild, and Optimal were .75mm, 5mm, and 5.6mm respectively. For T31 Severe, Mild, and Optimal the average daily ET was .7mm, 19.4mm, and 5.6mm respectively. KBG Severe Mild, and Optimal average daily ET rates of .45mm, 5.3mm, and 5.4 were reported (Supplementary Table 7).

Table 5. Statistical output for average daily Evapotranspiration (ET) over four dry down periods for a study comparing Grass Types (G) and Irrigation Treatments (I) and their interactions over two growing seasons.

	5/31/23-7/14/23		**8/8/23-9/21/23**		**6/3/24-6/24/24**		**7/31/24-10/14/24**	
Source	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**	**F Ratio**	**Prob > F**
G	1.3	0.3028	0.2	0.836	0.0	0.9749	1.0	0.3873
I	153	<.0001	6691.7	<.0001	3.6	0.0488	264.5	<.0001
G*I	0.3	0.8603	0.2	0.9304	0.4	0.7994	0.6	0.6511

DISCUSSION

Hybrid Bermudagrass in Cool-Season Climates

As temperatures rise and droughts become more frequent across the United States, the need for water-efficient turfgrass solutions in urban landscapes is becoming increasingly urgent (Abbott et al., 2023; Simon Wang & R., 2012; *State Climate Summaries 2022 - Utah*, 2022). Traditional turfgrass climate zones are shifting northward, reducing the adaptability of KBG in historically cool-season regions (Hatfield, 2017). In contrast, certain HBG cultivars exhibit cold tolerance and are now being successfully established in transition and cool-season zones.

Notable examples of this trend include successful use of HBG ('Iron Cutter') in 2022/2023 at the Northwestern University football field in Illinois (Simons, 2024), establishment and production of HBG sod (eg., Green Valley Turf Company, Platteville, CO, USA; Green Belt Turf Farm, Colorado Springs, CO, USA; NoCo Sod, Gill, CO, USA), and the practice fields and playing field for the Philadelphia Eagles since 2013 (Tony Leonard, personal communication). The Eagles did have some winterkill initially with 'Latitude 36' but then switched to more cold tolerant cultivars ('NorthBridge' and 'Tahoma 31').

Furthermore, demonstration plots with a wide variety of warm- and cool-season grasses were established in 2007 and have been grown continuously at the Brigham Young University campus in Provo, UT, USA. The warm season grasses die out each winter with exception of buffalograss (*Bouteloua dactyloides*) with moderate hardiness and HBG with virtually no winterkill over 18 years. These surprising observations led to formal research where cold tolerant HBG cultivars were identified and grown successfully (Burgin, 2021; Burgin et al., 2022). Our research was conducted at the same plot area, with similar findings of successful overwintering of HBG. These and other data and observations were used to leverage lobbying the State of Utah

Noxious Weed Board to approve use of interspecific triploid HBG cultivars(*State of Utah Noxious Weed List*, 2022; Utah Noxious Weed Act, 2024). This has resulted in HBG establishment with sod farms, residences, and sports fields (Bryan Hopkins, personal communication).

Water Conservation with Hybrid Bermudagrass

Despite the disadvantage of poor winter color (unless it is overseeded) and extended dormancy in these cool-season climates, the primary appeal for HBG is water conservation in regions plagued by droughts and water scarcity. The most commonly planted turfgrass is KBG, including in the arid and semi-arid cool-season zones (Christians et al., 2016). Although known for its ability to recover from drought, KBG requires relatively high rates of water to thrive, especially during hot summer periods in arid and semi-arid regions (Burgin et al., 2021, 2022; Bushman et al., 2012; Jazi et al., 2019).

Similarly, HBG is also known for its ability to withstand drought but, in contrast, it requires relatively low rates of water to flourish. Jespersen et al. (2019) evaluated several HBG and paspalum (*Paspalum vaginatum)* cultivars, identifying 'TifTuf' as a top performer under drought stress in Georgia, USA, which is a warm-season, humid climate. Du et al. (2011) investigated HBG's metabolic responses to drought in Shanghai, China, which is a humid, sub-tropical climate suited best to warm-season grasses. They observed higher concentrations of metabolites and better turf quality in HBG than KBG under heat stress. Steinke et al. (2011) compared HBG to buffalograss and found significant drought tolerance in HBG in a humid, warm-season climate. More recently, Arikilla et al. (2025) reinforced these findings in a glasshouse study where they studied HBG cultivars ('TifB16117', 'Tifway', TifTuf, and T31) with superior drought performance. They found That TifB16117 exhibited the highest ET rates among the cultivars studied, suggesting that its effective root water absorption increased drought tolerance. The research presented herein supports these findings. For example, the trend observed for VWC. T31 had higher VWC than L36 and both were higher than KBG (Figure 4A, Figure 4B). It is possible that T31 uses less water than either L36 or KBG, perhaps adapting better to drought conditions via deeper rooting and using water from deeper in the soil profile Root depth measurements support the possibility that HBG gets water from deeper in the soil profile, as HBG root depths were significantly deeper than KBG.

In a recent study, Serba et al. (2024) in Arizona, USA examined 46 interspecific HBG genotypes and two commercial cultivars under 40% ET irrigation. Although conducted in a warm-season climate with relatively high temperatures, the desert conditions of this study resemble Utah's summer desert climate. These researchers assessed spring green-up, finding that deficit-irrigated HBG emerged from dormancy more rapidly than those receiving moderate or full ET irrigation. Conversely, Banuelos et al. (2011) found slower spring green-up in HBG compared to seashore paspalum under deficit irrigation in the warm-season, dry desert of Tucson, AZ, USA. We did not measure spring green-up, although Burgin (Burgin, 2021; Burgin et al., 2022) did evaluate this at our location in previous years. While Serba et al. (2024) and Banuelos et al. (2011) focused on defined deficit irrigation levels and spring green-up, our research aimed to quantify the lower irrigation limits that HBG and KBG can tolerate before experiencing drought-induced decline.

Many other researchers have compared HBG cultivars to each other and/or to other warm-season grasses showing that HBG has a reduced need for irrigation water and is drought tolerant (Pinnix & Miller, 2019; Gopinath et al., 2022.; Du et al., 2011, Fu et al., 2004; Garrot et al., 1994). However, most HBG drought-related studies have been conducted in warm-season and transition zone climates (Arikilla et al., 2025; Bañuelos et al., 2011; Carrow, 1996; Du et al., 2011; Fu et al., 2004; Garrot Jnr & Mancino, 1994; Gopinath et al., 2022; Husmoen et al., 2012; Jazi et al., 2019; Jespersen et al., 2019; Kim, 1987; Steinke et al., 2011; Wherley et al., 2014). And, as HBG is a warm-season C4 grass and KBG is a cool-season C3 grass, they are rarely studied together and HBG has not typically been studied in a cool-season climate. Other than the program at BYU (Burgin, 2021; Burgin et al., 2022) the only exception is Bizhani and Selehi (2014) who conducted an experiment in a cool-season, semi-arid climate near Shiraz, Iran. They found that CBG outperformed KBG in visual quality under salinity stress but did not evaluate water requirements.

In one documented comparison of HBG and KBG, previous glasshouse and field studies at BYU were conducted to assess drought tolerance (Burgin et al., 2021, 2022). The findings of the glasshouse study exhibited results that support data we have collected with one exception. They observed significant HBG root growth in response to deficit irrigation, whereas KBG showed no measurable impact. Our results showed differences in root depth and biomass between species, but no significant difference between irrigation treatments or in the two-way interaction of species and irrigation treatment for either year of the study.

Although not including KBG, Carrow (1996) compared the cool-season tall fescue with warm-season grass species. They observed HBG to have the best drought tolerance and deepest root system among seven commonly planted turfgrass species in the southeastern United States. The research included two tall fescue cultivars *(Lolium arundinaceum* 'Rebel II' and 'Kentucky 31') as well as Tifway HBG, CBG (*Cynodon dactylon*), zoysiagrass (*Zoysia japonica* 'Meyer'), common centipedegrass (*Eremochloa ophiuroides*), and St. Augustinegrass (*Stenotaphrum secundatum* 'Raleigh'). Carrow concluded that in measures of root depth, Tifway bermudagrass was best, then followed by 'Rebel II' tall fescue and CBG. These all performed better than 'K-31' tall fescue and 'Raleigh' St. Augustinegrass. In the study reported herein, root biomass and depth were different between species but there were no significant differences between irrigation treatments.

The field studies conducted by Burgin (Burgin, 2021; Burgin et al., 2022) were conducted at the same field sites in a semi-arid cool-season environment with the same cultivars as in the study reported herein (Burgin et al., 2021, 2022). In their irrigation field study, on a sandy soil, the HBG cultivars and KBG blend were put under drought stress with irrigation applied at 30% and 50% of evapotranspiration (ET) compared to 100% ET replacement. Under extreme deficit irrigation (30% ET), KBG consistently underperformed across most turf health measures relative to HBG. In addition to the before mentioned root depth and biomass measures, the measures included NDVI, canopy cover percentage, and visual ratings. In all these measures, they found that deficit irrigated KBG to be severely impacted with decreased NDVI, lower visual turf quality ratings, and lower percent cover than all other treatments, including moderately irrigated and highly irrigated KBG. They report that deficit irrigated HBG cultivars were not impacted. They also reported significantly lower VWC in deficit-irrigated KBG than with HBG.

In the present study there were minimal differences between severe drought HBG and optimally irrigated HBG across these measures, but significant differences between severe drought KBG and optimally irrigated KBG. Additionally, we found differences in VWC between species under extreme drought conditions in 2024 but no significant differences in 2023. While the Burgin et al. (2022) research assessed turf quality under predetermined irrigation levels, our study took a more extreme approach—completely withholding irrigation until visible drought symptoms appeared in the turfgrass. This method provides a more comprehensive understanding of HBG’s ability to withstand prolonged drought stress in a cool-season climate. Our study built on information gathered in the Burgin et al. (2022) study, seeking to define the extreme lower limits of HBG’s drought tolerance in this climate.

We conducted a similar study where we shut the irrigation water off completely for two cycles in each of the two years. These results are found in a companion paper to be published (see chapter 2), which show very similar findings as Burgin et al. (2022) and with the study reported herein with KBG suffering from drought stress quickly as compared to HBG that went weeks longer before showing signs of moisture stress. One notable difference with the soil types is that the KBG tended to die out with extreme moisture stress in the study reported herein but mostly recovered from drought stress when grown on a loamy soil.

Hybrid Bermudagrass vs. Kentucky Bluegrass Differences in Evapotranspiration

The study reported herein employed several widely used turfgrass assessment tools, including NDVI, percent cover, VWC, and ET. However, unlike Arikilla et al., (2025) who used a lysimeter system for ET measurements, we utilized a water balance equation. They found varied results in significance of ET between HBG cultivars such as 'TifB16117', 'TifTuf', T31, and Tifway. Researchers reported higher ET from TifB16117 and TifTuf than other cultivars. We found no significant difference in ET in the grass type x irrigation treatment, and no significance between grass types. There were significant differences in ET between irrigation treatments. With reduced irrigation inputs, drought stressed mechanisms limited the rate of transpiration in Severe drought stressed plots.

Implications for Turfgrass Management

Findings herein suggest that HBG is a viable solution for urban landscapes in cool-season climates, offering water conservation benefits while maintaining acceptable turf quality during drought periods. Under extreme conditions, HBG can persist without irrigation for several weeks but requires water for post-drought recovery. This resilience presents substantial potential for water savings in drought-prone regions.

Additionally, there is potential for water savings with HBG in cool-season climates because of early fall dormancy and late spring green-up, which reduces overall water requirements (Burgin et al., 2021). Although ET rates are lower in spring and fall, a 2–3-month reduction of water application because of the grass's extended dormancy would contribute to overall water savings as well.

The HBG stands out as a premium turfgrass species, boasting excellent color, fine and soft leaf blades, dense coverage, superior drought resistance, excellent heat resistance and wear tolerance, and deep root systems (Beard & Beard, 2005; Christians et al., 2016). Among available "water-saving" turfgrass alternatives, HBG is a clear leader in both quality and playability, making it a preferred surface for sports fields in warm-season and transition zone climates and other high traffic use scenarios such as public parks and schools (Christians et al., 2016).

However, integrating HBG into cool-season climates requires specific management adaptations. Unlike KBG, which generally produces relatively less thatch, HBG requires regular thatch management. Additionally, as a warm-season grass, HBG thrives in temperatures between 27°C and 35°C (80°F–95°F) (Beard & Beard, 2005) but enters dormancy earlier than KBG when nighttime temperatures drop below 11-15°C (52-58°F). In Provo, UT, USA the KBG is dormant for about 3-4 months, whereas HBG is dormant about 5-7 months (Burgin et al., 202Xa. 202Xb). Dormant HBG has a tan appearance, which some may find less desirable compared to the dormant, light-green hue of well-maintained KBG (Figure 5). Although dormant grass has the advantage of not requiring much care, the poor aesthetics of the extended dormancy period is a stumbling block for adoption of this water saving species.

Figure 5 Aerial imagery of research grass plots displaying differences in color between grass species during seasonal dormancy (photo taken 13 March 2025). The tan-colored plots consist of hybrid bermudagrass (HBG), which enters dormancy in cooler temperatures. The green plots are Kentucky bluegrass (KBG), a cool-season species that maintains active growth and color during lower temperatures. The contrast highlights the seasonal growth patterns of warm- and cool-season turfgrasses under the given environmental conditions.

Future Research Directions

This study helps define the extreme lower limits of HBG drought tolerance in a cool-season, water-scarce environment, filling a critical gap in current research. Further work needs to be done to refine irrigation recommendations for homeowners and municipalities to optimize turf health in these climates.

Further research should also examine HBG performance in traditional loamy soils rather than sand-based substrates (see Chapter 2) as urban landscapes typically do not mimic the conditions of sand-based sports fields. Additionally, quantifying turf quality and drought performance in high-use athletic field applications would provide valuable insights for sports turf management. Understanding HBG's specific water requirements and application strategies will be crucial for maximizing its potential. This would include quantifying the water use of HBG and KBG in a cool-season climate under extreme drought as well as optimal irrigation.

To address concerns about dormancy, ongoing research is investigating methods to extend HBG's green season in cool-season climates. Additionally, defining HBG's cold tolerance limits will help establish practical climate zone recommendations for its use.

CONCLUSION

This research provides valuable insights into the use of HBG in a cool-season climate with potential to be a viable option for water conservation in semi-arid regions like Provo, Utah, where cool-season grasses are traditionally used. As water demands continue to rise, identifying sustainable turfgrass alternatives becomes increasingly important. This study demonstrates that HBG can not only survive but also maintain acceptable turf quality under severe drought stress, with no irrigation for several weeks. Notably, it exhibited higher NDVI readings, greater canopy coverage, and better visual ratings than Kentucky bluegrass under the same drought conditions.

These findings support the potential for HBG to play a significant role in water conservation efforts, offering a resilient and efficient alternative for turf management in water-limited environments. Solutions like HBG in cool-season climates allow for the continued benefits (ecosystem, social, economic, recreation) of turfgrass and help us be better stewards of the earth.

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SUPPLEMENTARY TABLES

Supplementary Table 1a. Means for a study comparing Normalized Difference Vegetation Index (NDVI) for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates in 2023.

Treatment	**4/25**	**5/1**	**5/12**	**5/19**	**5/31**	**6/7**	**6/9**	**6/16**	**6/22**	**6/29**
L36 Severe	0.14	0.15	0.34	0.46	0.56	0.66	0.69	0.73	0.75	0.72
L36 Mild	0.16	0.14	0.26	0.38	0.52	0.68	0.67	0.69	0.69	0.75
L36 Optimal	0.14	0.14	0.21	0.36	0.55	0.65	0.69	0.69	0.75	0.77
T31 Severe	0.14	0.15	0.34	0.46	0.56	0.66	0.69	0.73	0.75	0.72
T31 Mild	0.13	0.13	0.26	0.43	0.51	0.67	0.71	0.69	0.79	0.76
T31 Optimal	0.27	0.13	0.23	0.42	0.49	0.65	0.69	0.71	0.77	0.77
KBG Severe	0.48	0.31	0.42	0.51	0.49	0.41	0.36	0.31	0.29	0.21
KBG Mild	0.36	0.34	0.46	0.51	0.57	0.49	0.55	0.62	0.73	0.69
KBG Optimal	0.50	0.29	0.38	0.51	0.50	0.61	0.70	0.71	0.76	0.75

	7/3	**7/7**	**7/14**	**7/21**	**7/28**	**8/4**	**8/8**	**8/16**	**8/25**	**9/1**
L36 Severe	0.64	0.63	0.58	0.69	0.77	0.78	0.80	0.81	0.70	0.71
L36 Mild	0.71	0.75	0.73	0.79	0.81	0.76	0.78	0.78	0.71	0.77
L36 Optimal	0.68	0.77	0.75	0.80	0.81	0.79	0.80	0.78	0.69	0.75
T31 Severe	0.64	0.63	0.58	0.69	0.77	0.78	0.80	0.81	0.70	0.71
T31 Mild	0.74	0.79	0.79	0.81	0.82	0.78	0.81	0.82	0.73	0.78
T31 Optimal	0.76	0.79	0.79	0.80	0.82	0.79	0.81	0.84	0.78	0.79
KBG Severe	0.20	0.19	0.17	0.21	0.25	0.37	0.47	0.31	0.25	0.20
KBG Mild	0.68	0.72	0.71	0.78	0.77	0.80	0.80	0.61	0.52	0.52
KBG Optimal	0.70	0.73	0.72	0.63	0.76	0.79	0.81	0.80	0.78	0.79

	9/8	**9/15**	**9/21**
L36 Severe	0.68	0.66	0.63
L36 Mild	0.74	0.75	0.68
L36 Optimal	0.73	0.76	0.65
T31 Severe	0.68	0.66	0.63
T31 Mild	0.76	0.72	0.70
T31 Optimal	0.76	0.77	0.70
KBG Severe	0.00	0.00	0.00
KBG Mild	0.67	0.79	0.75
KBG Optimal	0.84	0.86	0.81

Supplementary Table 1b. Means for a study comparing Normalized Difference Vegetation Index (NDVI) for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates in 2024.

Treatment	4/4	4/10	4/17	4/25	5/10	5/16	5/23	5/30	6/3	6/8
L36 Severe	0.13	0.14	0.14	0.25	0.40	0.53	0.61	0.69	0.76	0.80
L36 Mild	0.15	0.16	0.15	0.25	0.38	0.49	0.60	0.67	0.75	0.78
L36 Optimal	0.15	0.15	0.16	0.29	0.43	0.55	0.60	0.68	0.77	0.78
T31 Severe	0.13	0.14	0.13	0.24	0.39	0.50	0.57	0.64	0.71	0.72
T31 Mild	0.14	0.15	0.13	0.24	0.40	0.52	0.57	0.62	0.70	0.71
T31 Optimal	0.13	0.14	0.14	0.27	0.42	0.55	0.58	0.63	0.71	0.73
KBG Severe	0.59	0.59	0.52	0.44	0.58	0.56	0.51	0.55	0.59	0.35
KBG Mild	0.69	0.63	0.63	0.52	0.70	0.70	0.65	0.69	0.78	0.47
KBG Optimal	0.68	0.66	0.61	0.53	0.67	0.61	0.57	0.58	0.61	0.41
	6/13	**6/20**	**6/26**	**7/2**	**7/10**	**7/17**	**7/31**	**8/6**	**8/15**	**8/22**
L36 Severe	0.80	0.75	0.62	0.61	0.73	0.78	0.80	0.77	0.78	0.78
L36 Mild	0.80	0.81	0.79	0.78	0.83	0.83	0.79	0.75	0.78	0.78
L36 Optimal	0.81	0.80	0.79	0.77	0.83	0.82	0.78	0.69	0.73	0.76
T31 Severe	0.75	0.73	0.70	0.72	0.77	0.82	0.80	0.77	0.76	0.78
T31 Mild	0.76	0.77	0.79	0.77	0.82	0.82	0.80	0.78	0.77	0.78
T31 Optimal	0.77	0.80	0.81	0.77	0.80	0.82	0.81	0.78	0.79	0.79
KBG Severe	0.23	0.18	0.17	0.25	0.38	0.50	0.60	0.52	0.21	0.21
KBG Mild	0.36	0.42	0.54	0.61	0.71	0.78	0.80	0.73	0.33	0.44
KBG Optimal	0.32	0.41	0.46	0.54	0.60	0.65	0.73	0.72	0.76	0.82
	8/28	**9/4**	**9/11**	**9/27**	**10/7**	**10/14**				
L36 Severe	0.75	0.81	0.71	0.69	0.63	0.56				
L36 Mild	0.75	0.79	0.76	0.68	0.72	0.56				
L36 Optimal	0.75	0.80	0.73	0.66	0.71	0.56				
T31 Severe	0.75	0.84	0.77	0.70	0.71	0.60				
T31 Mild	0.75	0.83	0.79	0.71	0.76	0.62				
T31 Optimal	0.75	0.83	0.79	0.70	0.74	0.62				
KBG Severe	0.22	0.19	0.19	0.20	0.21	0.21				
KBG Mild	0.54	0.62	0.68	0.81	0.87	0.79				
KBG Optimal	0.83	0.84	0.84	0.85	0.89	0.79				

Supplementary Table 2a. Means for a study comparing Visual Quality Ratings (verdure) (1 = poor, 9 = perfect) for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates in 2023.

Treatment	**5/1**	**5/12**	**5/19**	**5/31**	**6/7/31**	**6/9**	**6/16**	**6/22**	**6/29**
L36 Severe	2.0	2.0	5.0	7.7	7.0	7.0	6.0	5.7	4.3
L36 Mild	2.0	2.0	5.0	7.7	7.0	6.3	6.3	5.0	5.0
L36 Optimal	2.0	2.0	4.7	8.0	7.0	6.7	6.3	5.7	6.3
T31 Severe	2.0	2.3	6.0	7.3	7.7	7.0	7.7	6.7	5.7
T31 Mild	2.0	2.3	6.0	7.3	7.7	7.0	7.7	6.3	6.0
T31 Optimal	2.0	2.0	5.3	7.3	7.3	7.3	7.3	6.7	6.0
KBG Severe	3.7	3.0	5.0	8.0	5.0	3.7	2.7	2.7	1.7
KBG Mild	3.7	3.0	5.0	8.3	6.0	6.0	7.0	7.3	7.7
KBG Optimal	3.3	3.0	5.0	8.0	7.7	7.3	9.0	8.3	8.3
	7/3	**7/7**	**7/14**	**7/21**	**7/28**	**8/4**	**8/8**	**8/16**	**8/25**
L36 Severe	4.3	4.3	4.0	5.7	6.0	7.3	7.3	7.3	6.3
L36 Mild	5.7	6.0	6.0	6.7	6.3	7.0	7.0	6.3	6.3
L36 Optimal	5.7	6.0	5.7	7.0	6.0	6.7	7.7	6.7	6.0
T31 Severe	5.3	5.3	5.0	6.3	7.0	7.3	7.7	7.3	6.7
T31 Mild	6.0	6.0	6.3	6.7	7.0	7.0	7.7	7.3	6.3
T31 Optimal	6.0	6.3	6.3	7.0	7.0	7.0	7.7	7.3	7.0
KBG Severe	2.3	1.3	1.0	1.3	2.0	2.3	3.7	1.0	1.3
KBG Mild	6.7	6.3	6.0	6.7	6.3	7.7	7.7	3.3	6.3
KBG Optimal	6.7	6.0	5.7	5.7	6.0	7.3	7.7	6.3	8.0
	9/1	**9/8**	**9/15**	**9/21**					
L36 Severe	6.3	6.3	6.3	6.0					
L36 Mild	7.0	6.7	6.3	6.0					
L36 Optimal	6.7	7.0	6.3	6.3					
T31 Severe	6.7	7.0	6.7	6.0					
T31 Mild	6.7	7.0	7.0	6.0					
T31 Optimal	6.7	7.3	7.7	6.3					
KBG Severe	1.0	0.0	0.0	0.0					
KBG Mild	6.0	6.0	6.0	7.7					
KBG Optimal	7.0	8.0	8.0	8.0					

Supplementary Table 2b. Means for a study comparing Visual Quality Ratings (verdure) (1 = poor, 9 = perfect) for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates in 2024.

Treatment	**4/4**	**4/10**	**4/17**	**5/10**	**5/16**	**5/23**	**5/30**	**6/3**	**6/8**
L36 Severe	1.0	1.0	1.0	3.0	4.0	7.0	6.3	7.0	7.7
L36 Mild	1.0	1.0	1.0	3.0	4.0	6.7	5.3	6.3	7.7
L36 Optimal	1.0	1.0	1.0	3.0	3.7	6.3	6.0	6.3	8.0
T31 Severe	1.0	1.0	1.0	3.0	4.3	6.7	6.0	7.0	7.7
T31 Mild	1.0	1.0	1.0	3.0	4.0	6.3	5.7	6.0	7.7
T31 Optimal	1.0	1.0	1.0	3.0	4.0	7.0	5.7	6.7	7.3
KBG Severe	5.7	5.7	4.3	6.0	6.0	6.7	6.7	4.7	2.3
KBG Mild	6.0	6.0	5.6	7.3	6.7	6.7	7.0	7.7	3.3
KBG Optimal	6.0	6.0	5.6	7.0	6.3	7.00\	6.3	5.0	3.0
	6/13	**6/20**	**6/26**	**7/2**	**7/10**	**7/17**	**7/31**	**8/6**	**8/15**
L36 Severe	7.3	7.0	5.7	5.7	7.7	8.3	8.0	7.7	8.0
L36 Mild	7.7	8.3	8.7	7.7	8.7	8.3	7.3	8.0	7.7
L36 Optimal	7.7	8.3	8.0	7.7	8.7	8.0	7.0	6.7	8.0
T31 Severe	7.0	7.0	7.0	7.7	8.7	8.7	7.7	7.3	8.0
T31 Mild	7.3	8.0	8.0	8.3	8.7	8.7	7.3	7.0	8.0
T31 Optimal	7.7	8.0	9.0	8.7	9.0	8.7	7.3	7.7	8.0
KBG Severe	1.3	1.0	1.0	2.3	4.0	5.3	5.3	4.3	1.3
KBG Mild	3.3	4.7	6.3	6.7	6.3	7.3	7.0	6.3	4.0
KBG Optimal	3.0	4.7	6.0	5.7	6.0	6.3	6.0	6.3	7.3
	8/22	**8/28**	**9/4**	**9/11**	**9/27**	**10/7**	**10/14**		
L36 Severe	8.0	7.7	6.7	7.0	6.0	7.0	5.0		
L36 Mild	7.7	7.3	7.0	6.7	6.0	7.0	5.3		
L36 Optimal	7.7	7.3	7.7	7.0	6.0	7.0	5.3		
T31 Severe	8.0	8.0	7.7	7.0	6.3	7.0	5.3		
T31 Mild	8.0	8.0	7.7	7.7	6.7	7.3	5.7		
T31 Optimal	8.3	8.0	7.7	7.3	6.7	7.7	6.0		
KBG Severe	2.3	1.7	1.3	1.7	1.3	1.0	1.0		
KBG Mild	4.7	5.0	6.0	6.6	8.3	9.0	8.7		
KBG Optimal	7.7	7.7	7.0	8.0	9.0	9.0	8.7		

Supplementary Table 3a.Means for a study comparing Canopy Cover Percent for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates in 2023.

Treatment	5/19	5/31	6/7	6/9	6/16	6/22	6/29	7/7	7/14
L36 Severe	25.9	38.5	79.6	64.7	76.1	88.7	70.7	43.7	24.7
L36 Mild	14.6	37.8	71.9	61.7	80.0	80.4	83.4	81.2	80.1
L36 Optimal	16.3	39.8	78.9	66.4	72.3	88.1	83.4	85.7	80.5
T31 Severe	39.6	51.5	88.9	79.4	85.1	91.9	82.3	76.3	67.6
T31 Mild	39.6	44.2	87.4	78.5	80.8	93.6	89.8	89.7	89.1
T31 Optimal	36.7	33.7	86.6	77.3	87.1	91.6	91.7	91.9	91.3
KBG Severe	25.9	42.4	38.5	7.9	5.4	3.4	1.0	1.4	0.2
KBG Mild	22.7	39.4	32.5	39.0	62.8	83.6	75.6	67.3	64.5
KBG Optimal	21.1	42.5	81.4	73.7	82.4	87.6	85.0	73.6	69.4
	7/21	**7/28**	**8/4**	**8/8**	**8/16**	**9/1**	**9/8**	**9/15**	**9/21**
L36 Severe	56.4	87.5	91.1	96.1	85.7	91.8	69.6	76.1	83.4
L36 Mild	87.0	88.2	88.7	95.0	75.4	96.8	87.3	80.0	87.1
L36 Optimal	90.9	83.5	90.1	95.5	79.1	90.1	77.9	70.3	86.5
T31 Severe	74.3	92.0	95.6	97.2	91.8	96.0	80.1	76.1	81.6
T31 Mild	94.0	95.4	96.4	97.8	86.4	96.3	81.7	84.2	83.4
T31 Optimal	92.7	95.9	96.7	96.4	92.1	96.5	84.7	81.1	87.0
KBG Severe	2.2	5.7	18.0	34.2	3.2	01	0.0	0.0	0.0
KBG Mild	77.4	77.4	90.1	94.6	11.0	48.4	73.5	71.0	87.1
KBG Optimal	74.0	76.8	91.4	94.5	80.9	97.5	87.8	93.5	92.3

Supplementary Table 3b.Means for a study comparing Canopy Cover Percent for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates in 2024.

Treatment	**4/4**	**4/10**	**4/17**	**4/25**	**5/10**	**5/16**	**5/23**	**5/30**	**6/3**
L36 Severe	0.1	0.1	0.5	3.1	15.1	29.7	82.6	85.2	97.6
L36 Mild	0.2	0.2	0.5	1.5	8.5	22.4	73.6	80.1	97.3
L36 Optimal	0.1	0.1	0.4	3.0	14.9	29.1	74.3	75.6	95.8
T31 Severe	0.0	0.0	0.2	3.8	15.1	32.8	80.0	71.9	94.9
T31 Mild	0.0	0.0	0.2	2.7	17.7	32.3	72.1	70.2	94.3
T31 Optimal	0.0	0.0	0.1	4.6	24.0	40.1	77.9	71.6	95.5
KBG Severe	25.0	25.0	22.1	24.3	78.8	40.9	71.9	44.9	55.6
KBG Mild	46.3	46.3	46.0	42.8	90.6	82.1	86.9	80.9	95.1
KBG Optimal	30.5	30.5	45.2	35.8	79.3	49.1	79.5	53.4	68.3
	6/8	**6/13**	**6/20**	**6/26**	**7/2**	**7/10**	**7/17**	**7/31**	**8/6**
L36 Severe	98.7	96.5	92.8	59.4	75.7	93.3	98.4	97.6	92.0
L36 Mild	97.7	95.9	99.3	99.4	98.5	99.8	98.9	97.5	90.1
L36 Optimal	96.8	97.3	99.6	99.5	98.33	99.6	99.0	94.4	77.0
T31 Severe	85.9	91.3	92.0	82.6	94.7	99.4	98.6	93.9	87.6
T31 Mild	85.2	93.3	97.2	97.4	98.6	99.4	98.6	94.7	88.0
T31 Optimal	89.8	96.7	98.9	99.2	98.9	99.1	99.1	94.6	91.4
KBG Severe	8.4	0.4	0.0	1.0	1.0	18.9	60.6	60.3	36.6
KBG Mild	19.6	12.1	19.1	57.5	76.4	87.6	94.5	95.3	76.1
KBG Optimal	21.5	7.4	20.3	48.1	60.0	59.4	75.6	78.6	84.8
	8/15	**8/22**	**8/28**	**9/4**	**9/11**	**9/27**	**10/7**	**10/14**	
L36 Severe	91.8	96.1	92.8	93.2	85.6	49.5	47.6	41.6	
L36 Mild	94.5	99.0	98.2	99.1	89.4	51.9	54.9	66.8	
L36 Optimal	94.5	98.5	97.1	98.7	82.7	46.2	47.2	64.6	
T31 Severe	92.1	97.8	97.0	97.5	85.9	69.2	60.9	54.5	
T31 Mild	93.2	98.7	98.2	98.6	92.1	76.3	74.1	75.2	
T31 Optimal	96.1	98.8	97.3	97.6	94.3	71.6	78.3	67.5	
KBG Severe	0.8	2.0	1.0	0.1	0.4	1.8	3.5	6.5	
KBG Mild	15.5	29.4	55.1	62.4	66.9	96.2	96.0	98.4	
KBG Optimal	84.1	94.0	90.5	93.6	91.2	97.2	92.5	96.5	

Supplementary Table 4a. Means for a study comparing surface volumetric water content (VWC) (measured with handheld sensor) for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates in 2023.

Treatment	**6/9**	**6/16**	**6/22**	**6/29**	**7/3**	**7/7**	**7/14**	**7/22**
L36 Severe	9.6	5.6	3.0	3.0	9.4	3.0	6.2	16.2
L36 Mild	20.3	8.6	10.3	11.2	27.2	16.1	27.8	25.2
L36 Optimal	20.5	11.6	9.6	12.3	25.0	13.3	26.0	19.6
T31 Severe	8.8	3.9	2.8	3.0	10.9	3.0	13.1	16.1
T31 Mild	18.0	7.4	6.3	7.8	28.2	14.7	25.3	21.6
T31 Optimal	19.8	8.3	7.4	6.6	25.7	11.3	18.2	25.1
KBG Severe	3.0	9.7	3.0	3.0	1.1	3.0	0.8	23.0
KBG Mild	12.8	13.0	14.5	15.3	24.6	14.6	23.3	33.1
KBG Optimal	17.5	10.2	15.9	10.2	24.1	14.9	20.1	27.1
	7/28	**8/4**	**8/8**	**8/16**	**8/25**	**9/1**	**9/8**	**9/15**
L36 Severe	24.6	25.4	22.5	10.2	14.3	10.2	19.2	14.7
L36 Mild	34.3	33.4	28.9	16.1	26.7	27.2	24.2	24.3
L36 Optimal	32.9	27.8	26.6	24.3	26.4	27.6	24.5	25.9
T31 Severe	30.9	26.9	23.7	7.5	18.9	13.5	15.8	16.2
T31 Mild	31.7	29.9	24.4	12.0	25.3	24.4	24.5	20.5
T31 Optimal	32.1	29.9	24.8	25.3	31.3	27.9	27.7	23.5
KBG Severe	26.5	26.2	23.3	9.4	11.5	6.4	10.1	8.8
KBG Mild	29.3	29.1	25.9	5.1	23.0	22.8	27.2	28.4
KBG Optimal	31.0	31.2	24.6	28.8	28.6	25.0	30.3	30.1

Supplementary Table 4b. Means for a study comparing surface volumetric water content (VWC) (measured with handheld sensor) for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates in 2023.

Treatment	4/4	4/10	4/17	4/25	5/23	5/30	6/3	6/8
L36 Severe	20.2	19.1	22.0	16.6	19.3	20.9	25.8	16.3
L36 Mild	27.5	29.7	27.8	26.1	25.0	25.9	29.0	18.5
L36 Optimal	27.3	29.0	30.0	29.5	25.1	24.5	26.9	25.2
T31 Severe	23.7	24.2	26.9	20.0	25.1	23.7	29.1	18.5
T31 Mild	24.9	26.5	31.6	24.4	24.5	25.8	25.8	16.7
T31 Optimal	26.7	26.5	30.2	21.1	23.5	24.8	27.4	22.1
KBG Severe	20.2	9.8	17.0	6.9	13.1	13.5	18.1	4.7
KBG Mild	22.8	12.3	20.1	6.2	19.0	21.8	19.3	6.1
KBG Optimal	21.6	11.5	20.2	6.3	16.0	19.0	20.4	17.4
	6/13	**6/20**	**6/26**	**7/2**	**7/10**	**7/17**	**7/31**	**8/6**
L36 Severe	9.0	6.3	5.5	19.8	21.6	23.4	24.7	15.2
L36 Mild	25.0	25.0	25.5	26.5	27.3	28.1	27.8	20.5
L36 Optimal	24.9	26.9	25.8	28.0	27.8	26.9	28.7	27.9
T31 Severe	13.4	9.7	8.1	23.4	25.2	25.3	27.2	19.3
T31 Mild	23.5	23.4	24.5	27.4	27.0	25.0	26.5	17.5
T31 Optimal	25.0	25.9	25.7	24.7	27.2	28.0	26.6	26.4
KBG Severe	3.9	1.5	0.3	17.9	17.3	16.8	20.7	5.3
KBG Mild	19.9	24.5	23.6	24.6	23.8	24.4	26.4	8.1
KBG Optimal	22.1	23.3	22.0	25.3	23.9	24.5	25.4	26.6
	8/15	**8/22**	**8/28**	**9/4**	**9/11**	**9/27**	**10/7**	**10/14**
L36 Severe	22.2	16.9	10.3	14.2	5.6	7.17	6.00	9.9
L36 Mild	25.6	24.3	26.8	27.2	25.5	29.97	28.03	31.9
L36 Optimal	28.1	29.6	28.7	29.7	29.3	32.17	29.37	34.5
T31 Severe	23.8	19.3	15.2	16.2	11.0	18.33	8.27	10.4
T31 Mild	22.1	24.6	25.9	26.2	27.6	28.5	27.7	31.5
T31 Optimal	28.9	29.3	28.6	29.9	31.0	33.6	30.4	30.5
KBG Severe	19.1	13.8	5.1	3.9	1.8	4.5	0.6	5.6
KBG Mild	21.7	23.5	22.7	26.4	26.9	32.6	28.4	31.7
KBG Optimal	27.6	25.3	27.6	29.1	30.3	28.5	31.1	34.6

Supplementary Table 5. Means for a study comparing buried volumetric water content (VWC) and Soil Temperature, Co for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates over two growing seasons

	2023 Teros VWC Means		**2024 Teros VWC Means**	
Treatment	**5/31/23-7/14/23**	**8/8/23-9/21/23**	**6/3/24-6/24/24**	**7/31/24-10/14/24**
L36 Severe	0.1	0.1	0.1	0.1
L36 Mild	0.2	0.3	0.2	0.2
L36 Optimal	0.3	0.3	0.3	0.3
T31 Severe	0.2	0.2	0.2	0.2
T31 Mild	0.2	0.3	missing data	0.2
T31 Optimal	0.3	0.3	0.3	0.3
KBG Severe	0.1	0.3	0.1	0.1
KBG Mild	0.1	0.2	0.2	0.2
KBG Optimal	0.2	0.2	0.2	0.2
	2023 Teros Soil Temp Means		**2024 Teros Soil Temp Means**	
Treatment	**5/31/23-7/14/23**	**8/8/23-9/21/23**	**6/3/24-6/24/24**	**7/31/24-10/14/24**
L36 Severe	21.0	22.7	19.8	21.2
L36 Mild	21.0	22.6	21.5	20.7
L36 Optimal	20.0	22.4	19.1	21
T31 Severe	20.0	22.3	20.4	20.6
T31 Mild	20.3	22.4	missing data	20.9
T31 Optimal	20.6	22.7	19.4	21.2
KBG Severe	20.4	23.5	20.3	20.9
KBG Mild	20.8	22.2	21.2	20.7
KBG Optimal	20.5	22.3	21.5	21.2

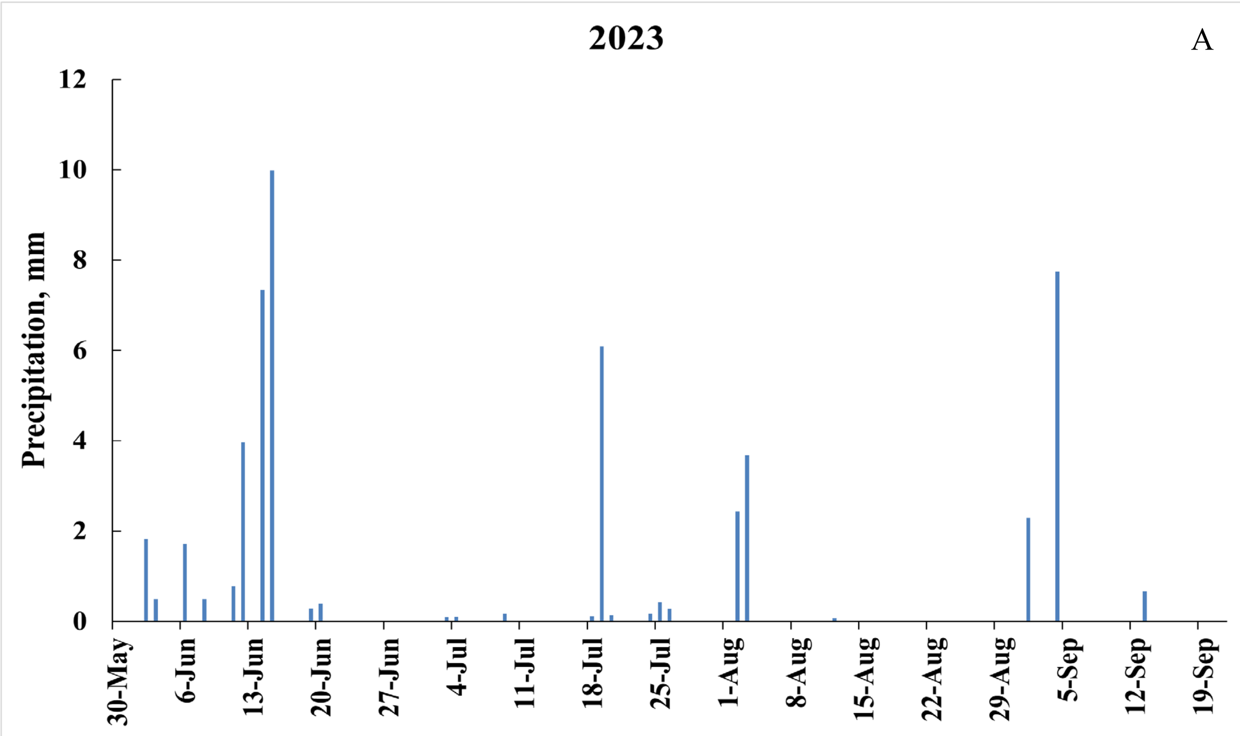
Supplementary Table 6. Means for a study comparing Max Root Depth, cm; Average Root Depth, cm; and Root Biomass, g for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates over two growing seasons

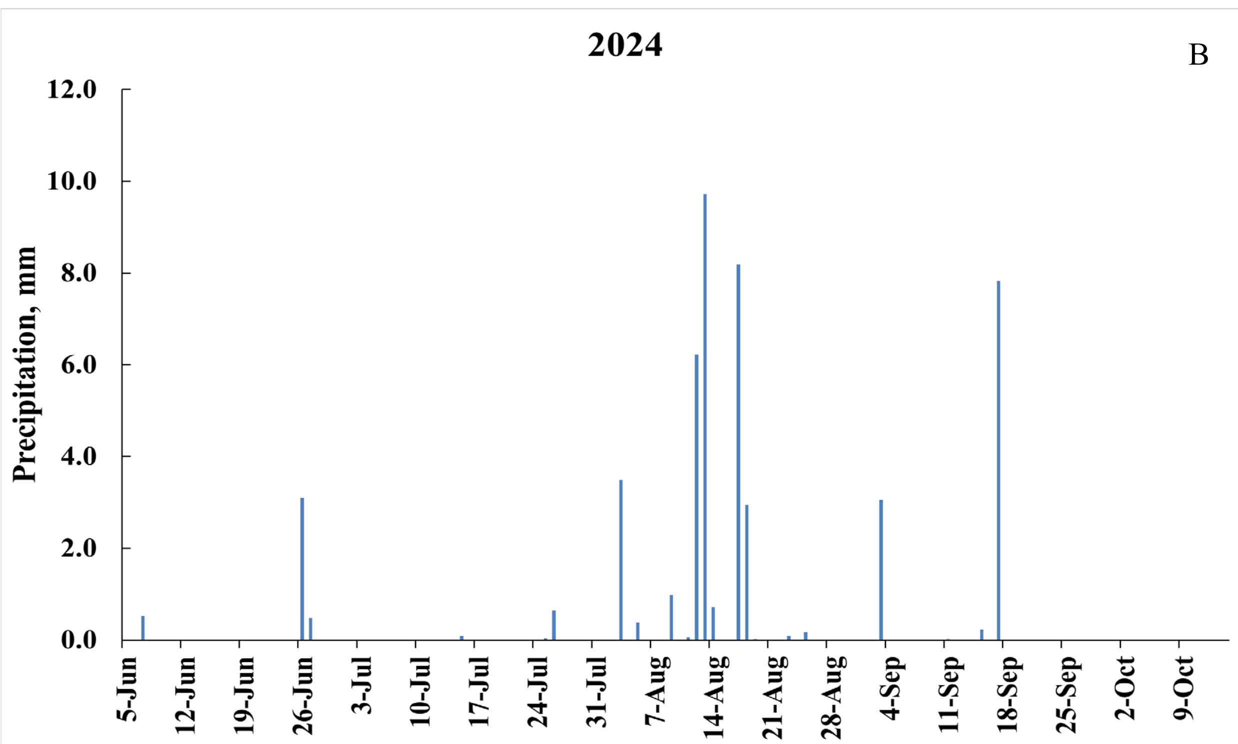
	Max Depth, cm		**Mean Depth, cm**		**Biomass, g**	
	2023	**2024**	**2023**	**2024**	**2023**	**2024**
L36 Severe	40	35	28	29	84	50
L36 Mild	41	31	25	24	94	34
L36 Optimal	47	41	34	31	82	80
T31 Severe	43	35	28	26	82	25
T31 Mild	43	37	26	27	81	22
T31 Optimal	43	40	28	29	57	30
KBG Severe	14	13	10	4	0	28
KBG Mild	21	19	13	10	24	46
KBG Optimal	21	16	13	8	38	23

Supplementary Table 7. Daily Evapotranspiration (mm) means for two hybrid bermudagrass cultivars (Latitude 36 = L36 and Tahoma 31=T31) compared to a blend of Kentucky bluegrass (KBG) cultivars with three irrigation treatments (Severe, Mild, and Optimal) across several dates over two growing seasons

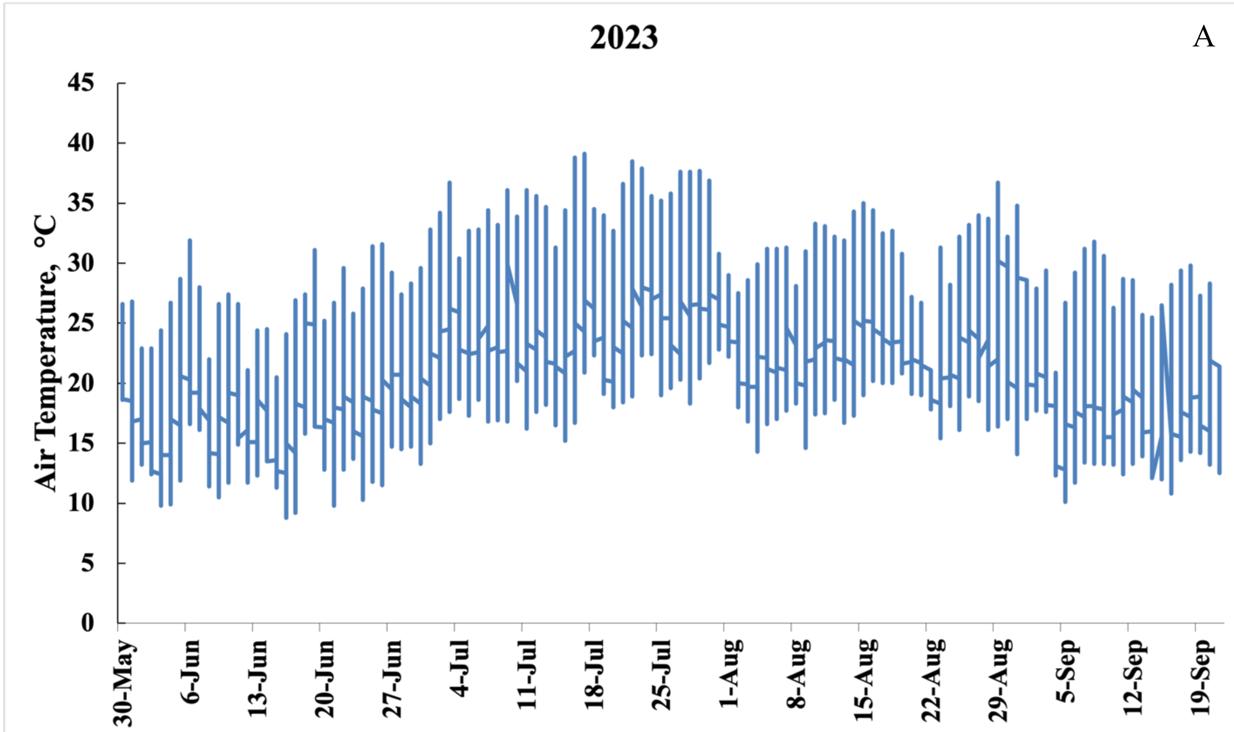
Treatment	5/31/23-7/14/23	8/8/23-9/21/23	6/3/24-6/24/24	7/31/24-10/14/24	Mean
L36 Severe	1.0	1.0	1.7	-0.7	0.75
L36 Mild	2.6	13.6	2.7	1.4	5.08
L36 Optimal	2.7	15.0	2.8	1.7	5.55
T31 Severe	1.0	0.9	1.4	-0.5	0.7
T31 Mild	2.6	13.6	2.9	1.2	5.08
T31 Optimal	2.8	14.7	3.3	1.5	5.58
KBG Severe	0.7	1.0	0.8	-0.7	0.45
KBG Mild	2.6	13.5	3.8	1.3	5.3
KBG Optimal	2.6	14.9	2.6	1.4	5.38

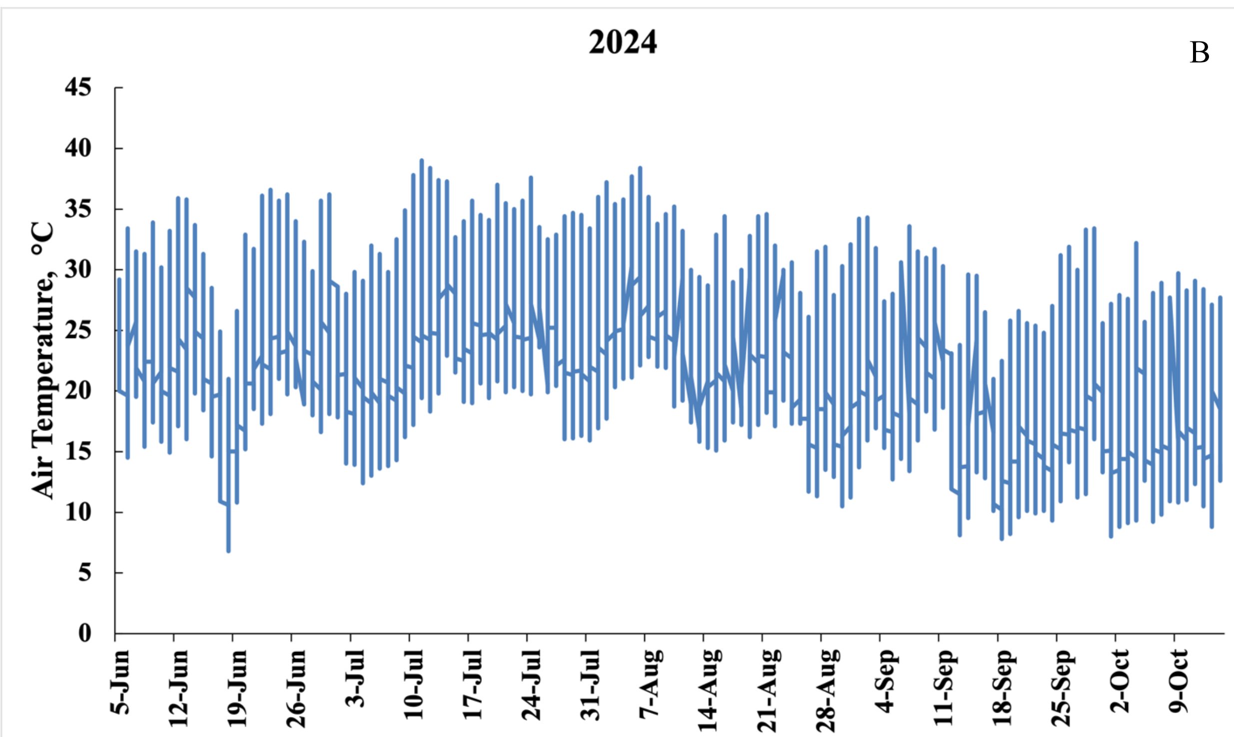
SUPPLEMENTARY FIGURES



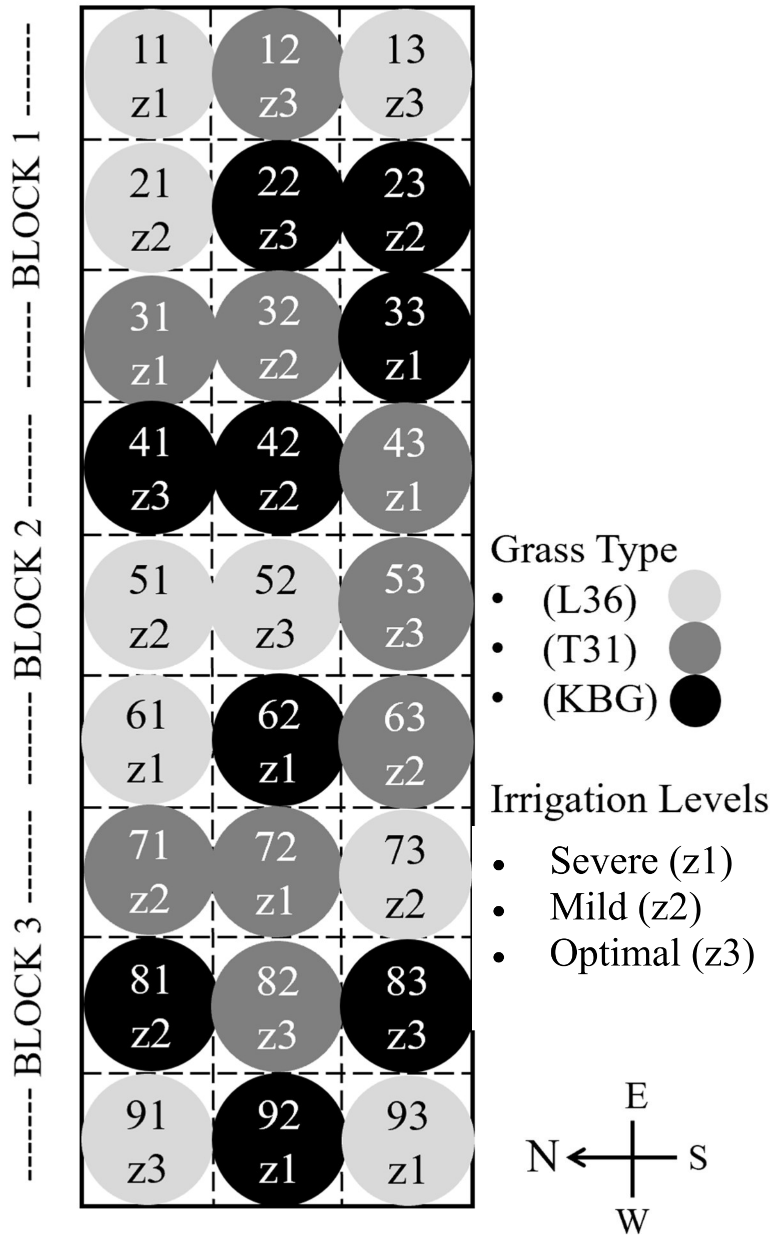


Supplementary Figure 1. Seasonal precipitation for a hybrid bermudagrass for a study site in Provo, UT, USA in 2023 (A) and 2024 (B).





Supplementary Figure 2. Air temperature for a study site in Provo, UT, USA in 2023 (A) and 2024 (B).



Supplementary Figure 3. Study set-up including three grass types (Latitude 36 hybrid bermudagrass, Tahoma 31 hybrid bermudagrass, and a blend of Kentucky bluegrass cultivars) and three irrigation levels (Severe, Mild, Optimal).

CHAPTER 2

Cool-Season Bermudagrass species/cultivars and Kentucky Bluegrass Drought Tolerance When Grown in a Loam Root Zone

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ABSTRACT

Kentucky bluegrass (*Poa pratensis* L.) (KBG) is the most commonly grown cool-season C3 grass. As global temperatures rise, these grasses, which thrive in moderate climates (22–26°C), struggle to tolerate higher temperatures. This leads to increased irrigation demands and a growing concern in arid regions facing escalating drought conditions. Hybrid bermudagrass (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) is the triploid interspecific hybrid cross between common bermudagrass (*Cynodon dactylon* [L.] Pers.) (CBG) and African bermudagrass (*Cynodon transvaalensis* Burtt Davy) (ABG). These species are warm-season C4 grasses that are increasingly adapted to cool-season climates. Six HBG cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1163' [O63], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31]) were compared to CBG ('Transcontinental'), ABG ('OKC 1163'), and a blend of KBG cultivars grown in a loam soil in a semi-arid, cool-season climate to evaluate for drought tolerance and recovery. Two dry-down cycles, with no irrigation applied, were conducted each year during the 2023 and 2024 growing seasons. The KBG consistently scored lower than all HBG cultivars in Normalized Difference Vegetation Index (NDVI), canopy cover, and visual turfgrass quality ratings. CBG also

performed poorly. Kentucky bluegrass exhibited significant drought stress, with complete turfgrass loss before the second dry-down cycle, while HBG cultivars demonstrated superior tolerance and recovery. There was not much statistical difference between cultivars, however T31 often recording the highest overall means. These findings suggest that irrigation needs for HBG are significantly lower than for KBG, highlighting HBG as a viable, water-efficient alternative in semi-arid, cool-season regions facing increasing water scarcity.

INTRODUCTION

As urban environments expand, turfgrass is the largest irrigated crop in the USA. It is estimated to cover ~163,800 km2, occupying roughly 2% of the surface of the continental United States (Milesi et al., 2005). Turfgrass provides many environmental, economic, and psychological/social benefits to society. Turfgrass supports environmental processes by sequestering carbon, respiring oxygen, reducing nutrient pollution, minimizing soil erosion, improving soil health, reducing fire hazards, cleaning atmospheric pollutants, and lowering temperatures and noise pollution in urban areas (Li et al., 2011; Monteiro, 2017; Zirkle et al., 2011). The turfgrass industry makes a significant impact on the economy, generating billions of dollars of revenue and creating nearly a million jobs (Haydu et al., 2006). Increased aesthetic value, sports, recreation, and reduced crime rates are also benefits associated with maintained turfgrass in a community (Brosnan et al., 2020;Troy et al., 2016).

Despite its benefits, turfgrass is often scrutinized because it is often found in large tracts of monoculture, as well as for chemical use, maintenance pollution, and water consumption (Robbins & Sharp, 2003; Whitney, 2010). It is especially under fire in semi-arid regions because of its water consumption (*Principles of Water Wise Landscaping*, n.d.). Increasing water scarcity is a major concern in many regions of the world, including the western USA. For example, the potential drying up of the Great Salt Lake poses significant risks to the ecosystem, potential future water restrictions, agriculture, and the economy (Abbott et al., 2023; Steed, 2024). Lake Mead faces a similar fate with potentially serious impacts on the environment and communities to which its water is distributed. Availability of hydroelectric power, agricultural irrigation, and municipal water supply for several states is a major concern (Edalat & Stephen, 2019).

It is vital to find solutions that minimize water consumption while maintaining the essential services provided by turfgrass in urban ecosystems. Efficient irrigation systems should be considered to conserve water. Many systems are inefficient and have poor distribution uniformity (DU; Kruse, 1978) measures of only 40-50% (Baum et al., 2005). Proper design and installation with continual maintenance to repair leaks, replace broken or improperly sized sprinklers/nozzles, adjust spray patterns, and installation of smart controllers (Evans et al., 2022) will increase DU and irrigation system efficiency for water savings (*Principles of Water Wise Landscaping*, n.d.). Reducing non-practical lawn space is also a possible solution to conserve water and maintain many of the benefits of turfgrass in the urban environment. For example, "parking strips", between sidewalks and roads, are small areas of turfgrass that don't serve much of a purpose and are especially wasteful of water (Martini, 2025).

Another option for improving water conservation is utilization of water-conserving species and cultivars. One of the worst turfgrasses in terms of water use is Kentucky bluegrass (KBG; *Poa pratensis* L.), which is the most commonly grown turfgrass species because it has many excellent properties (Christians et al., 2016). Some cultivars require less water than others with, for example, drought tolerance ranging from 3.8-7.5 on a 1-9 scale where 9 represented no wilting under drought conditions (*NTEP 2017 National Kentucky Bluegrass Test*, 2017). These cultivars employ varying drought escape ability as it slides into dormancy under severe water and/or temperature stress, but KBG has an outstanding ability to stay alive during dormancy and recover efficiently (Bonos et al., 2008; Jiang & Huang, 2000). However, turfgrass managers generally want green grass and KBG requires more than 10 mm d-1 to stay out of dormancy and thrive (Beard & Beard, 2005; Huang, 2008). As such, KBG is generally classified as having moderate to low drought resistance (Abraham et al., 2004; Aronson et al., 1987).

Many other turfgrass species have lower water requirements. For example, another cool-season species is tall fescue [*Lolium arundinaceum* (Schreb.) S.J. Darbyshire], but it has been shown to use ~10% less water than KBG (Ervin & Koski, 1998). Furthermore, warm-season grasses typically need less water than cool-season grasses with evapotranspiration (ET) rates 1-6 mm d-1 lower (Huang, 2008). The warm-season grasses generally require less water than cool-season grasses (Christians et al., 2016). For example, hybrid bermudagrass (HBG; *Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy), the most commonly grown turfgrass in warm-season climates, is very water efficient (Beard & Beard, 2005) (Pinnix & Miller, 2019). The HBG ET rates are 6-7 mm d-1 (Beard & Beard, 2005; Council for Agricultural Science and Technology, 2006). Some cultivars display acceptable turfgrass quality after receiving irrigation at 10-15% of ET (Wherley et al., 2014), and others are so drought-tolerant that they can recover in less than 2 weeks from a 55 or 90 d drought (Steinke et al., 2011). Burgin et al. (2022) found that HBG grew well with 30-50% less irrigation water applied than KBG. Proposed mechanisms for HBG water efficiency include the use of a deep, dense, efficient root system (Carrow, 1996; Fu et al., 2004; Garrot Jnr & Mancino, 1994; Husmoen et al., 2012; Zhou et al., 2013; Burgin et al., 2021), bulliform cells (Bizhani & Salehi, 2014; Iqbal et al., 2022; Tufail et al., 2023), metabolite accumulation (namely sugars, sugar alcohols, organic acids, and amino acids) (Du et al., 2011), and closing wax-protected stomata quickly in dry periods (Kim, 1987; Romero & Dukes, 2009; Zhou et al., 2013).

As a result, HBG and other warm-season grasses are a great option to provide the ecosystem services provided by grass while also conserving water in these regions. However, droughts are also very common in northern climates (Abbott et al., 2023), but warm-season grasses are not generally an option as they die out in cold winters. Although HBG is a warm-season grass, it is adapted to cold weather better than most other C4 species.

As the climate warms (*State Climate Summaries 2022 - Utah*, 2022), the use of HBG is moving northward into transition and cool-season climates (Burgin. et al., 2021). Notable examples of this trend include successful use of HBG ('Iron Cutter') in 2022/2023 at the Northwestern University football field in Illinois (Simons, 2024), establishment and production of HBG sod (e.g., Green Valley Turf Company, Platteville, CO, USA; Green Belt Turf Farm, Colorado Springs, CO, USA; NoCo Sod, Gill, CO, USA), and the practice fields and playing field for the Philadelphia Eagles since 2013 (Tony Leonard, personal communication). The Eagles did have some winterkill initially with the 'Latitude 36' cultivar, but then successfully switched to 'NorthBridge' and 'Tahoma 31' cultivars. Some researchers are using daily light integral measures to estimate the potential for success of HBG in cool-season climates (Simons, 2024).

Furthermore, HBG has been grown continuously in the cool-season, semi-arid zone of Provo, UT, USA since 2008 without any significant winter kill (Bryan G. Hopkins, personal communication). This region in the Inter-Mountain West (IMW) of the USA has had dramatic increases in average temperatures. As evidence of this, the average annual temperatures in Salt Lake City, Utah, USA show an overall upward trend over the last four decades, with greater incidences of drought (Carter et al., 2010; Simon Wang & R., 2012). These observations led to studies with common bermudagrass [CBG; *Cynodon dactylon* (L.) Pers.] and seven HBG cultivars, with no winter kill in any of these studies over nearly a decade and with significant evidence of reduced water requirements (Burgin et al., 2021; Burgin et al., 2022).

Many researchers have compared HBG cultivars for drought tolerance to each other in warm season climates (Arikilla et al., 2025; Bañuelos et al., 2011; Gopinath et al., 2022; Jespersen et al., 2019; SERBA et al., 2024). SERBA et al., (2024) compared 46 interspecific hybrid bermudagrass cultivars and two commercial cultivars ('TifTuf' and 'Tifway') to each other under drought stress, finding several experimental hybrids that performed better than TifTuf in mean density and mean greenness under deficit irrigation. This will guide future breeding initiatives. Another study identified 'TifB16117', an experimental hybrid genotype, as a highly resilient to drought in a greenhouse setting (Arikilla et al. 2025). Gopinath et al., (2022) compared cultivars that are currently available on the market finding a range of drought performance with TifTuf being the best and Latitude 36 being the worst-performing according to industry standards.

As the use of HBG moves North, it is important to understand which varieties are best suited for cool-season climates. National Turfgrass Evaluation Program (NTEP) research identified several HBG cultivars for their cold tolerance. These include T31, L36, IC, NB, O66, and O63 (source). The research presented herein seeks to further understand the performance of these turfgrasses under severe drought stress in a cool-season climate compared to CBG and KBG, the most commonly planted turfgrass in cool-season climates (Christians et al., 2016). The HBG cultivars Hollywood™, Jackpot™, and Southern Star™ have been grown continuously (5 cm mowing height) with virtually no winter kill for over a decade at Brigham Young University in Provo, UT, USA, which is located in a cool-season zone (Bryan Hopkins, personal communication).

When considering the unprecedented use of a species in a different region, such as the use of HBG in a cool-season climate, it is important to consider many factors. The traffic tolerance of HBG in a cool-season climate must be considered. In warm-season climates, HBG cultivars are popular in high-traffic environments (such as sports fields), because they can thrive at very low mowing heights, establish or repair themselves quickly, and withstand significant wear (Pinnix & Miller, 2019). Burgin et al., (2022) found that traffic simulation typically did not have significant impact on cover percent, visual rating, or NDVI of HBG cultivars, CBG, and KBG in a study conducted at the same research plots as the study described herein. However, it is unknown how HBG in a cool-season climate with high-traffic will perform when subjected to severe drought stress. Implementing HBG cultivars with cold, traffic, and drought tolerance may allow continued use of turfgrass in cool-season regions while reducing water consumption.

Building on these previous studies, we hypothesize that HBG will be able to thrive with no irrigation for significantly longer than KBG under extreme drought conditions even when subjected to high-traffic conditions. The objectives of this study are to determine the impact of severe drought stress and high traffic on plant health of KBG, CBG, ABG, and six HBG cultivars when grown in a loam soil by evaluating verdure, normalized difference vegetation index (NDVI), and canopy density.

MATERIALS AND METHODS

Establishment and Management

A field study was conducted in 2023-2024 at Brigham Young University in Provo, UT (40° 14′ 43″ N, 111° 38′ 29″ W, 1406 m above mean sea level). The study area is semi-arid with a cool-season climate, although daytime high temperatures during the summer typically ranged 30 to 40°C. Winter nighttime low temperatures during the study period typically ranged -1 to -11°C. This area falls under the USDA Hardiness Zone 7a (U.S. Department of Agriculture, 2023).

The plot area was originally established as KBG in 2010 as sod laid over 0.05 m of a native calcareous loam soil with low organic matter and moderate soil fertility (Burgin et al.,202Xa, 202Xb; Table 1). The blend of KBG cultivars (Table 2) were commonly grown throughout BYU campus at the time and had been chosen for known desirable traits. A Randomized Complete Block Design (RCBD) with three blocks (replicates) was created. Each plot measured 1 m x 2 m and was separated from the next with a 0.2 m barrier of bare soil (grass killed with glyphosate and then hand weeded through the growing season). All but the KBG plots were sprayed with glyphosate herbicide, at labeled rates, to kill the existing grass on two dates in early May (Burgin et al., 2024). On 21 May, the dead sod was cut out with a sod cutter to a depth of 3 cm. Extra soil, with approximately the same properties as the existing topsoil, was spread over the top of the empty plots to make the ground height uniform with the KBG before planting the HBG. The bermudagrass plots were then established in early summer of 2020 (Table 1). All grasses were fully established prior to the beginning of the prior Burgin et al. (202Xa, 202Xb) study in 2021-2022; with the plots transitioning to this study the following year.

Table 1. Soil properties of a study conducted on a loam soil

Variety Trial		
Property	**Method**	**Value**
VWC at field capacity, %	Gravimetric	?
Texture	Hydrometer[1]	Sandy loam
Sand, %		75.4
Clay, %		9.8
Silt, %		14.7
Bulk density, g cm-3	Gravimetric	1.62
pH	Saturated Paste	7.7
EC, dS m-1	EC Meter	0.5
OM, %	Dichromate Oxidation	1.3
NO3-N, ppm	Lachat	4
P, ppm	Olsen	13
K, ppm	" "	92
Zn, ppm	DTPA	2.2
Mn, ppm	" "	4.3
Fe, ppm	" "	20.0
Cu, ppm	" "	0.7

[1]Gavlak et al., 2000.

Table 2. Grass species and cultivars (Burgin et al., 2024).

Species	Cultivar(s)	Abbreviation	Establishment Method (Date)
Kentucky Bluegrass	'Rugby II', 'Midnight II', 'Impact'	KBG	Sod (April 2010)
Common Bermudagrass	'Transcontinental'™	CBG	Seed (June 2020)
African Bermudagrass	'OKC 1163'	ABG	Sprigs (June 2020)
Hybrid Bermudagrass	'Iron-Cutter'™ (JSC 2-21-18)	IC	Sprigs (July 2020)
	'Latitude 36'™	L36	Plugs (June 2020)
	'Northbridge'™	NB	Plugs (June 2020)
	'OKC 1666'	O66	Sprigs (June 2020)
	'Patriot' (OKC 18-4)	PAT	Sprigs (June 2020)
	'Tahoma 31'® (OKC 1131)	T31	Plugs (July 2020)

Best Management Practices were generally followed for soil, nutrient, water, and cultural management before the study (Burgin et al.,202Xa, 202Xb). Plots were fertilized when the plots were established at a rate of 400 kg fertilizer ha-1 (Pro Prills; 12-8-16-17(S)-3(Fe), Simplot, Boise, ID, USA). Other than various weeds, which were treated with herbicides as needed, there were no notable pest pressure problems in the plot area. Mowing occurred 2-3 times weekly at a height of 4 cm using a reel mower. Clippings were recycled in place during mowing. During the study, fertilizer was added at a rate of 98 kg N ha-1 (urea; 46-0-0), 49 kg P2O5 ha-1 (monoammonium phosphate; 11-52-0), 49 kg K2O ha-1 (potassium chloride; 0-0-60), 0.49 kg H3BO3 ha-1 (boric acid) on 28 July 2023. An additional 98 kg N ha-1 (urea 46-0-0) TSF-1 was applied on 24 October 2023. GameOn™ (Corteva Agriscience, Wilmington, DE, USA) was applied on 9 August 2023 and WeedBGone™ (Scotts Miracle-Gro Company, Marysville, OH, USA) was applied on 8 September 2023. Plots were dethatched with a Classen TR-20HD Power Rake on 17 April 2024 and fertilized with 98 kg N ha-1 (urea; 46-0-0) on 10 May 2024. GameOn and glyphosate were used to spot spray broadleaf weeds as needed. 294 kg K2O ha-1 (potassium chloride; 0-0-60) was applied 28 August 2024. Weather during the study time frame was mostly typical for this semi-arid region with low humidity (average ~20-30% relative humidity) and hot days and cool nights with minimal precipitation (Burgin et al., 2021).

Treatments

Treatments consisted of nine grass types in a RCBD with three replicates to compare HBG cultivars with CBG, AFB, and a blend of KBG cultivars (Table 2). The ABG (OKC 1163) and four of the HBG cultivars (T31, L36, PAT, and IC) were chosen following analysis of NTEP’s 2017 bermudagrass test results, while the other bermudagrass cultivars were recommended by experts (Parsons et al., 2018; Burgin et al.,202Xa, 202Xb).

These cultivars were chosen based primarily on their cold and drought tolerance-related characteristics. It should be noted that KBG is commonly grown in blends of cultivars, while bermudagrass is typically established as a single cultivar (Burgin et al.,202Xa, 202Xb).

Half of each plot was subjected to heavy traffic pressure with two passes of a traffic simulator (Toro ProCore 648, 121.9 cm wide aeration swath [HN6]). Traffic simulations occurred about every four or two weeks in 2023 and 2024, respectively.

All of the grass was drought-stressed with no irrigation during the two dry-down (DD) periods each year. Irrigation was turned off so that the plots received no water until most of the HBG cultivars began showing signs of stress. The DD periods were: DD1) 31 May to 14 July 2023, DD2) 8 August to 21 September 2023, DD3) 3 June to 15 July 2024, and DD4) 30 July 2024 to 15 October 2024. After each DD period, the grasses received irrigation to bring them back to nearly full plant health recovery. Irrigation was supplied via a buried PVC pipe system at 400 kPa pressure with a controller (ESP-Modular, Rain Bird, Azusa, CA, USA). The irrigation system on and near the plot area was observed to ensure no irrigation water was reaching the plots during the DD periods.

Measurements

Measurements were taken by hand every ~7 d (Supplementary Materials Spreadsheets 1 and 2). These included Normalized Difference Vegetation Index (NDVI), volumetric water content (VWC), canopy cover percentage, and visual turfgrass quality ratings (verdure). (Note: Timing had to be altered slightly at times, primarily due to cloud cover interfering with obtaining consistent NDVI readings under full sun.)

The NDVI measurements were taken in each plot with a handheld sensor passed directly above at 1m height midday (Trimble Handheld GreenSeeker, Trimble Agriculture, Sunnyvale, CA, USA). Other sensors were employed aboveground to capture local weather data (ATMOS 41, METER Group, Pullman, WA, USA). The VWC was measured every ~7 days using a mobile, handheld Teros 12 sensor (METER Group, Pullman, WA, USA).

Canopy cover percentage was evaluated ~7 d in every plot with a smartphone app using a camera that passed directly overhead of every plot midday, avoiding shadows (Canopeo, Oklahoma State University Department of Plant and Soil Sciences, Stillwater, OK, USA). Visual turfgrass quality ratings (verdure) were evaluated every ~7 days on a scale from 1-9, with 9 healthy green full canopy and 1 unhealthy tan/brown canopy.

An ANOVA determined statistical significance for each measurement with mean separation by the Tukey method (JMP statistical software version 18.0.2, SAS, Cary, NC, USA) using an alpha of 0.05. Orthogonal comparisons combining HBG cultivars were analyzed with a mixed model and mean separation by the Tukey method (JMP statistical software version 18.0.2, SAS, Cary, NC, USA). Each dry-down period was analyzed separately for both the non-traffic and the traffic studies. The effect of block was never significant ($p > 0.10$) and, thus, it was removed from the statistical analysis; with only Grass Type (G), Date/Time (T), and the G x T interaction evaluated.

RESULTS

Generally, drought stress had a significant impact as a function of grass type for most measured parameters (Supplementary Tables 1-6). The HBG was always numerically and generally statistically better than ABG, CBG, and especially KBG (Figures 1-12).

For the most part, weather conditions during this study were hot and dry, which is typical for this region. During the study periods (30 May to 21 September 2023 and 5 June 2024 and 14 October 2024) the precipitation was 53 and 49 mm, respectively, and the average temperature was 22.7 and 23.1°C (Supplementary Figures 1 and 2).

The resulting effect of moisture stress was evaluated over time during the growing season. However, the interaction between measurement date and grass type was not significant in most cases (18 of 24 instances; Supplementary Tables 1a, 2a, 3a, 4a, 5a, 6a). And, when the interaction was significant (which occurred at DD1 for NDVI Traffic and Visual and Cover for both No-Traffic and Traffic, as well as DD4 for NDVI No-Traffic) the F Ratios for the interaction were an order of magnitude lower (range between 8.8 and 49.4 times lower) than the F Ratios for grass type. This indicates that the effect of grass type far exceeded that of the interaction with date. Thus, the results presented herein focus on grass type averaged over time rather than the interaction between grass type and date. The effect of grass type was always highly significant ($p <0.0001$).

Though the Traffic and No-Traffic plots were evaluated as separate studies, it is interesting to note that the average NDVI measurements were similar (Supplementary Spreadsheet data 1a, 1b, 1c, 2a, 2b,2c,2d; Figures 1-4). Across all dry downs and grass types the average NDVI for No-Traffic was 0.67 and 0.69 for plots with Traffic.

As the HBG cultivars appeared very similar, orthogonal comparisons were made by comparing the combined measurements of these cultivars against CBG, ABG, and KBG. Similar to when all grass types were separately evaluated, there was generally no impact of dates when measurements were taken. The interaction between measurement date and grass type was not significant in 13 of 24 instances (Supplementary Tables 1b, 2b, 3b, 4b, 5b, 6b). When the interaction was significant (which occurred at DD1 for NDVI and visual for both traffic studies and cover for the traffic study; DD3 for visual and cover for Traffic; and DD4 for NDVI and visual for both traffic studies) the F Ratios ranged between 8.6 and 56.2 times lower than the F Ratios for grass type. Therefore, as with the individual comparisons, the focus is on grass type for these orthogonal comparisons, which were highly significant in every circumstance with a $p < 0.0001$ for all but NDVI for DD2 with Traffic ($p = 0.0035$).

The HBG cultivars performed better than CBG, AGB, and KBG in nearly all measures regardless of DD period or traffic. Typically, KBG was the lowest performer, although occasionally, CBG performed worse, as in several instances in DD1 (Figures 7-12). There were also instances where ABG performed as well as HBG, although it typically ranked second place in the orthogonal comparisons across all measurement analyses. The in-situ VWC measurements were not statistically analyzed, but graphics for each dry down period are informative to show the pattern of when the soil was losing water content (Supplementary Figure 3).

The HBG cultivars all performed statistically similar to each other under severe drought stress. The only major exception was O66, which did not perform as well as the other cultivars in some circumstances (Figures 1-12). There was some minor variation, but T31, NB, L36, and IC typically performed very well and were similar to each other.

NDVI

The NDVI results for grass under severe drought stress with no traffic applied were consistently highest for HBG in the orthogonal comparison (Figure 1). The only exception was in DD1 when ABG performed statistically similar as HBG. Typically, ABG, KBG, and CBG performed similarly, with the only exception was for KBG in DD2 where it performed lower than all others. When all grass types were compared (Figure 2), there were no statistical differences between HBG cultivars except that the experimental hybrid (O66) was lower than all others for DD1 and DD2, and lower than most in DD4.

There were fewer differences in NDVI observed between grass types with the traffic study. Similar to the No-Traffic results, HBG was always observed to be numerically highest in the orthogonal comparisons (Figure 3). It was not different than KBG in DD2 nor was it different than CBG in late summer of both years (DD2 and DD4). Interestingly, the opposite was true for ABG. Furthermore, KBG was better than CBG in DD1, with the reverse results in DD4. When all grass types were compared in the traffic study (Figure 4), the O66 generally performed worse than the rest except for DD3, which was similar as when there was no traffic. And Patriot was similar, but just for DD1.

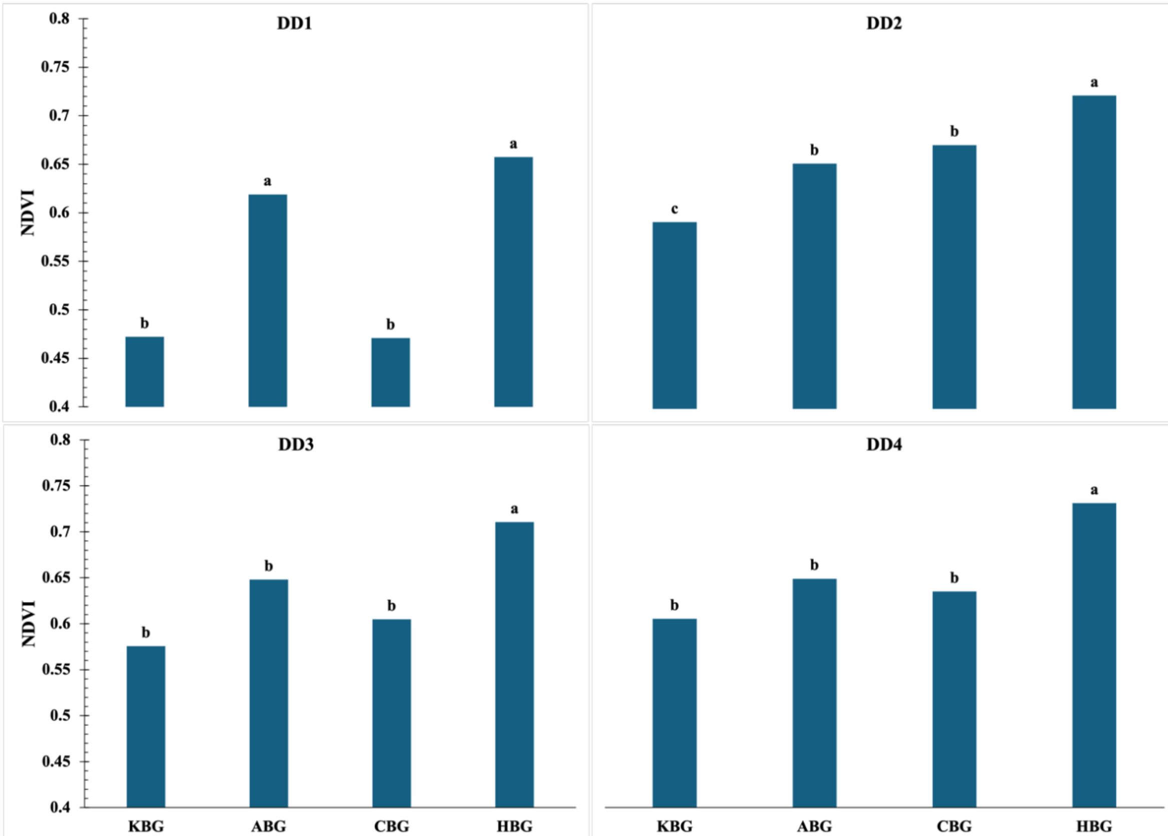

Figure 1. Normalized Difference Vegetation Index (NDVI) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared orthogonally to the average of six hybrid bermudagrass (HBG; *C. dactylon* [L.] 'Pers.' x *C. transvaalensis* 'Burtt Davy') cultivars ('Iron Cutter', 'Latitude 36', 'NorthBridge', 'OKC 1666', 'Patriot', and 'Tahoma 31') for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

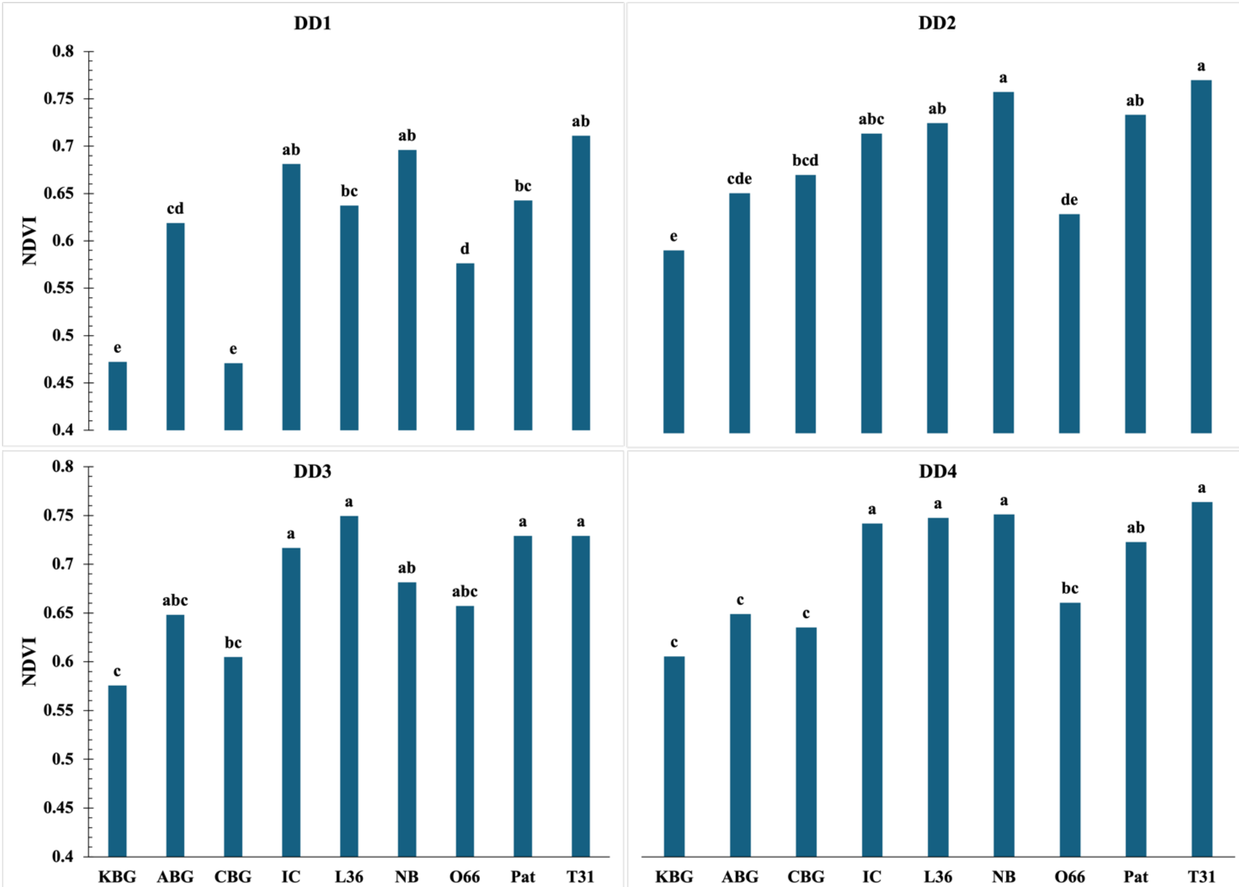

Figure 1. Normalized Difference Vegetation Index (NDVI) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared to the six hybrid bermudagrass (*C. dactylon* [L.] Pers. x *C. transvaalensis* Burtt Davy) cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

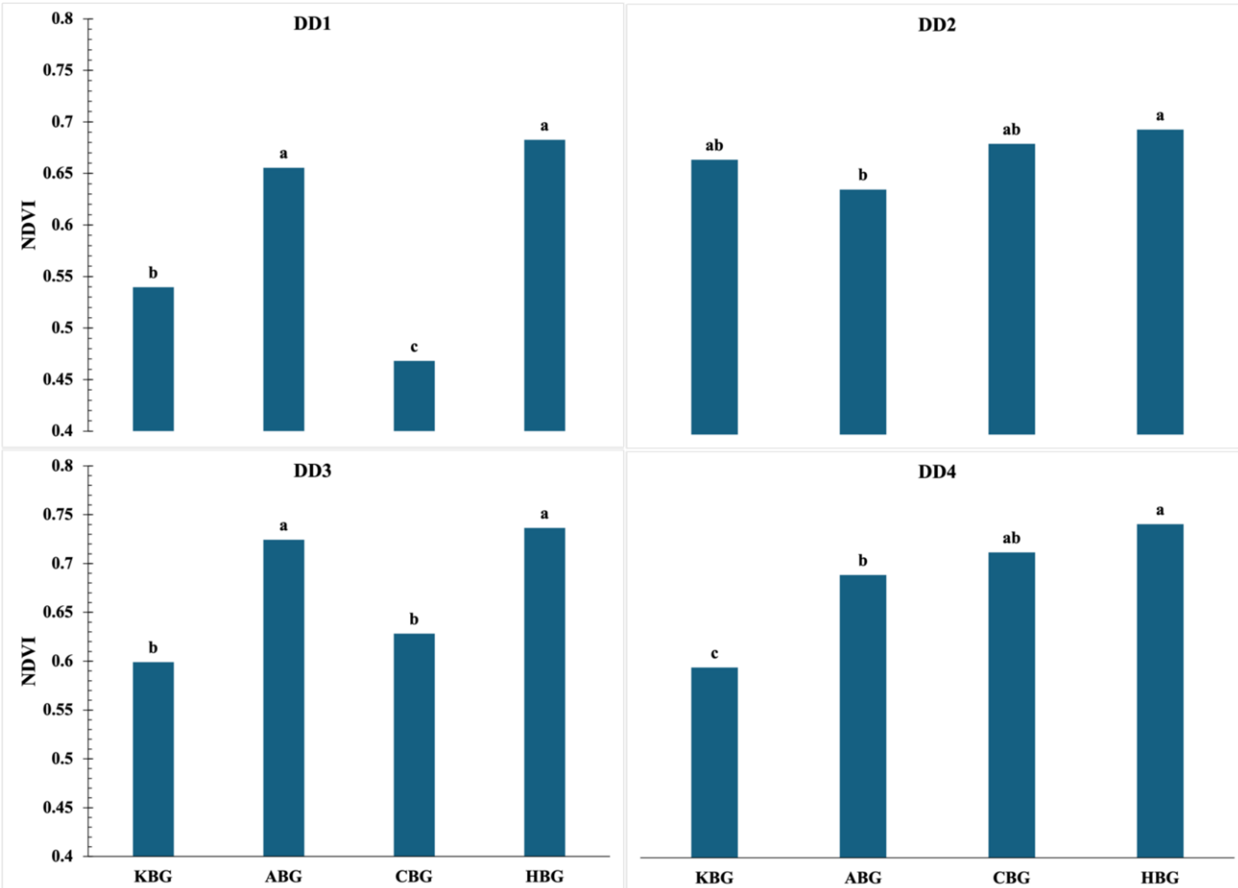

Figure 2. Normalized Difference Vegetation Index (NDVI) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared orthogonally to the average of six hybrid bermudagrass (HBG; *C. dactylon* [L.] 'Pers.' x *C. transvaalensis* 'Burtt Davy') cultivars ('Iron Cutter', 'Latitude 36', 'NorthBridge', 'OKC 1666', 'Patriot', and 'Tahoma 31') for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

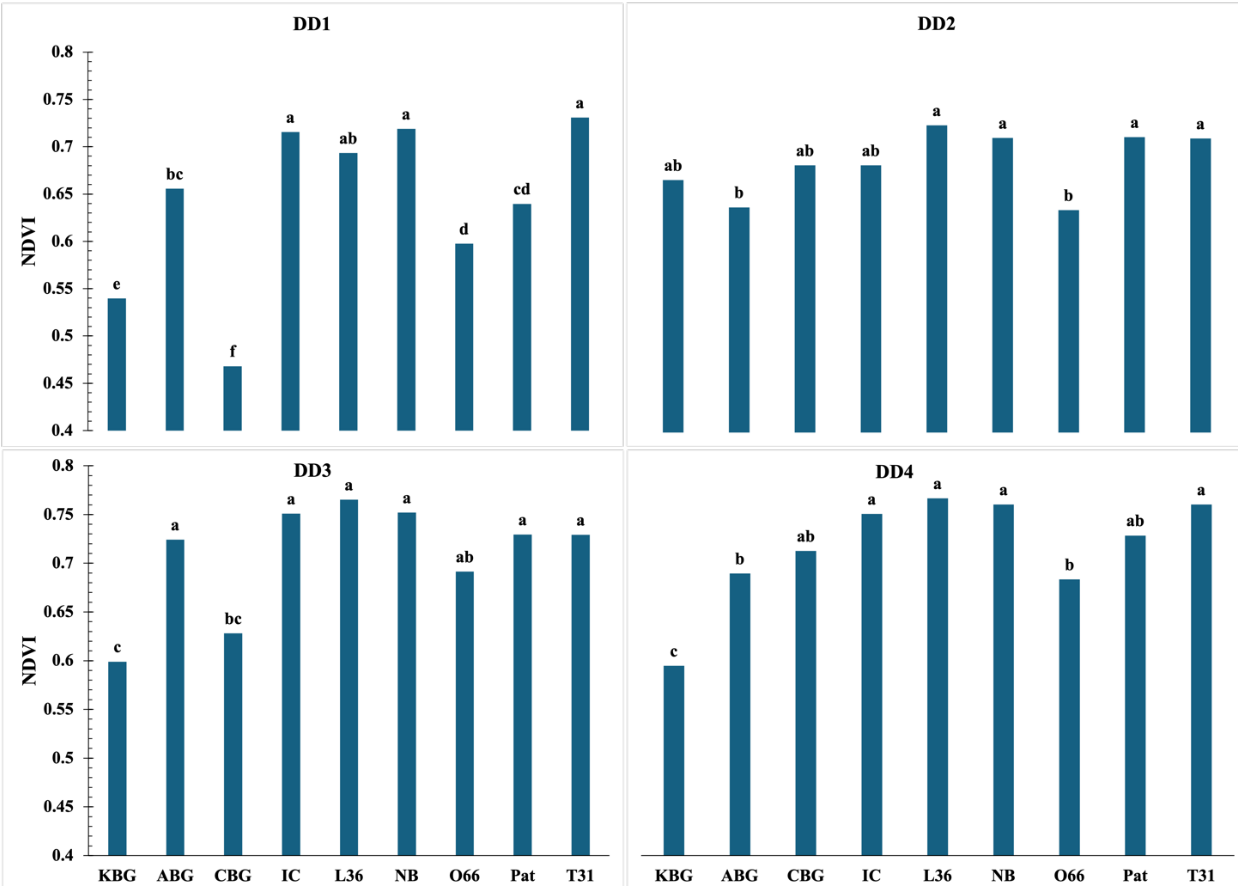

Figure 3. Normalized Difference Vegetation Index (NDVI) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared to the six hybrid bermudagrass (*C. dactylon* [L.] Pers. x *C. transvaalensis* Burtt Davy) cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

Visual Ratings (Verdure)

Similar patterns as NDVI were observed in visual turfgrass quality ratings when under extreme drought stress. For the orthogonal comparisons the grass with no traffic applied always had HBG among the highest (Figure 5). Typically, the KBG had the lowest visual quality, but CBG was lower than KBG in DD1 and was statistically equivalent in DD3—which were both early season DD periods. The CBG and AGB were lower than HBG except in DD1 for AGB.

When all grass types were compared (Figure 6), O66 often had lower visual quality than other cultivars, especially in DD4. All other hybrids performed similarly to each other.

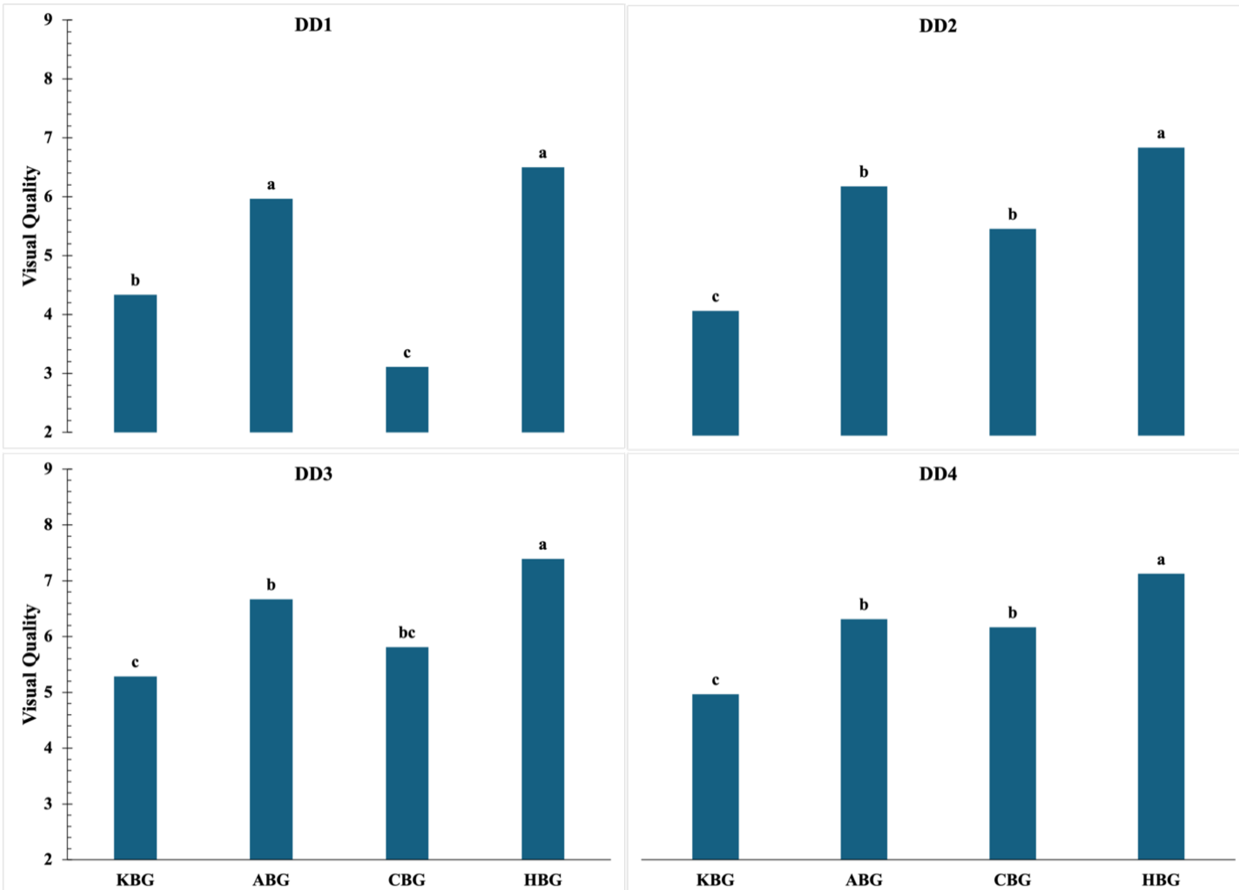

Figure 4. Visual quality (verdure) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared orthogonally to the average of six hybrid bermudagrass (HBG; *C.* dactylon [L.] 'Pers.' x *C. transvaalensis* 'Burtt Davy') cultivars ('Iron Cutter', 'Latitude 36', 'NorthBridge', 'OKC 1666', 'Patriot', and 'Tahoma 31') for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

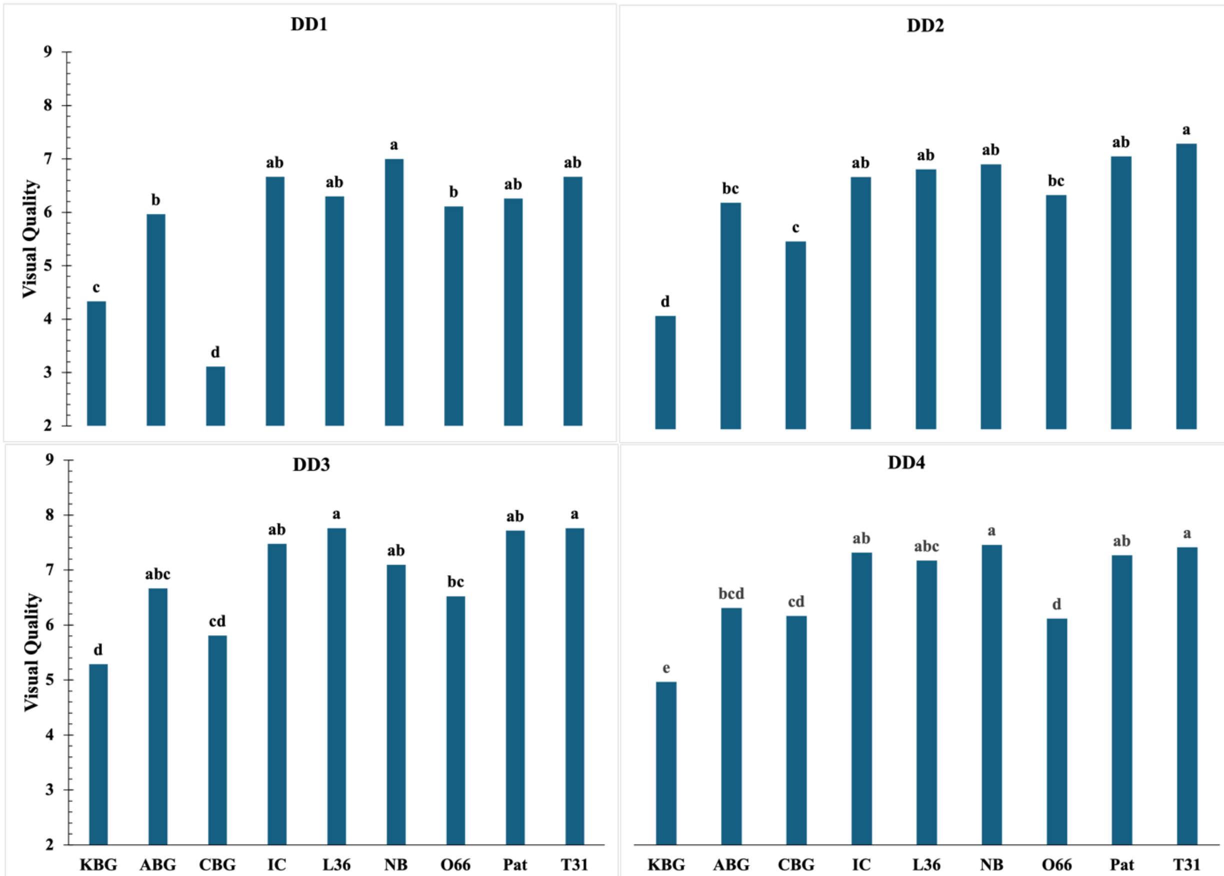

Figure 5. Visual Quality (verdure) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared to the six hybrid bermudagrass *(C. dactylon* [L.] Pers. x *C. transvaalensis* Burtt Davy) cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

The trends were very similar for visual ratings of the grasses receiving traffic (Figure 7). The HBG always had the highest visual ratings, while KBG and CBG tended to perform the worst. When all grass types were compared, (Figure 8), the HBG cultivars tended to be similar to each other, which was in contrast for O66 for the no-traffic study and for the NDVI results.

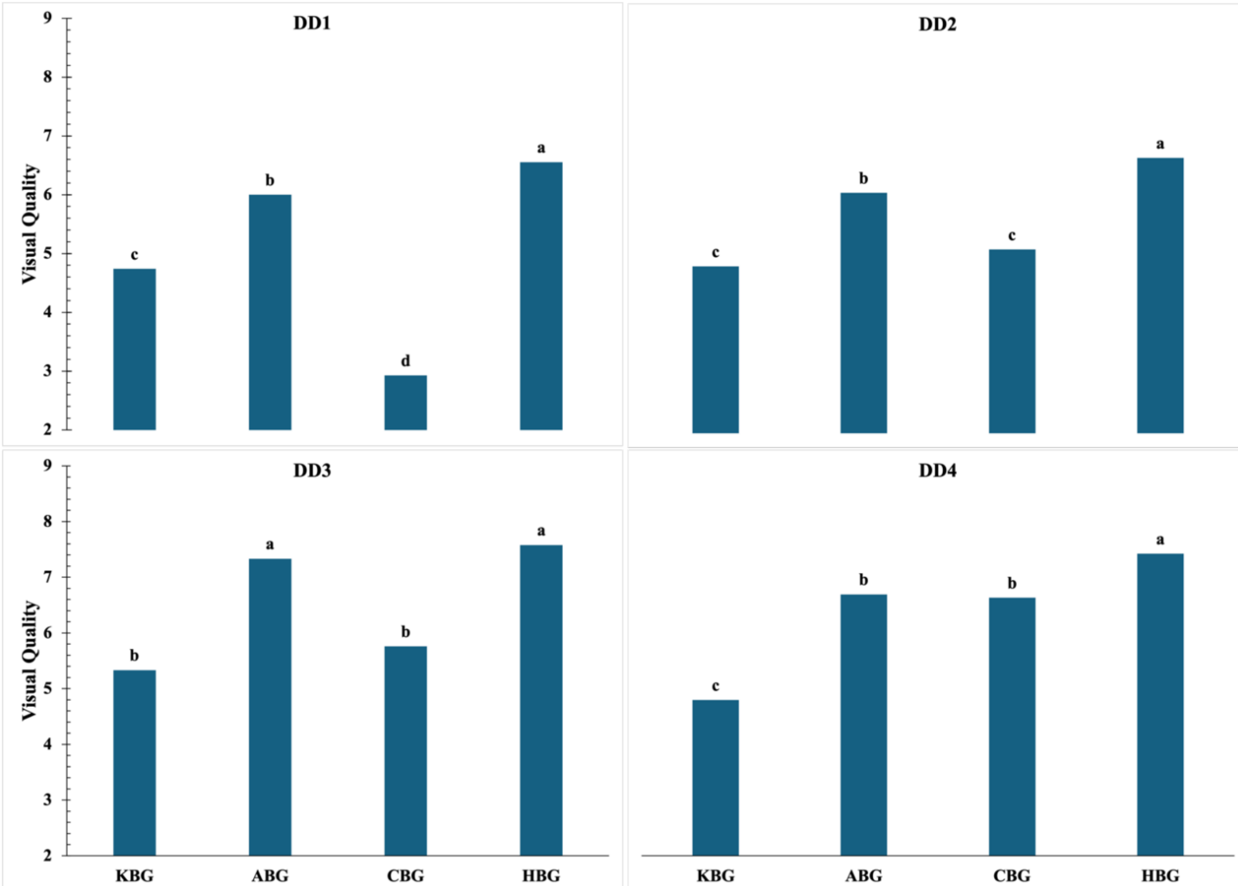

Figure 6. Visual quality (verdure) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared orthogonally to the average of six hybrid bermudagrass (HBG; *C. dactylon* [L.] 'Pers.' x *C. transvaalensis* 'Burtt Davy') cultivars ('Iron Cutter', 'Latitude 36', 'NorthBridge', 'OKC 1666', 'Patriot', and 'Tahoma 31') for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

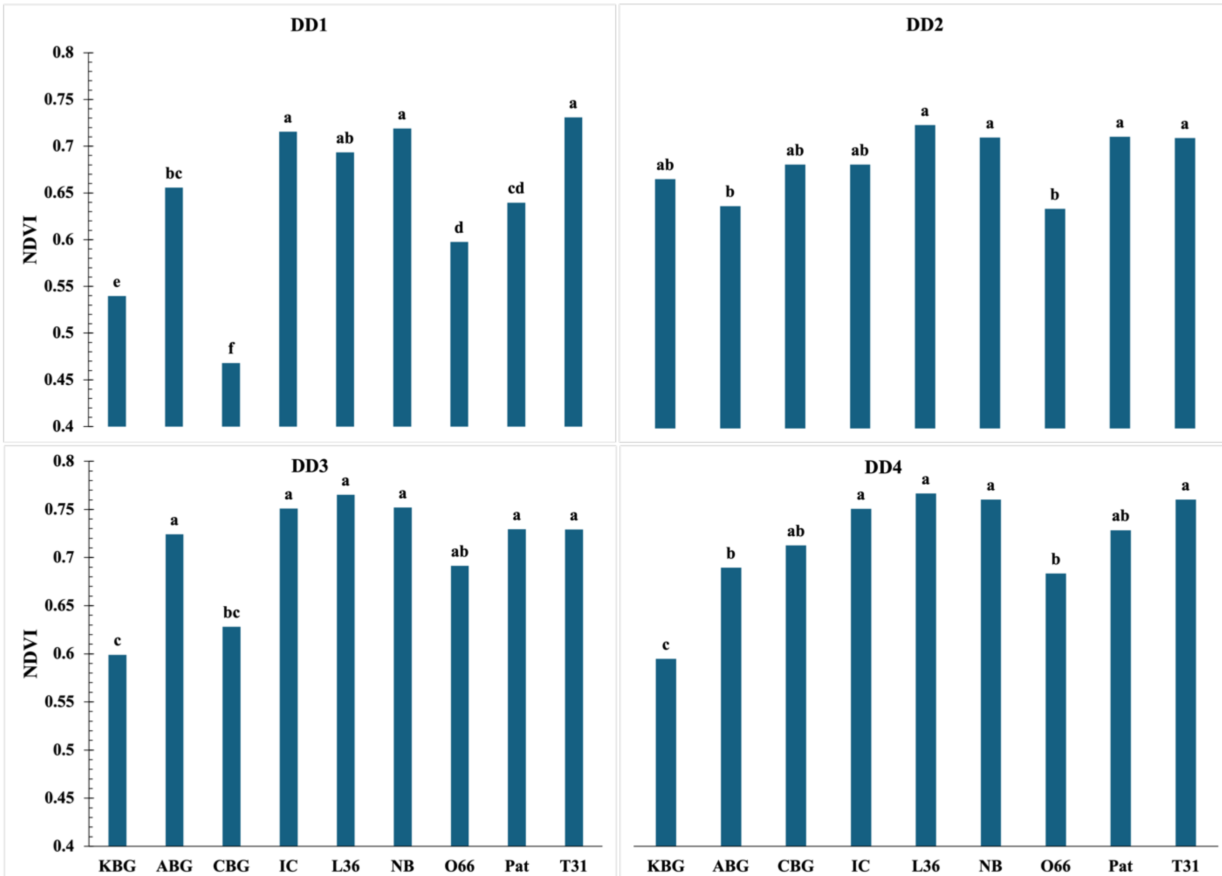

Figure 7. Visual Quality (verdure) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared to the six hybrid bermudagrass (*C. dactylon* [L.] Pers. x *C. transvaalensis* Burtt Davy) cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

Canopy Cover

Similar results were observed when measuring canopy cover percentage for grasses under extreme drought stress. In the no traffic study, HBG had superior canopy coverage than all other grasses (Figure 9). The KBG had a poor canopy, being statistically lower than the rest except for CBG in the early season DD periods (DD1 and DD3) and ABG in the late season DD periods (DD2 and DD4). The CBG was lower than AGB, but only in DD1. When all grass types were evaluated (Figure 10), the O66 was again lower than all other HBG except Pat in DD4. Also, Pat and L36 had less canopy cover than T31 and NB, but only in DD1.

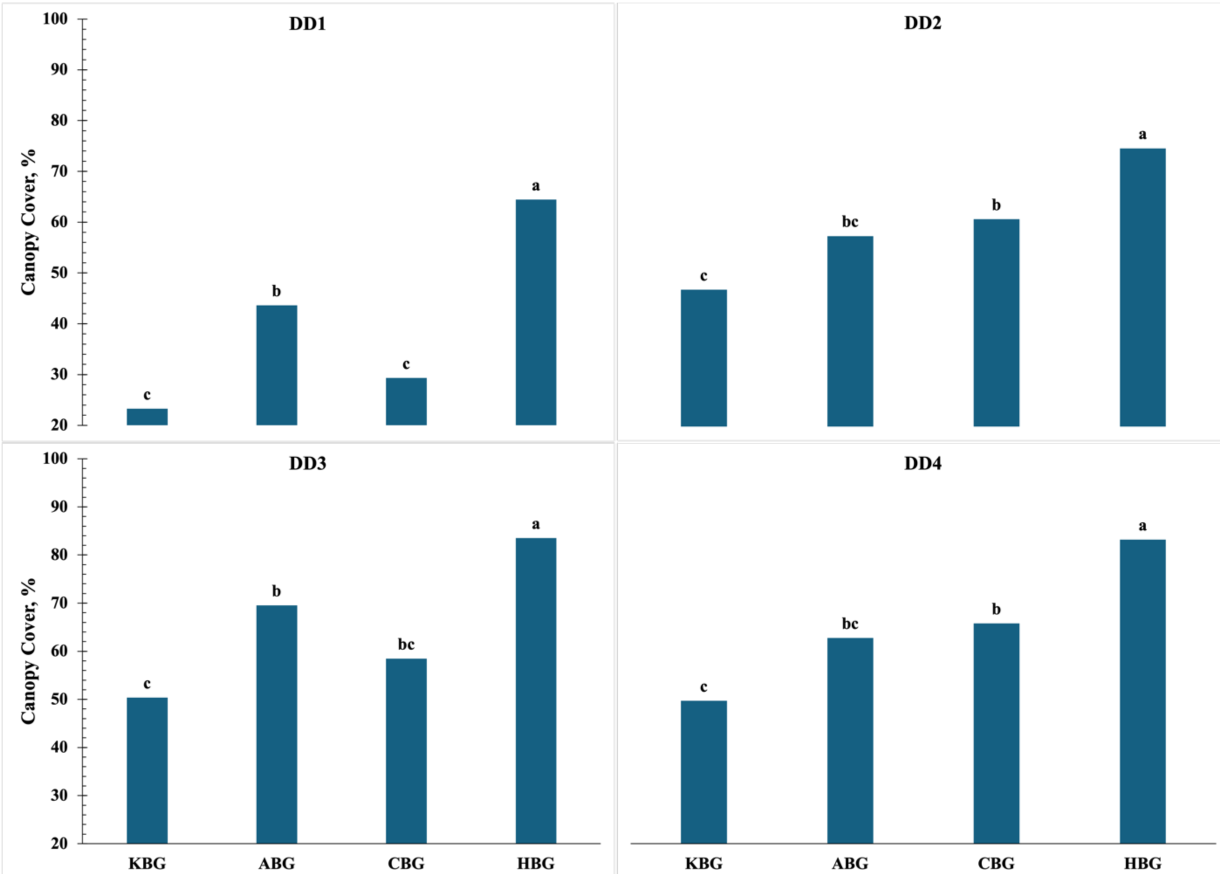

Figure 8. Canopy Cover, % of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared orthogonally to the average of six hybrid bermudagrass (HBG; *C. dactylon* [L.] 'Pers.' x *C. transvaalensis* 'Burtt Davy') cultivars ('Iron Cutter', 'Latitude 36', 'NorthBridge', 'OKC 1666', 'Patriot', and 'Tahoma 31') for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

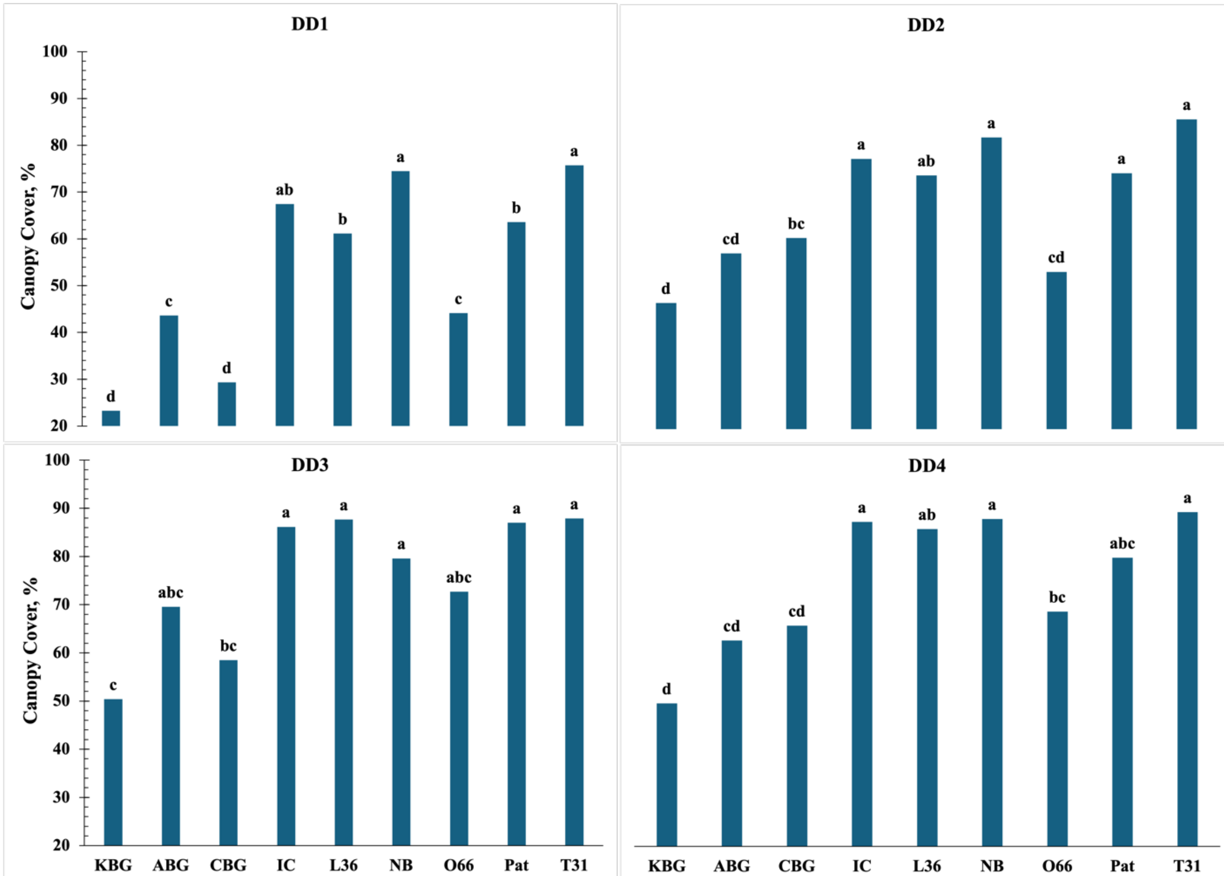

Figure 9. Canopy Cover, % of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared to the six hybrid bermudagrass *(C. dactylon* [L.] Pers. *x C. transvaalensis* Burtt Davy) cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

Results were similar in the traffic study, with HBG always higher than KBG and higher than CBG in the early season DD periods (DD1 and DD3) and higher than AGB in 2023 (Figure 11). When comparing all grass types under traffic pressure (Figure 12), O66 had lower canopy percentage than most other HBG, but only in 2023. The canopy cover for Pat was lower than all of the rest of the cultivars (besides O66), but only in DD1 and IC had lower cover than T31 in DD2.

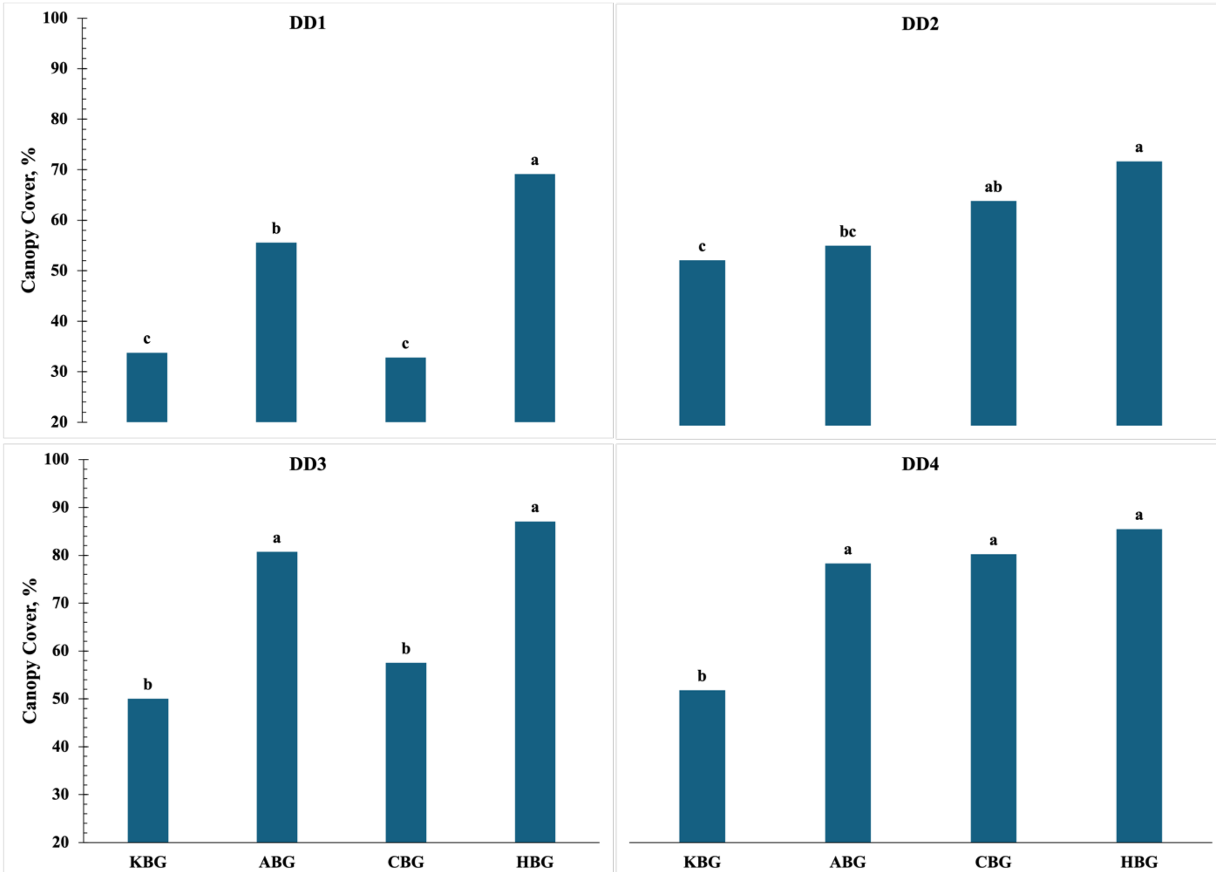

Figure 10. Canopy Cover, % of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared orthogonally to the average of six hybrid bermudagrass (HBG*; C. dactylon* [L.] 'Pers.' x *C. transvaalensis* 'Burtt Davy') cultivars ('Iron Cutter', 'Latitude 36', 'NorthBridge', 'OKC 1666', 'Patriot', and 'Tahoma 31') for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

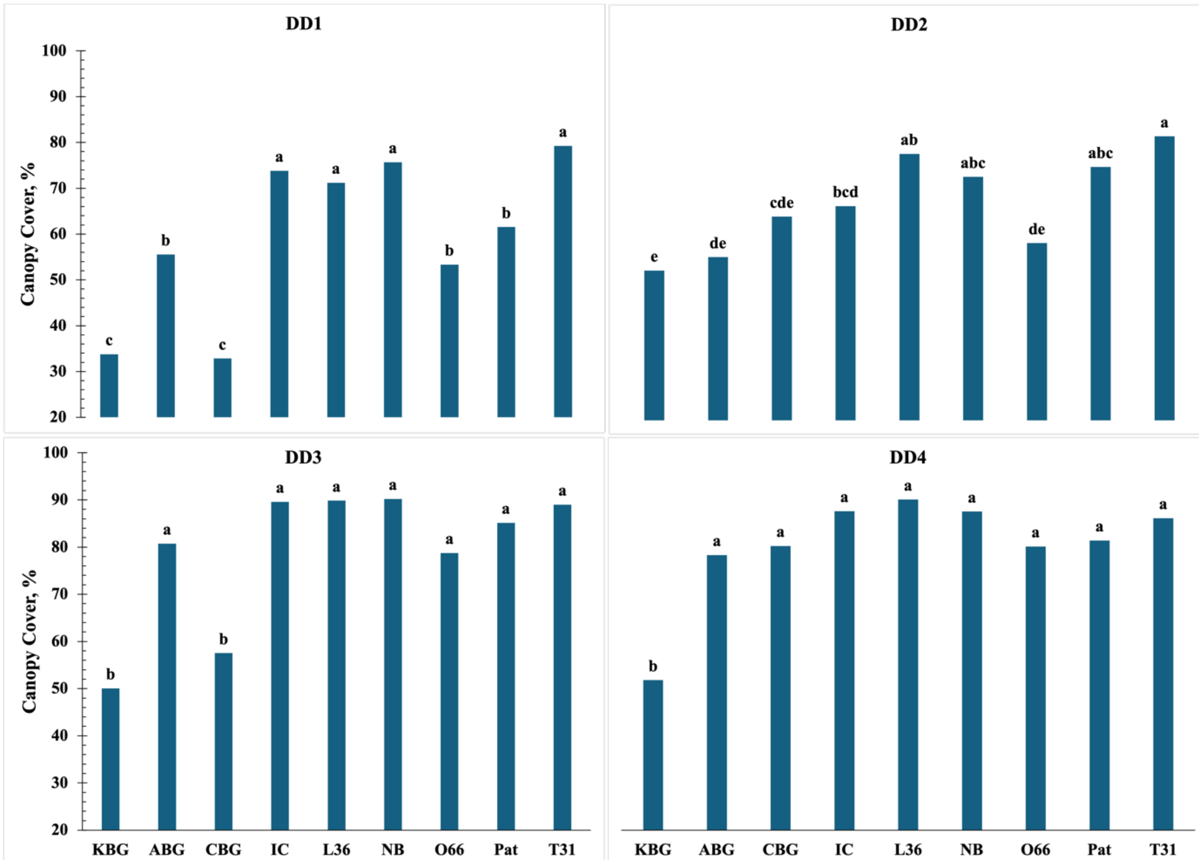

Figure 11. Canopy Cover, % of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), common bermudagrass (CBG; *C. dactylon* [L.] Pers.) compared to the six hybrid bermudagrass (*C. dactylon* [L.] Pers. x Burtt Davy) cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

DISCUSSION

Hybrid Bermudagrass in Cool-Season Climates

As temperatures rise and droughts become more frequent across the United States, the need for water-efficient turfgrass solutions in urban landscapes is becoming increasingly urgent (Wang et al., 2012; Abbott et al., 2023; State Climate Summaries, 2022). Traditional turfgrass climate zones are shifting northward, reducing the adaptability of KBG in historically cool-season regions (Hatfield, 2017). In contrast, certain HBG cultivars exhibit cold tolerance and are now being successfully established in transition and cool-season zones.

Notable examples of this trend include successful use of HBG ('Iron Cutter') in 2022/2023 at the Northwestern University football field in Illinois (Simons, 2024), establishment and production of HBG sod (e.g., Green Valley Turf Company, Platteville, CO, USA; Green Belt Turf Farm, Colorado Springs, CO, USA; NoCo Sod, Gill, CO, USA), and the practice fields and playing field for the Philadelphia Eagles since 2013 (Tony Leonard, personal communication). The Eagles did have some winterkill initially with 'Latitude 36' but then switched to more cold tolerant cultivars ('NorthBridge' and 'Tahoma 31').

Furthermore, demonstration plots with a wide variety of warm- and cool-season grasses were established in 2007 and have been grown continuously at the Brigham Young University campus in Provo, UT, USA. The warm season grasses die out each winter with exception of buffalograss with moderate hardiness and HBG with virtually no winterkill over 18 years. These surprising observations led to formal research where cold tolerant HBG cultivars were identified and grown successfully (Burgin, 2021; Burgin et al., 2022, 202Xa, 202Xb). Our research was conducted at the same plot area as Burgin et al. (2022), with similar findings of successful overwintering of HBG. These and other data and observations were used to leverage lobbying the State of Utah Noxious Weed Board to approve use of interspecific triploid HBG cultivars (Utah Noxious Weed Act, 2024)(*State of Utah Noxious Weed List*, 2022). This has resulted in HBG establishment with sod farms, residences, and sports fields (Bryan Hopkins, personal communication).

Many researchers have conducted studies comparing cultivars of HBG to each other (Arikilla et al., 2025; Bañuelos et al., 2011; Gopinath et al., 2022; SERBA et al., 2024).

However, they are generally conducted in warm-season zones and do not include cool-season grasses, such as KBG, for comparison. Similar to Burgin (2021)/Burgin et al. (2022, 202Xa, 202Xb), who reviewed HBG studies in cool-season and transitional zones, the study presented herein seeks to understand which cold-tolerant HBG cultivars perform best under severe drought conditions compared to KBG and CBG.

Water Conservation with Hybrid Bermudagrass

Despite the disadvantage of poor winter color (unless it is overseeded) and extended dormancy in these cool-season climates, the primary appeal for HBG is water conservation in regions plagued by droughts and water scarcity. The most frequently used turfgrass in the world is KBG, including in the arid and semi-arid cool-season zones (Christians et al., 2016). Although known for its excellent ability to recover from drought, KBG requires relatively high rates of water to thrive (Burgin, 2021; Burgin et al., 2022; Bushman et al., 2012; Jazi et al., 2019)

Similarly, HBG is also known for its ability to withstand drought but, in contrast, it requires relatively low rates of water to flourish. Jespersen et al. (2019) evaluated several HBG and paspalum cultivars, identifying TifTuf as a top performer under drought stress in Georgia, USA, which is a warm-season, humid climate. Du et al. (2011) investigated HBG's metabolic responses to drought in Shanghai, China, which is a humid, sub-tropical climate suited best to warm-season grasses. They observed higher concentrations of metabolites and better turfgrass quality in HBG than KBG under heat stress. Steinke et al. (2011) compared HBG to buffalograss and found significant drought tolerance in HBG in a humid, warm-season climate. More recently, Arikilla et al. (2025) reinforced these findings in a glasshouse study where they further identified HBG cultivars with superior drought performance.

In a recent study, Serba et al. (2024) in Arizona, USA examined 46 interspecific HBG genotypes and two commercial cultivars under 40% ET irrigation. Although conducted in a warm-season climate with relatively higher temperatures, the desert conditions of this study resemble Utah's summer desert climate. These researchers assessed spring green-up, finding that deficit-irrigated HBG emerged from dormancy more rapidly than those receiving moderate or full ET irrigation. Conversely, Banuelos et al. (2011) found slower spring green-up in HBG compared to seashore paspalum under deficit irrigation in the warm-season, dry desert of Tucson, AZ, USA. We did not measure spring green-up, although Burgin (2021)/ Burgin et al. (2022) did evaluate this at our location in previous years. While Serba et al. (2024) and Banuelos et al. (2011) focused on defined deficit irrigation levels and spring green-up, our research aimed to identify differences between HBG cultivars, CBG, AGB, and KBG under severe drought stress in a cool-season climate.

Many other researchers have compared HBG cultivars to each other and/or to other warm-season grasses showing that HBG has a reduced need for irrigation water and is drought tolerant (Pinnix & Miller, 2019; Gopinath et al., 2022.; Du et al., 2011, Fu et al., 2004; Garrot et al., 1994). However, most HBG drought-related studies have been conducted in warm-season and transition zone climates (Arikilla et al., 2025; Bañuelos et al., 2011; Carrow, 1996; Du et al., 2011; Fu et al., 2004; Garrot Jnr & Mancino, 1994; Gopinath et al., 2022; Husmoen et al., 2012; Jazi et al., 2019; Jespersen et al., 2019; Kim, 1987; Steinke et al., 2011; Wherley et al., 2014). And, as HBG is a warm-season C4 grass and KBG is a cool-season C3 grass, they are rarely studied together and HBG has not typically been studied in a cool-season climate. Other than the program at BYU (Burgin et al. (2021)), the only exception is Bizhani and Selehi (2014) who conducted an experiment in a cool-season, semi-arid climate near Shiraz, Iran. They found that CBG outperformed KBG in visual quality under salinity stress.

In one documented comparison of HBG and KBG, previous glasshouse and field studies at BYU were conducted to assess drought tolerance (Burgin et al., 2021, 2022). The findings of the glasshouse study exhibited results that support data we have collected.

The field studies conducted by Burgin et al. were conducted at the same field sites in a semi-arid cool-season environment with the same cultivars as in the study reported herein (Burgin et al., 2021, 2022). In their irrigation field study, on a sandy soil, the HBG cultivars and KBG blend were put under drought stress with irrigation applied at 30% and 50% of evapotranspiration (ET) compared to 100% ET replacement. Under extreme deficit irrigation (30% ET), KBG consistently underperformed across most turfgrass health measures relative to HBG. In addition to the before mentioned root depth and biomass measures, the measures included NDVI, canopy cover percentage, and visual ratings. In all these measures, they found that deficit irrigated KBG to be severely impacted with decreased NDVI, lower visual turfgrass quality ratings, and lower percent cover than all other treatments, including moderately irrigated and highly irrigated KBG. They report that deficit irrigated HBG cultivars were not impacted. They also reported significantly lower VWC in deficit-irrigated KBG than with HBG.

In the present study there were significant differences between grass types, but typically no significant differences between traffic treatments (traffic and no-traffic). Burgin's research assessed turfgrass quality under predetermined irrigation levels, our study took a more extreme approach—completely withholding irrigation until visible drought symptoms appeared in the turfgrass. This method provides a more comprehensive understanding of each grass type's ability to withstand prolonged drought stress in a cool-season climate. Our study built on information gathered in Burgin's study, seeking to define the extreme lower limits of HBG's drought tolerance in this climate.

Another previous field study was done on the same loam texture soil as the research presented herein, also with the same cultivars and location (Burgin, 2021; Burgin et al., 2022). The study was irrigated following best management practices. Results reported herein show similar results, with KBG suffering from drought stress quickly as compared to HBG that went weeks longer before showing signs of moisture stress. One notable difference between the sandy and loam soil is that the KBG tended to die out with extreme moisture stress in the study on sandy soil but mostly recovered from drought stress when grown on a loamy soil.

Implications for Turfgrass Management

Findings herein suggest that HBG is a viable solution for urban landscapes in cool-season climates, offering water conservation benefits while maintaining acceptable turfgrass quality during drought periods. Under extreme conditions, HBG can persist without irrigation for several weeks but requires water for post-drought recovery. This resilience presents substantial potential for water savings in drought-prone regions.

HBG stands out as a premium turfgrass species, boasting excellent color, fine and soft leaf blades, dense coverage, superior drought resistance, excellent heat resistance and wear tolerance, and deep root systems (Beard & Beard, 2005; Christians et al., 2016). Among available "water-saving" turfgrass alternatives, HBG is a clear leader in both quality and playability, making it a preferred surface for sports fields in warm-season and transition zone climates and other high traffic use scenarios such as public parks and schools (Christians et al., 2016).

However, integrating HBG into cool-season climates requires specific management adaptations. Unlike KBG, which generally produces relatively less thatch, HBG requires regular thatch management. Additionally, as a warm-season grass, HBG thrives in temperatures between 27°C and 35°C (80°F–95°F) (Beard & Beard, 2005) but enters dormancy earlier than KBG when nighttime temperatures drop below 11-15°C (52-58°F). In Provo, UT, USA the KBG is dormant for about 3-4 months, whereas HBG is dormant about 5-7 months (Burgin, 2021; Burgin et al., 2022). Dormant HBG has a tan appearance, which some may find less desirable compared to the dormant, light-green hue of well-maintained KBG (Figure 13). Although dormant grass has the advantage of not requiring much care, the poor aesthetics of the extended dormancy period is a stumbling block for adoption of this water saving species.

Figure 123. Research grass plots displaying differences in winter color between grass species during seasonal dormancy (photo taken 13 March 2025). The tan-colored plots consist of bermudagrasses and the green are Kentucky bluegrass.

Future Research Directions

This study helps compare performance of several grass types under drought stress in a cool-season, water-scarce environment, filling a critical gap in current research. Further work needs to be done to refine irrigation recommendations for homeowners and municipalities to optimize turfgrass health in these climates.

Further research should continue to examine HBG performance in traditional loamy soils rather than sand-based substrates, as urban landscapes typically do not mimic the conditions of sand-based sports fields. This research begins this process in a cool-season climate. Additionally, quantifying turfgrass quality and drought performance in high-use athletic field applications would provide valuable insights for sports turfgrass management. Understanding HBG's specific water requirements and application strategies will be crucial for maximizing its potential. This would include quantifying the water use of HBG and KBG in a cool-season climate under extreme drought as well as optimal irrigation.

To address concerns about dormancy, ongoing research is investigating methods to extend HBG's green season in cool-season climates. Additionally, defining HBG's cold tolerance limits will help establish practical climate zone recommendations for its use.

CONCLUSION

This study offers critical insights into the viability of warm-season turfgrass in traditionally cool-season regions. In semi-arid climates like Provo, Utah, where water scarcity is a growing concern, hybrid bermudagrass emerges as a promising alternative to conventional cool-season species. The research shows that hybrid bermudagrass not only survives prolonged drought without irrigation but also maintains superior turf quality—demonstrated by higher NDVI values, greater canopy cover, and better visual ratings compared to Kentucky bluegrass. Among the cultivars tested, Tahoma 31, Latitude 36, and NorthBridge typically outperformed others, while KBG and CBG lagged behind. These findings highlight hybrid bermudagrass as a resilient, water-efficient solution for sustainable turfgrass management in drought-prone environments.

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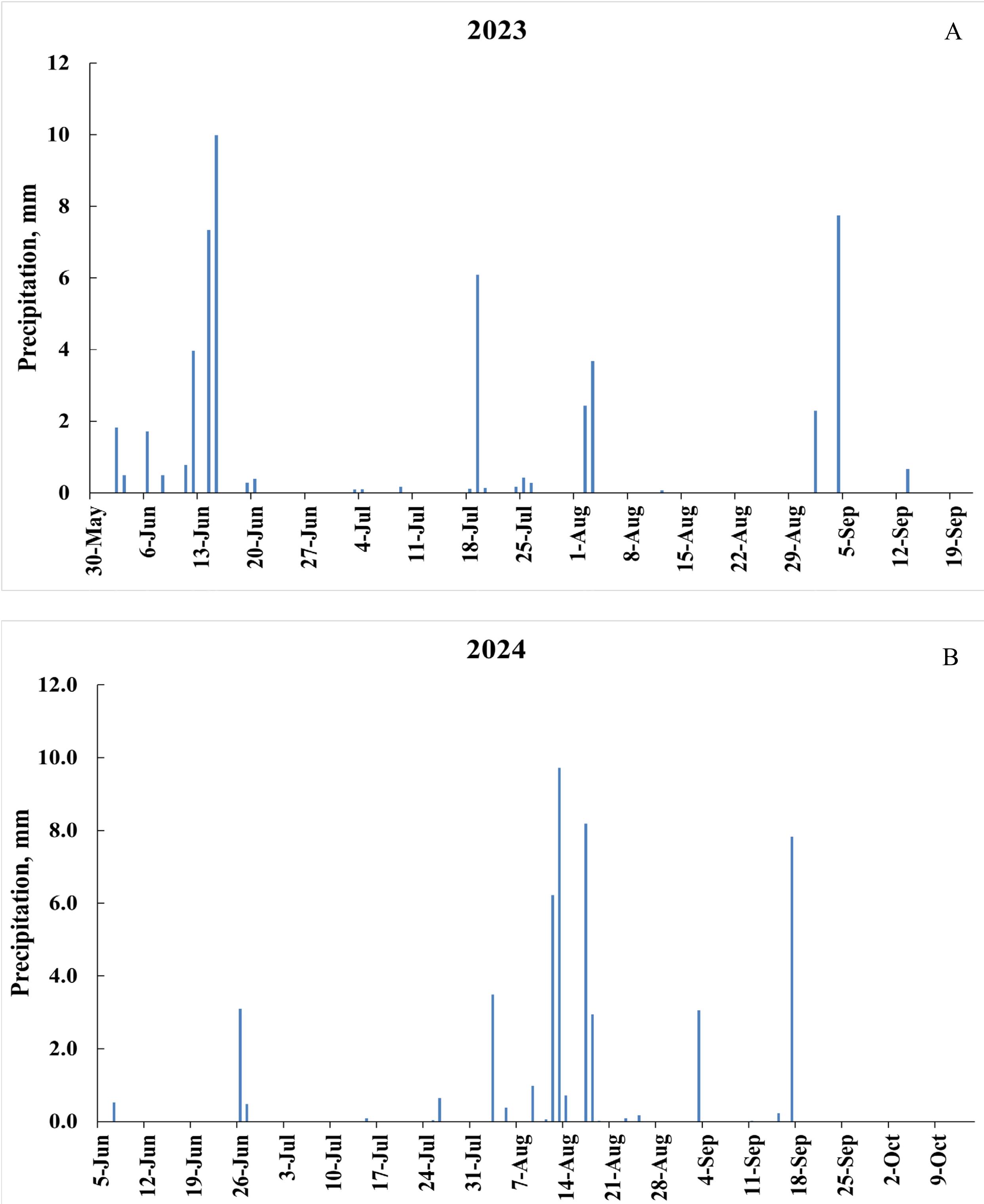
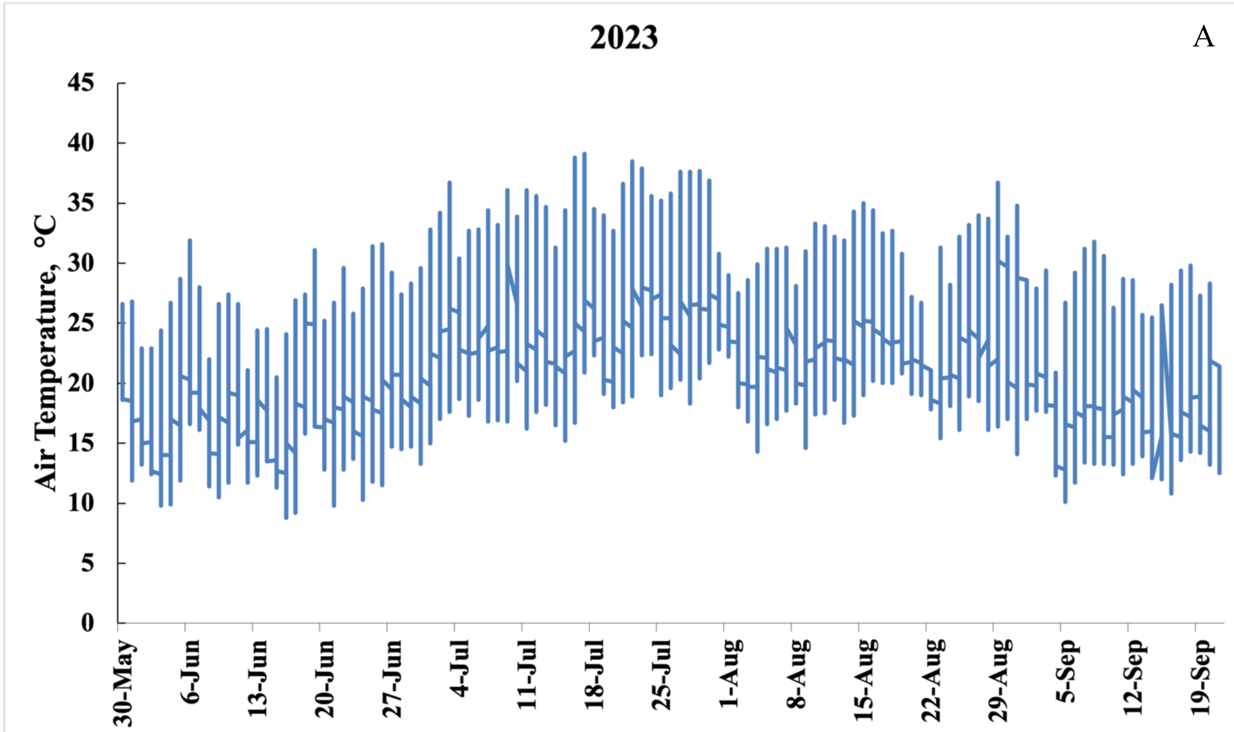
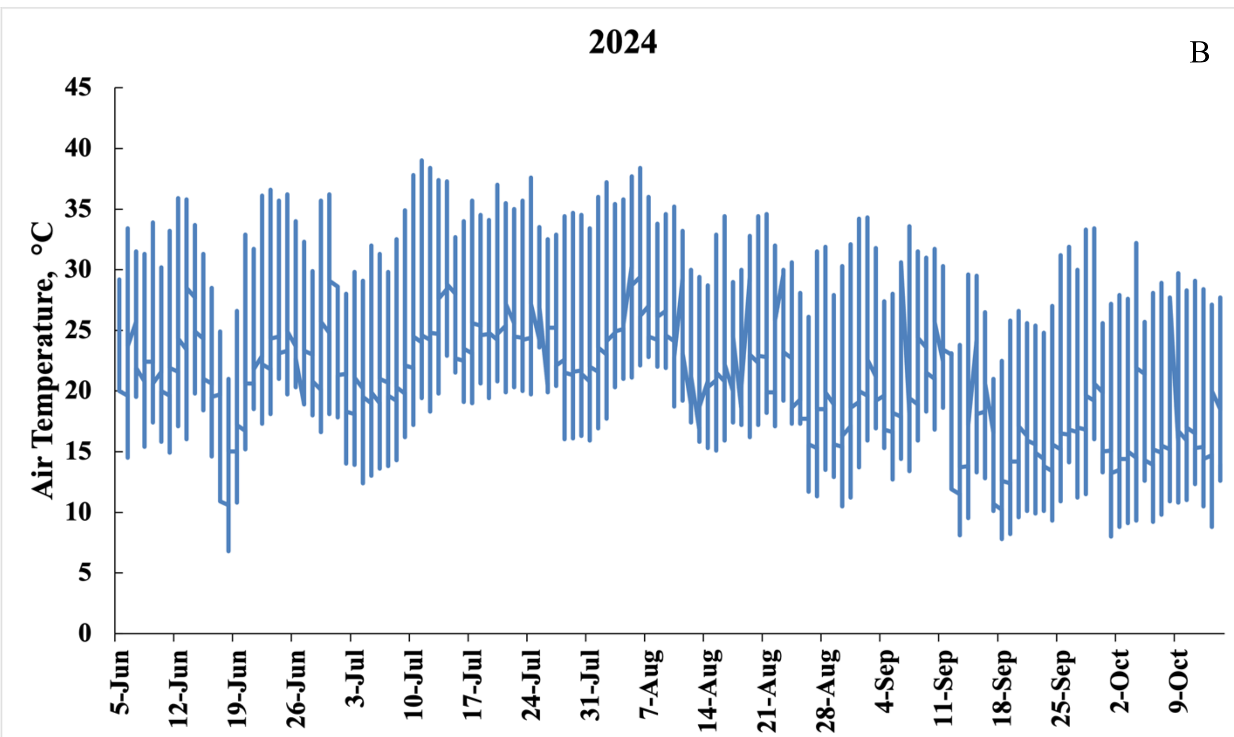


Supplementary Figure 1. Seasonal precipitation for a hybrid bermudagrass for a study site in Provo, UT, USA in 2023 (A) and 2024 (B).





Supplementary Figure 2. Air temperature for a study site in Provo, UT, USA in 2023 (A) and 2024 (B).

Supplementary Figure 3. volumetric water content (VWC) of a blend of Kentucky bluegrass (KBG; *Poa pratensis* L.), compared orthogonally to the average of all bermudagrass (HBG; *C. dactylon* [L.] 'Pers.' x *C. transvaalensis* 'Burtt Davy') cultivars ('Iron Cutter', 'Latitude 36', 'NorthBridge', 'OKC 1666', 'Patriot', and 'Tahoma 31'), African bermudagrass (ABG; *Cynodon transvaalensis* 'OKC 1163'), and common bermudagrass (CBG; *C. dactylon* [L.] Pers.)for a drought study with four dry-down periods (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied (Supplementary Figure 3A) and Traffic applied (Supplementary Figure 3B).

SUPPLEMENTARY TABLES

Supplementary Table 1a. ANOVA statistical analysis for a study comparing Normalized Difference Vegetation Index (NDVI) of Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) ‘Iron Cutter’ [IC], ‘Latitude 36’ [L36], ‘NorthBridge’ [NB], ‘OKC 1666’ [O66], ‘Patriot’ [PAT], and ‘Tahoma 31’ [T31] compared to African bermudagrass (*Cynodon transvaalensis*) ‘OKC 1163’ [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

NDVI NO-TRAFFIC DD1

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	1.69	42.5	<.0001*
Date	8	8	1.27	3	<.0001*
Grass*Date	64	64	0.44	1.4	0.0547

NDVI NO-TRAFFIC DD2

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	0.62	18.64	<.0001*
Date	6	6	0.30	12.14	<.0001*
Grass*Date	48	48	0.13	0.68	0.9373

NDVI NO-TRAFFIC DD3

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	0.61	6.75	<.0001*
Date	6	6	1.27	18.78	<.0001*
Grass*Date	48	48	0.26	0.48	0.9977

NDVI NO-TRAFFIC DD4

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	0.59	14.08	<.0001*
Date	6	6	0.72	22.83	<.0001*
Grass*Date	48	48	0.41	1.60	0.0200*

Supplementary Table 1b statistical analysis of Normalized Difference Vegetation Index (NDVI) for an orthogonal comparison combining Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

NDVI NO-TRAFFIC DD1

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	204	76.12	<.0001*
Date	8	8	204	15.16	<.0001*
Grass Group*Date	24	24	204	1.89	0.0099*

NDVI NO-TRAFFIC DD2

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	22.86346	<.0001*
Date	6	6	159	3.948798	0.0010*
Grass Group*Date	18	18	159	0.642728	0.8613

NDVI NO-TRAFFIC DD3

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	18.32	<.0001*
Date	6	6	159	16.90	<.0001*
Grass Group*Date	18	18	159	0.74	0.7696

NDVI NO-TRAFFIC DD4

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
GrassGroup	3	3	159	28.04	<.0001*
Date	6	6	159	11.82	<.0001*
GrassGroup*Date	18	18	159	3.25	<.0001*

Supplementary Table 2a ANOVA statistical analysis for a study comparing Normalized Difference Vegetation Index (NDVI) of Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

NDVI TRAFFIC DD1

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	1.71	65.39	<.0001*
Date	8	8	0.79	30.46	<.0001*
Grass*Date	64	64	0.33	1.60	0.0098*

NDVI TRAFFIC DD2

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	0.18	5.07	<.0001*
Date	6	6	0.34	12.72	<.0001*
Grass*Date	48	48	0.20	0.95	0.5635

NDVI TRAFFIC DD3

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	0.56	11.70	<.0001*
Date	6	6	0.80	22.10	<.0001*
Grass*Date	48	48	0.21	0.75	0.8755

NDVI TRAFFIC DD4

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	0.79	18.54	<.0001*
Date	10	10	1.46	27.24	<.0001*
Grass*Date	80	80	0.38	0.89	0.7135

Supplementary Table 2b statistical analysis of Normalized Difference Vegetation Index (NDVI) for an orthogonal comparison combining Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

NDVI TRAFFIC DD1					
Source	**Nparm**	**DFNum**	**DFDen**	**F Ratio**	**Prob > F**
Grass Group	3	3	204	114	<.0001*
Date	8	8	204	15.93	<.0001*
Grass Group*Date	24	24	204	3.03	<.0001*
NDVI TRAFFIC DD2					
Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	4.72	0.0035*
Date	6	6	159	8.38	<.0001*
Grass Group*Date	18	18	159	0.69	0.8214
NDVI TRAFFIC DD3					
Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	35.29	<.0001*
Date	6	6	159	24.41	<.0001*
Grass Group*Date	18	18	159	1.57	0.0731
NDVI TRAFFIC DD4					
Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	251	41.71	<.0001*
Date	10	10	251	11.51	<.0001*
Grass Group*Date	30	30	251	1.51	0.0485*

Supplementary Table 3a ANOVA statistical analysis for a study comparing Visual quality (verdure) of Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

VERDURE NO-TRAFFIC DD1

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	348.28	49.20	<.0001*
Date	8	8	74.50	10.53	<.0001*
Grass*Date	64	64	121.28	2.14	<.0001*

VERDURE NO-TRAFFIC DD2

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	164.68	21.98	<.0001*
Date	6	6	27.77	4.94	0.0001*
Grass*Date	48	48	26.14	0.58	0.983

VERDURE NO-TRAFFIC DD3

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	136.71	10.91	<.0001*
Date	6	6	24.72	2.63	0.0195*
Grass*Date	48	48	56.33	0.75	0.8722

VERDURE NO-TRAFFIC DD4

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	109.56	12.29	<.0001*
Date	6	6	71.28	10.66	<.0001*
Grass*Date	48	48	62.62	1.17	0.2431

Supplementary Table 3b statistical analysis of Visual quality (verdure) for an orthogonal comparison combining Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

VERDURE NO-TRAFFIC DD1

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	205	111.44	<.0001*
Date	8	8	205	6.18	<.0001*
Grass Group*Date	24	24	205	3.08	<.0001*

VERDURE NO-TRAFFIC DD2

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	58.81	<.0001*
Date	6	6	159	2.44	0.0280*
Grass Group*Date	18	18	159	0.81	0.6869

VERDURE NO-TRAFFIC DD3

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	26.58	<.0001*
Date	6	6	159	3.97	0.0010*
Grass Group*Date	18	18	159	1.14	0.322

VERDURE NO-TRAFFIC DD4

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	158	25.75	<.0001*
Date	6	6	158	4.80	0.0002*
Grass Group*Date	18	18	158	2.24	0.0043*

Supplementary Table 4a ANOVA statistical analysis for a study comparing Visual quality (verdure) of Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

VERDURE TRAFFIC DD1

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	362.85	45.50	<.0001*
Date	8	8	82.27	10.32	<.0001*
Grass*Date	64	64	106.05	1.66	0.0056*

VERDURE TRAFFIC DD2

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	98.80	14.77	<.0001*
Date	6	6	42.87	8.55	<.0001*
Grass*Date	48	48	28.75	0.72	0.9055

VERDURE TRAFFIC DD3

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	141.76	15.58	<.0001*
Date	6	6	15.39	2.25	0.0423*
Grass*Date	48	48	42.61	0.78	0.8351

VERDURE TRAFFIC DD4

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	188.73	27.66	<.0001*
Date	10	10	118.08	13.85	<.0001*
Grass*Date	80	80	73.45	1.08	0.3367

Supplementary Table 4b statistical analysis of Visual quality (verdure) for an orthogonal comparison combining Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

VERDURE TRAFFIC DD1

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	204	112.76	<.0001*
Date	8	8	204	8.39	<.0001*
Grass Group*Date	24	24	204	2.77	<.0001*

VERDURE TRAFFIC DD2

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	39.20	<.0001*
Date	6	6	159	3.62	0.0021*
Grass Group*Date	18	18	159	0.94	0.5339

VERDURE TRAFFIC DD3

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	52.39	<.0001*
Date	6	6	159	4.83	0.0001*
Grass Group*Date	18	18	159	1.91	0.0182*

VERDURE TRAFFIC DD4

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	250	90.15	<.0001*
Date	10	10	250	7.32	<.0001*
Grass Group*Date	30	30	250	2.77	<.0001*

Supplementary Table 5a ANOVA statistical analysis for a study comparing Canopy cover of Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

COVER NO-TRAFFIC DD1

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	80593.77	88.91	<.0001*
Date	8	8	38296.83	42.25	<.0001*
Grass*Date	64	64	13082.46	1.80	0.0016*

COVER NO-TRAFFIC DD2

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	31343.96	19.82	<.0001*
Date	6	6	12511.03	10.55	<.0001*
Grass*Date	48	48	10543.81	1.11	0.3166

COVER NO-TRAFFIC DD3

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	32106.74	8.65	<.0001*
Date	6	6	35003.99	12.57	<.0001*
Grass*Date	48	48	18669.57	0.84	0.7545

COVER NO-TRAFFIC DD4

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	23483.65	12.63	<.0001*
Date	4	4	14699.3	15.81	<.0001*
Grass*Date	32	32	8472.40	1.14	0.3096

Supplementary Table 5b statistical analysis of Canopy cover for an orthogonal comparison combining Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with No-Traffic applied.

COVER NO-TRAFFIC DD1 Effect Test

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	204	101.80	<.0001*
Date	8	8	204	9.98	<.0001*
Grass Group*Date	24	24	204	1.21	0.234

COVER NO-TRAFFIC DD2 Effect Test

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	21.12	<.0001*
Date	6	6	159	5.05	<.0001*
Grass Group*Date	18	18	159	0.52	0.9465

COVER NO-TRAFFIC DD3 Effect Test

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	23.87	<.0001*
Date	6	6	159	13.88	<.0001*
Grass Group*Date	18	18	159	1.09	0.3701

COVER NO-TRAFFIC DD4 Effect Test

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	113	24.27	<.0001*
Date	4	4	113	10.87	<.0001*
Grass Group*Date	12	12	113	1.22	0.275

Supplementary Table 6a ANOVA statistical analysis for a study comparing Canopy cover of Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

COVER TRAFFIC DD1

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Date	8	8	34144.23	34.27	<.0001*
Grass	8	8	65658.6	65.89	<.0001*
Grass*Date	64	64	11547.7	1.45	0.0327*

COVER TRAFFIC DD2

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	17743.21	12.67	<.0001*
Date	6	6	10743.26	10.23	<.0001*
Grass*Date	48	48	7956.51	0.95	0.5749

COVER TRAFFIC DD3

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	37691.9	18.17	<.0001*
Date	6	6	24621.4	15.83	<.0001*
Grass*Date	48	48	11508.4	0.92	0.6131

COVER TRAFFIC DD4

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Grass	8	8	28145.22	16.46	<.0001*
Date	8	8	48508.54	28.37	<.0001*
Grass*Date	64	64	7817.5	0.57	0.9943

Supplementary Table 6b statistical analysis of Canopy cover for an orthogonal comparison combining Hybrid bermudagrass cultivars (*Cynodon dactylon* [L.] Pers. x *Cynodon transvaalensis* Burtt Davy) (HBG) 'Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31] compared to African bermudagrass (*Cynodon transvaalensis*) 'OKC 1163' [ABG], Common bermudagrass (*Cynodon dactylon*) (CBG) and a blend of Kentucky bluegrass (*Poa pratensis*) (KBG) across four dry-down periods in two years (DD1 = 31 May to 14 July 2023, DD2 = 8 August to 21 September 2023, DD3 = 3 June to 15 July 2024, and DD4 = 30 July 2024 to 15 October 2024) with Traffic applied.

COVER TRAFFIC DD1

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	204	114.13	<.0001*
Date	8	8	204	15.05	<.0001*
Grass Group*Date	24	24	204	2.033	0.0044*

COVER TRAFFIC DD2

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	18.85	<.0001*
Date	6	6	159	6.54	<.0001*
Grass Group*Date	18	18	159	1.4	0.1387

COVER TRAFFIC DD3

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	159	56.41	<.0001*
Date	6	6	159	20.09	<.0001*
Grass Group*Date	18	18	159	1.845	0.0243*

COVER TRAFFIC DD4

Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
Grass Group	3	3	205	46.17	<.0001*
Date	8	8	205	15.97	<.0001*
Grass Group*Date	24	24	205	0.83	0.6906

SUPPLEMENTARY SPREADSHEET DATA

The following data (collected about weekly over the 2023 and 2024 growing seasons) is the Normalized Difference Vegetation Index (NDVI), verdure rating (Visual), percentage of canopy cover (Cover), and volumetric water content of the surface 15 cm (VWC) with (Yes) or without (No) traffic simulation for six hybrid bermudagrass cultivars ('Iron Cutter' [IC], 'Latitude 36' [L36], 'NorthBridge' [NB], 'OKC 1163' [O63], 'OKC 1666' [O66], 'Patriot' [PAT], and 'Tahoma 31' [T31]) compared to common bermudagrass (CBG; 'Transcontinental'), African bermudagrass (ABG; 'OKC 1163'), and a blend of Kentucky bluegrass (KBG) cultivars.

Supplementary Spreadsheet Data 1a. Grass measurements for 2023.

Date	Grass	NDVI	Visual	Cover	VWC	NDVI	Visual	Cover	VWC
		----- No Traffic Simulation -----				----- With Traffic Simulation -----			
5/19	ABG	0.40	5.0	22	n/a	0.49	5.3	27	n/a
	CBG	0.38	2.7	16	n/a	0.34	1.7	35	n/a
	IC	0.40	5.3	22	n/a	0.41	5.3	28	n/a
	KBG	0.61	6.3	39	n/a	0.64	6.0	44	n/a
	L36	0.42	5.3	22	n/a	0.51	5.3	35	n/a
	NB	0.39	5.0	28	n/a	0.42	5.0	35	n/a
	O66	0.35	5.0	14	n/a	0.45	5.0	20	n/a
	Pat	0.46	5.3	35	n/a	0.51	5.3	35	n/a
	T31	0.43	6.0	32	n/a	0.48	6.0	25	n/a
5/31	ABG	0.39	5.7	13	3.0	0.51	6.0	55	3.0
	CBG	0.25	2.0	7	3.0	0.29	2.0	20	3.0
	IC	0.52	6.3	39	3.0	0.59	6.7	58	3.0
	KBG	0.44	7.3	25	3.0	0.57	7.3	46	3.0
	L36	0.47	6.7	34	3.0	0.52	6.7	53	3.0
	NB	0.45	6.7	42	3.0	0.61	7.0	57	3.0
	O66	0.42	6.0	27	3.0	0.50	6.0	49	3.0
	Pat	0.42	5.3	28	3.0	0.48	5.3	34	3.0
	T31	0.52	5.7	47	3.0	0.57	6.0	53	3.0
6/9	ABG	0.62	7.0	39	19.6	0.71	7.0	68	18.2
	CBG	0.45	3.0	32	21.5	0.41	3.0	27	20.5
	IC	0.71	8.0	63	23.7	0.73	8.0	78	25.6
	KBG	0.59	6.7	30	12.4	0.60	6.7	49	26.6
	L36	0.69	7.3	53	19.4	0.71	7.3	71	24.1
	NB	0.71	8.0	66	19.6	0.73	8.0	82	24.9
	O66	0.65	7.7	49	21.1	0.62	7.7	66	21.6
	Pat	0.67	7.3	56	21.4	0.64	7.3	65	23.4
	T31	0.73	8.0	69	21.0	0.74	8.0	82	25.5
6/16	ABG	0.67	6.3	51	10.1	0.77	6.7	75	9.0
	CBG	0.59	4.3	37	9.7	0.48	4.3	40	5.1
	IC	0.66	6.7	80	13.6	0.76	7.0	89	17.0
	KBG	0.59	3.7	40	8.8	0.67	5.7	61	9.5
	L36	0.58	6.3	71	11.8	0.74	7.0	85	11.8
	NB	0.69	6.7	87	12.8	0.77	7.3	92	14.5
	O66	0.65	6.7	78	11.2	0.67	6.7	78	9.6
	Pat	0.68	5.3	76	12.0	0.66	5.3	78	13.1
	T31	0.70	6.7	78	15.1	0.78	7.0	91	16.6
6/22	ABG	0.71	6.7	58	4.9	0.73	6.7	70	8.1
	CBG	0.54	3.0	38	6.3	0.55	2.7	46	3.9
	IC	0.75	7.3	83	3.7	0.77	7.5	89	11.6
	KBG	0.53	4.3	33	9.7	0.65	5.7	54	9.2
	L36	0.69	6.3	72	8.7	0.76	6.7	86	8.7
	NB	0.78	7.0	88	8.9	0.78	7.7	92	7.4
	O66	0.71	7.0	71	5.5	0.67	7.0	76	6.1
	Pat	0.70	6.0	75	5.9	0.71	6.3	80	7.8
	T31	0.75	7.3	83	3.5	0.79	7.7	91	7.9
6/27	ABG	0.67	6.7	53	3.0	0.69	6.3	57	3.0
	CBG	0.48	3.3	33	3.0	0.50	2.7	34	3.0
	IC	0.73	7.0	74	3.0	0.76	7.0	79	3.0
	KBG	0.44	4.0	15	3.0	0.54	3.7	29	3.0
	L36	0.67	6.7	64	3.0	0.71	6.7	73	3.0
	NB	0.73	7.7	79	3.0	0.76	7.3	80	3.0
	O66	0.59	6.7	46	3.0	0.65	6.7	55	3.0
	Pat	0.67	6.7	70	3.0	0.68	6.0	64	3.0
	T31	0.74	7.0	78	3.0	0.73	7.0	78	3.0
6/29	ABG	0.69	5.7	63	3.0	0.66	5.3	57	3.0
	CBG	0.54	2.7	41	3.0	0.52	2.0	41	3.0
	IC	0.73	6.7	83	3.0	0.74	6.7	81	3.0
	KBG	0.49	2.7	28	3.0	0.54	3.0	27	3.0
	L36	0.68	6.7	78	3.0	0.72	6.3	79	3.0
	NB	0.77	8.0	93	3.0	0.72	7.3	85	3.0
	O66	0.67	5.3	56	3.0	0.60	6.0	60	3.0
	Pat	0.71	6.7	79	3.0	0.66	5.7	70	3.0
	T31	0.76	7.0	88	3.0	0.76	6.7	87	3.0

Supplementary Spreadsheet Data 1b. Grass measurements for 2023.									
Date	Grass	NDVI	Visual	Cover	VWC	NDVI	Visual	Cover	VWC
		----- No Traffic Simulation -----				----- With Traffic Simulation -----			
7/3	ABG	0.61	5.0	51	3.0	0.62	5.0	46	3.0
	CBG	0.50	3.0	36	3.0	0.47	2.7	38	3.0
	IC	0.68	5.0	70	3.0	0.70	5.7	67	3.0
	KBG	0.36	2.7	10	3.0	0.43	3.0	15	3.0
	L36	0.61	5.7	68	3.0	0.69	5.7	73	3.0
	NB	0.73	6.7	82	3.0	0.69	6.3	68	3.0
	O66	0.53	4.3	32	3.0	0.56	5.0	40	3.0
	Pat	0.65	6.0	75	3.0	0.66	5.7	64	3.0
	T31	0.73	6.3	84	3.0	0.74	6.7	80	3.0
7/7	ABG	0.68	6.0	38	n/a	0.66	6.3	35	n/a
	CBG	0.49	3.7	27	n/a	0.51	4.0	32	n/a
	IC	0.72	7.0	68	n/a	0.73	7.0	68	n/a
	KBG	0.40	4.7	10	n/a	0.49	4.7	11	n/a
	L36	0.68	5.0	60	n/a	0.70	5.3	66	n/a
	NB	0.72	5.7	77	n/a	0.73	5.7	68	n/a
	O66	0.48	6.7	27	n/a	0.59	6.7	34	n/a
	Pat	0.66	7.0	64	n/a	0.67	7.0	54	n/a
	T31	0.75	5.0	80	n/a	0.73	4.7	77	n/a
7/14	ABG	0.53	4.7	19	10.1	0.55	4.7	27	8.2
	CBG	0.41	3.0	12	5.0	0.49	3.0	19	5.8
	IC	0.64	6.0	48	7.8	0.66	6.0	55	8.7
	KBG	0.40	3.0	17	3.1	0.36	3.0	12	3.1
	L36	0.66	6.0	52	10.8	0.69	6.0	54	9.5
	NB	0.68	6.7	56	12.5	0.68	6.7	57	13.5
	O66	0.48	4.7	12	5.1	0.52	4.7	23	7.6
	Pat	0.63	6.0	48	9.4	0.61	6.0	44	9.2
	T31	0.72	7.0	74	13.1	0.73	7.0	73	14.9
7/23	ABG	0.61	5.3	35	15.6	0.61	5.7	50	17.5
	CBG	0.46	3.0	33	16.3	0.55	2.7	40	17.7
	IC	0.64	6.0	60	17.9	0.69	6.3	67	20.0
	KBG	0.35	3.0	17	17.7	0.38	3.7	21	23.8
	L36	0.66	6.3	64	18.4	0.69	6.7	75	19.8
	NB	0.72	6.7	67	17.2	0.70	6.7	75	19.6
	O66	0.52	4.0	31	15.5	0.55	5.0	53	15.4
	Pat	0.65	6.3	59	16.3	0.59	6.7	58	16.9
	T31	0.73	7.0	76	14.0	0.73	7.0	83	18.5
7/27	ABG	0.72	6.7	87	22.7	0.71	6.7	86	24.9
	CBG	0.71	4.7	87	23.8	0.70	4.0	81	24.5
	IC	0.77	7.0	90	22.5	0.74	7.0	86	24.9
	KBG	0.55	3.3	65	24.2	0.64	4.3	67	28.2
	L36	0.76	7.0	87	23.7	0.78	6.7	92	24.4
	NB	0.79	7.3	74	24.0	0.78	8.0	92	25.2
	O66	0.71	6.7	93	22.4	0.73	7.0	86	23.9
	Pat	0.77	7.0	95	22.7	0.72	7.0	91	23.3
	T31	0.81	8.0	85	23.6	0.80	8.0	97	24.9
8/4	ABG	0.68	6.3	64	20.9	0.71	6.3	71	23.7
	CBG	0.75	5.7	81	22.5	0.71	5.3	73	22.5
	IC	0.72	7.0	76	22.5	0.72	7.0	77	24.2
	KBG	0.50	4.7	40	22.6	0.67	5.3	65	25.0
	L36	0.77	7.0	87	24.3	0.76	7.0	84	24.3
	NB	0.80	7.0	89	23.0	0.78	7.0	87	24.7
	O66	0.73	7.3	88	22.3	0.69	7.3	78	23.8
	Pat	0.77	8.0	87	22.3	0.73	8.0	83	23.0
	T31	0.81	7.7	92	21.4	0.77	7.7	91	25.0
8/8	ABG	0.69	6.3	74	22.6	0.71	5.7	77	24.1
	CBG	0.70	5.7	68	23.3	0.73	4.7	65	23.3
	IC	0.74	6.7	71	23.4	0.69	6.3	66	25.0
	KBG	0.62	3.7	59	22.4	0.73	5.0	69	28.0
	L36	0.82	7.0	81	24.2	0.73	6.3	82	25.4
	NB	0.82	7.3	81	24.2	0.78	7.0	80	25.7
	O66	0.76	7.7	81	21.0	0.69	6.3	75	24.2
	Pat	0.81	7.3	84	22.7	0.74	6.7	81	25.0
	T31	0.82	7.3	79	23.1	0.81	6.7	80	25.7

Supplementary Spreadsheet Data 1c. Grass measurements for 2023.									
Date	Grass	NDVI	Visual	Cover	VWC	NDVI	Visual	Cover	VWC
		----- No Traffic Simulation -----				----- With Traffic Simulation -----			
8/16	ABG	0.68	5.7	56	13.9	0.69	5.7	53	15.9
	CBG	0.68	5.0	58	15.1	0.70	4.7	64	17.3
	IC	0.76	6.3	75	15.8	0.70	6.0	62	20.3
	KBG	0.61	3.7	44	12.3	0.71	4.7	59	11.8
	L36	0.77	6.7	76	16.9	0.75	6.7	75	21.4
	NB	0.80	7.0	82	16.0	0.78	6.3	76	21.9
	O66	0.67	5.3	53	14.1	0.68	4.7	59	18.8
	Pat	0.80	6.7	82	18.6	0.74	6.0	78	21.1
	T31	0.81	7.0	86	16.8	0.79	7.0	84	20.1
8/25	ABG	0.71	6.7	44	16.2	0.68	6.7	46	18.3
	CBG	0.70	6.0	41	14.7	0.71	6.0	56	18.0
	IC	0.77	7.3	81	18.3	0.73	7.3	60	19.2
	KBG	0.59	5.0	35	12.4	0.77	5.3	68	15.5
	L36	0.73	7.3	61	18.7	0.75	7.7	76	23.2
	NB	0.78	7.3	78	17.1	0.75	7.7	66	22.2
	O66	0.66	7.0	44	11.4	0.64	7.3	44	19.8
	Pat	0.75	7.7	64	18.7	0.74	7.7	76	20.8
	T31	0.79	7.7	88	18.2	0.75	7.7	82	18.4
8/29	ABG	0.60	6.0	60	14.7	0.60	6.3	59	11.5
	CBG	0.64	5.7	56	9.8	0.67	5.3	65	13.3
	IC	0.73	7.3	91	14.4	0.67	7.0	73	15.6
	KBG	0.51	4.3	47	8.1	0.67	5.7	53	9.6
	L36	0.64	7.0	71	14.5	0.69	7.0	87	19.2
	NB	0.72	7.3	88	13.0	0.64	7.0	79	18.5
	O66	0.58	6.3	31	9.5	0.62	6.3	55	14.6
	Pat	0.64	7.3	58	14.3	0.66	7.3	70	14.6
	T31	0.70	7.7	87	15.7	0.69	7.7	89	16.6
9/8	ABG	0.66	6.7	38	14.9	0.61	6.7	30	15.7
	CBG	0.65	5.0	53	15.8	0.66	4.7	56	17.6
	IC	0.66	6.7	52	17.8	0.65	6.7	46	20.2
	KBG	0.66	3.3	46	12.2	0.57	4.0	36	12.5
	L36	0.70	6.3	60	15.6	0.73	6.7	67	21.5
	NB	0.70	6.7	68	16.8	0.66	6.3	52	20.4
	O66	0.57	6.3	31	12.6	0.61	6.7	39	18.2
	Pat	0.72	7.0	72	15.6	0.72	7.3	68	20.2
	T31	0.77	8.0	80	16.0	0.75	7.3	72	18.4
9/12	ABG	0.62	6.7	77	8.3	0.59	6.0	66	6.2
	CBG	0.67	6.0	78	3.9	0.66	5.3	75	3.0
	IC	0.68	7.0	92	11.2	0.66	6.3	84	12.7
	KBG	0.56	4.0	53	4.1	0.63	4.0	52	3.5
	L36	0.69	6.7	87	8.3	0.71	7.0	84	13.6
	NB	0.74	7.0	94	10.1	0.68	7.0	82	14.0
	O66	0.58	6.3	68	4.9	0.59	6.3	69	8.1
	Pat	0.70	6.7	86	9.2	0.68	6.0	82	7.6
	T31	0.73	7.0	95	9.0	0.50	7.0	87	10.2
9/21	ABG	0.59	5.3	51	9.9	0.56	5.3	54	8.6
	CBG	0.64	5.0	69	7.2	0.63	5.0	67	9.5
	IC	0.64	5.3	78	12.4	0.65	5.7	72	12.4
	KBG	0.58	4.7	43	3.0	0.56	5.0	29	5.9
	L36	0.71	6.7	80	13.3	0.70	6.3	71	16.4
	NB	0.73	5.7	82	10.1	0.67	5.7	73	11.7
	O66	0.57	5.3	64	7.4	0.60	5.3	66	11.5
	Pat	0.71	6.7	73	9.6	0.67	6.3	68	11.0
	T31	0.75	6.3	82	9.9	0.67	5.0	75	13.1

Supplementary Spreadsheet Data 2a. Grass measurements for 2024.

Date	Grass	NDVI	Visual	Cover	VWC	NDVI	Visual	Cover	VWC
		----- No Traffic Simulation -----				----- With Traffic Simulation -----			
4/4	ABG	0.18	1.0	0	20.5	0.37	1.0	0	18.8
	CBG	0.16	1.0	0	19.3	0.28	1.0	0	18.5
	IC	0.19	1.0	0	19.9	0.18	1.0	0	23.0
	KBG	0.51	6.0	26	18.9	0.69	6.0	26	19.0
	L36	0.18	1.0	0	21.5	0.19	1.0	0	20.9
	NB	0.18	1.0	0	21.6	0.19	1.0	0	21.6
	O66	0.19	1.0	0	20.2	0.19	1.0	0	21.0
	Pat	0.18	1.0	0	21.5	0.19	1.0	0	21.3
	T31	0.17	1.0	0	21.6	0.20	1.0	0	20.8
4/10	ABG	0.17	1.0	0	19.5	0.17	1.0	0	19.5
	CBG	0.18	1.0	4	17.9	0.18	1.0	4	17.9
	IC	0.19	1.0	0	23.6	0.19	1.0	0	23.6
	KBG	0.71	5.0	61	12.6	0.71	5.0	61	12.6
	L36	0.19	1.0	1	21.6	0.19	1.0	1	21.6
	NB	0.18	1.0	0	21.6	0.18	1.0	0	21.6
	O66	0.18	1.0	1	21.1	0.18	1.0	1	21.1
	Pat	0.18	1.0	1	19.9	0.18	1.0	1	19.9
	T31	0.17	1.0	0	21.0	0.17	1.0	0	21.0
4/17	ABG	0.19	1.0	2	23.8	0.19	1.0	2	23.8
	CBG	0.26	1.7	22	22.3	0.26	1.7	22	22.3
	IC	0.22	1.0	2	25.5	0.22	1.0	2	25.5
	KBG	0.70	4.7	73	19.3	0.70	4.7	73	19.3
	L36	0.23	1.3	3	25.3	0.23	1.3	3	25.3
	NB	0.21	1.0	2	25.4	0.21	1.0	2	25.4
	O66	0.20	1.0	2	21.9	0.20	1.0	2	21.9
	Pat	0.18	1.3	5	22.6	0.18	1.3	5	22.6
	T31	0.18	1.0	1	24.3	0.18	1.0	1	24.3
4/25	ABG	0.32	n/a	4	14.9	0.32	n/a	4	14.9
	CBG	0.37	n/a	33	15.8	0.37	n/a	33	15.8
	IC	0.38	n/a	10	21.6	0.38	n/a	10	21.6
	KBG	0.69	n/a	86	14.2	0.69	n/a	86	14.2
	L36	0.38	n/a	18	17.9	0.38	n/a	18	17.9
	NB	0.37	n/a	15	23.9	0.37	n/a	15	23.9
	O66	0.36	n/a	17	16.7	0.36	n/a	17	16.7
	Pat	0.36	n/a	20	18.8	0.36	n/a	20	18.8
	T31	0.33	n/a	12	23.4	0.33	n/a	12	23.4
5/10	ABG	0.44	3.7	19	n/a	0.44	3.7	19	n/a
	CBG	0.54	3.0	33	n/a	0.54	3.0	33	n/a
	IC	0.51	4.0	37	n/a	0.51	4.0	37	n/a
	KBG	0.73	8.0	75	n/a	0.73	8.0	75	n/a
	L36	0.51	3.7	30	n/a	0.51	3.7	30	n/a
	NB	0.51	4.0	40	n/a	0.51	4.0	40	n/a
	O66	0.52	4.0	50	n/a	0.52	4.0	50	n/a
	Pat	0.51	4.0	34	n/a	0.51	4.0	34	n/a
	T31	0.48	4.0	25	n/a	0.48	4.0	25	n/a
5/16	ABG	0.52	4.7	39	n/a	0.52	4.7	39	n/a
	CBG	0.60	4.0	60	n/a	0.60	4.0	60	n/a
	IC	0.61	5.7	49	n/a	0.61	5.7	49	n/a
	KBG	0.71	7.0	84	n/a	0.71	7.0	84	n/a
	L36	0.58	5.0	49	n/a	0.58	5.0	49	n/a
	NB	0.61	5.3	53	n/a	0.61	5.3	53	n/a
	O66	0.59	5.3	61	n/a	0.59	5.3	61	n/a
	Pat	0.59	5.7	52	n/a	0.59	5.7	52	n/a
	T31	0.54	5.0	40	n/a	0.54	5.0	40	n/a
5/23	ABG	0.65	6.7	84	15.4	0.65	6.7	84	15.4
	CBG	0.64	7.0	86	20.8	0.64	7.0	86	20.8
	IC	0.68	7.0	94	23.3	0.68	7.0	94	23.3
	KBG	0.64	7.0	84	20.6	0.64	7.0	84	20.6
	L36	0.65	7.0	85	20.3	0.65	7.0	85	20.3
	NB	0.69	7.0	92	21.5	0.69	7.0	92	21.5
	O66	0.66	7.0	95	18.5	0.66	7.0	95	18.5
	Pat	0.66	6.3	82	21.1	0.66	6.3	82	21.1
	T31	0.63	6.7	78	22.0	0.63	6.7	78	22.0

Supplementary Spreadsheet Data 2b. Grass measurements for 2024.									
Date	Grass	NDVI	Visual	Cover	VWC	NDVI	Visual	Cover	VWC
		----- No Traffic Simulation -----				----- With Traffic Simulation -----			
5/30	ABG	0.66	8.0	92	23.7	0.66	8.0	92	23.7
	CBG	0.66	7.0	82	22.6	0.66	7.0	82	22.6
	IC	0.71	7.7	96	25.2	0.71	7.7	96	25.2
	KBG	0.65	7.7	74	24.2	0.65	7.7	74	24.2
	L36	0.65	7.7	91	24.8	0.65	7.7	91	24.8
	NB	0.68	8.0	94	22.8	0.68	8.0	94	22.8
	O66	0.66	8.3	93	22.8	0.66	8.3	93	22.8
	Pat	0.62	7.3	84	22.9	0.62	7.3	84	22.9
	T31	0.61	7.0	87	25.9	0.61	7.0	87	25.9
6/3	ABG	0.78	7.7	96	25.6	0.78	7.7	96	25.6
	CBG	0.80	7.0	90	23.9	0.80	7.0	90	23.9
	IC	0.83	8.0	99	23.2	0.83	8.0	99	23.2
	KBG	0.78	7.7	90	20.6	0.78	7.7	90	20.6
	L36	0.81	7.7	97	25.1	0.81	7.7	97	25.1
	NB	0.81	7.7	97	23.0	0.81	7.7	97	23.0
	O66	0.80	8.0	96	24.0	0.80	8.0	96	24.0
	Pat	0.75	7.0	89	23.9	0.75	7.0	89	23.9
	T31	0.74	7.0	92	25.1	0.74	7.0	92	25.1
6/13	ABG	0.74	7.3	84	15.4	0.80	7.7	95	14.7
	CBG	0.67	5.7	68	13.7	0.70	5.7	68	9.1
	IC	0.78	7.7	92	15.5	0.79	8.0	98	12.9
	KBG	0.71	5.7	65	13.1	0.70	6.0	69	13.1
	L36	0.86	7.7	96	17.0	0.83	8.0	91	17.3
	NB	0.80	8.0	94	13.3	0.83	8.0	98	14.1
	O66	0.81	8.0	91	13.2	0.77	7.7	95	9.4
	Pat	0.80	7.7	90	13.4	0.80	7.7	94	11.2
	T31	0.81	8.0	89	16.5	0.81	8.0	91	15.0
6/20	ABG	0.68	6.0	81	11.6	0.78	7.0	94	11.8
	CBG	0.65	5.3	72	9.2	0.65	5.0	60	5.6
	IC	0.77	7.3	96	11.0	0.79	8.0	94	9.9
	KBG	0.60	4.3	50	11.7	0.66	4.7	55	11.9
	L36	0.80	8.0	92	12.3	0.78	7.3	92	13.1
	NB	0.74	7.3	94	10.9	0.77	8.3	97	13.2
	O66	0.72	6.7	92	11.9	0.76	7.3	94	4.9
	Pat	0.77	8.0	95	12.4	0.72	7.3	93	8.3
	T31	0.74	8.3	94	13.2	0.77	8.0	91	12.7
6/26	ABG	0.63	6.7	85	11.9	0.75	7.7	95	13.8
	CBG	0.56	5.7	68	8.9	0.60	5.7	59	6.7
	IC	0.70	7.7	93	8.3	0.71	7.7	93	12.5
	KBG	0.53	5.7	47	10.3	0.61	5.7	47	11.7
	L36	0.73	8.0	74	12.3	0.79	7.7	92	12.4
	NB	0.65	7.3	94	11.3	0.77	8.0	96	11.8
	O66	0.65	6.3	86	12.1	0.69	7.0	91	6.5
	Pat	0.71	8.0	84	12.4	0.75	7.7	95	9.7
	T31	0.69	7.7	72	12.6	0.71	7.7	91	11.0
7/2	ABG	0.59	6.7	65	8.4	0.68	7.0	75	11.5
	CBG	0.58	5.0	56	8.9	0.63	5.3	52	4.1
	IC	0.70	7.0	87	8.5	0.75	7.3	84	8.0
	KBG	0.48	4.7	33	7.3	0.54	4.7	30	10.9
	L36	0.76	7.7	91	8.9	0.71	7.3	86	11.1
	NB	0.70	6.7	73	8.9	0.74	7.7	86	12.4
	O66	0.63	6.0	54	10.9	0.70	7.0	75	8.1
	Pat	0.74	7.7	93	14.0	0.75	7.7	84	8.0
	T31	0.78	8.0	94	10.1	0.73	7.7	85	12.6
7/10	ABG	0.55	5.7	40	10.4	0.65	7.3	56	12.1
	CBG	0.49	6.3	33	6.7	0.53	6.3	32	4.9
	IC	0.61	7.3	77	7.8	0.71	8.0	77	6.3
	KBG	0.46	4.3	36	8.0	0.45	4.0	29	9.8
	L36	0.65	7.7	86	8.9	0.74	8.0	89	10.2
	NB	0.53	6.7	69	10.2	0.68	8.0	79	9.7
	O66	0.50	5.3	53	8.7	0.58	6.7	45	5.3
	Pat	0.68	8.0	81	9.4	0.69	7.7	70	8.0
	T31	0.70	7.7	88	9.7	0.69	8.0	83	8.4

Supplementary Spreadsheet Data 2c. Grass measurements for 2024.

Date	Grass	NDVI	Visual	Cover	VWC	NDVI	Visual	Cover	VWC
		----- No Traffic Simulation -----				----- With Traffic Simulation -----			
7/15	ABG	0.57	6.7	35	9.5	0.64	7.0	54	11.3
	CBG	0.49	5.7	23	6.4	0.49	5.3	40	2.1
	IC	0.62	7.3	59	8.9	0.67	7.3	83	8.0
	KBG	0.46	4.7	32	10.6	0.45	4.7	31	8.1
	L36	0.63	7.7	78	10.3	0.69	7.7	82	10.1
	NB	0.53	6.0	36	11.1	0.65	7.0	78	9.8
	O66	0.50	5.3	38	12.3	0.54	5.7	53	4.7
	Pat	0.67	7.7	77	10.1	0.65	7.3	71	5.1
	T31	0.65	7.7	86	10.1	0.66	7.7	88	9.4
7/17	ABG	0.62	7.3	47	23.0	0.67	7.3	64	24.2
	CBG	0.53	6.3	43	22.4	0.53	6.0	42	23.1
	IC	0.68	7.7	70	17.8	0.69	7.7	77	22.7
	KBG	0.51	4.7	33	23.1	0.46	4.7	31	26.9
	L36	0.72	8.0	83	22.2	0.70	8.0	84	23.0
	NB	0.54	6.0	43	20.8	0.68	7.3	77	22.2
	O66	0.50	6.0	36	21.8	0.56	6.3	52	23.8
	Pat	0.72	8.3	83	21.2	0.66	8.0	74	23.0
	T31	0.69	8.7	88	22.0	0.68	8.7	84	22.9
7/31	ABG	0.69	7.0	74	24.9	0.69	7.7	84	24.6
	CBG	0.75	7.3	86	22.6	0.78	7.7	84	23.2
	IC	0.73	6.7	80	21.5	0.77	7.3	81	24.7
	KBG	0.59	5.3	49	24.1	0.57	5.3	50	26.8
	L36	0.74	7.3	91	24.2	0.79	8.0	96	24.8
	NB	0.73	7.7	89	23.4	0.79	7.7	93	25.0
	O66	0.74	6.3	80	22.7	0.74	8.0	90	22.0
	Pat	0.78	7.7	94	22.9	0.78	7.7	90	24.4
	T31	0.76	8.0	95	23.3	0.79	8.0	96	24.8
8/6	ABG	0.76	7.3	n/a	16.6	0.73	7.3	81	19.6
	CBG	0.76	7.0	n/a	12.5	0.75	7.0	83	17.9
	IC	0.79	7.7	n/a	17.0	0.80	7.7	92	20.6
	KBG	0.53	5.0	n/a	15.9	0.58	5.0	51	19.0
	L36	0.83	8.0	n/a	17.4	0.81	8.0	92	21.9
	NB	0.80	8.0	n/a	14.4	0.82	8.0	92	20.8
	O66	0.70	6.7	n/a	15.4	0.75	7.7	89	17.3
	Pat	0.82	8.0	n/a	16.1	0.81	8.0	94	19.7
	T31	0.84	8.0	n/a	17.9	0.81	8.0	95	19.1
8/15	ABG	0.74	7.0	87	21.3	0.72	7.3	89	21.3
	CBG	0.76	7.3	91	19.7	0.77	7.3	89	19.7
	IC	0.78	8.0	85	21.9	0.80	8.0	95	21.9
	KBG	0.57	4.7	58	20.2	0.60	4.7	62	16.5
	L36	0.81	8.0	96	20.7	0.82	8.0	96	20.7
	NB	0.82	8.0	98	21.7	0.83	8.0	98	21.7
	O66	0.80	7.7	95	21.0	0.76	7.7	94	21.0
	Pat	0.80	8.0	96	21.4	0.81	8.0	95	21.4
	T31	0.81	8.0	98	22.4	0.80	8.0	97	22.4
8/22	ABG	n/a	n/a	n/a	n/a	0.72	6.7	89	20.2
	CBG	n/a	n/a	n/a	n/a	0.78	7.0	95	18.1
	IC	n/a	n/a	n/a	n/a	0.81	8.0	99	20.0
	KBG	n/a	n/a	n/a	n/a	0.58	5.7	61	17.7
	L36	n/a	n/a	n/a	n/a	0.82	8.0	100	21.5
	NB	n/a	n/a	n/a	n/a	0.82	8.0	99	20.7
	O66	n/a	n/a	n/a	n/a	0.77	8.0	99	19.1
	Pat	n/a	n/a	n/a	n/a	0.81	7.7	98	19.3
	T31	n/a	n/a	n/a	n/a	0.82	7.7	96	20.4
8/28	ABG	n/a	n/a	n/a	n/a	0.74	7.0	95	11.7
	CBG	n/a	n/a	n/a	n/a	0.80	7.3	93	12.9
	IC	n/a	n/a	n/a	n/a	0.80	8.0	98	16.4
	KBG	n/a	n/a	n/a	n/a	0.58	4.7	53	4.7
	L36	n/a	n/a	n/a	n/a	0.81	8.0	96	17.1
	NB	n/a	n/a	n/a	n/a	0.82	8.0	95	16.9
	O66	n/a	n/a	n/a	n/a	0.79	8.0	95	10.7
	Pat	n/a	n/a	n/a	n/a	0.78	8.0	90	14.2
	T31	n/a	n/a	n/a	n/a	0.76	8.0	93	16.9

Supplementary Spreadsheet Data 2d. Grass measurements for 2024.									
Date	Grass	NDVI	Visual	Cover	VWC	NDVI	Visual	Cover	VWC
		----- No Traffic Simulation -----				----- With Traffic Simulation -----			
9/4	ABG	n/a	n/a	n/a	n/a	0.75	7.0	98	17.4
	CBG	n/a	n/a	n/a	n/a	0.78	7.7	98	16.0
	IC	n/a	n/a	n/a	n/a	0.83	8.0	100	16.7
	KBG	n/a	n/a	n/a	n/a	0.63	4.0	54	10.7
	L36	n/a	n/a	n/a	n/a	0.80	8.0	99	18.2
	NB	n/a	n/a	n/a	n/a	0.84	8.0	99	18.3
	O66	n/a	n/a	n/a	n/a	0.80	8.0	99	14.8
	Pat	n/a	n/a	n/a	n/a	0.79	8.0	95	17.6
	T31	n/a	n/a	n/a	n/a	0.81	8.0	95	16.1
9/11	ABG	n/a	n/a	n/a	n/a	0.71	6.0	n/a	10.9
	CBG	n/a	n/a	n/a	n/a	0.73	7.0	n/a	10.0
	IC	n/a	n/a	n/a	n/a	0.76	7.0	n/a	8.1
	KBG	n/a	n/a	n/a	n/a	0.67	4.3	n/a	3.0
	L36	n/a	n/a	n/a	n/a	0.73	7.0	n/a	13.5
	NB	n/a	n/a	n/a	n/a	0.80	7.7	n/a	15.0
	O66	n/a	n/a	n/a	n/a	0.69	6.7	n/a	4.5
	Pat	n/a	n/a	n/a	n/a	0.77	8.0	n/a	7.3
	T31	n/a	n/a	n/a	n/a	0.78	8.0	n/a	14.1
9/27	ABG	0.63	5.7	56	9.2	0.68	7.0	60	9.6
	CBG	0.66	6.7	68	4.0	0.72	7.0	72	5.8
	IC	0.75	7.7	91	10.2	0.70	7.0	78	8.7
	KBG	0.62	4.3	49	10.6	0.58	4.0	44	3.4
	L36	0.77	6.7	88	9.8	0.73	7.3	80	12.5
	NB	0.78	8.0	87	7.0	0.74	7.3	79	11.8
	O66	0.68	5.3	73	3.3	0.67	7.0	67	3.6
	Pat	0.73	7.3	81	7.3	0.71	7.3	69	7.3
	T31	0.79	7.7	91	11.8	0.76	7.7	74	11.6
10/7	ABG	0.62	6.3	52	9.6	0.67	6.7	57	11.1
	CBG	0.59	5.3	46	4.5	0.65	5.3	58	3.4
	IC	0.76	8.0	91	9.1	0.69	7.0	74	9.9
	KBG	0.67	4.0	42	12.3	0.56	3.7	40	9.0
	L36	0.75	7.3	83	9.3	0.76	7.3	75	11.3
	NB	0.77	7.3	84	9.7	0.66	7.0	70	10.2
	O66	0.62	5.7	55	3.4	0.57	6.3	46	5.1
	Pat	0.73	7.7	72	6.3	0.66	6.3	57	6.8
	T31	0.78	8.0	83	9.8	0.72	7.3	68	5.6
10/14	ABG	0.56	6.3	44	10.0	0.56	6.3	49	11.3
	CBG	0.49	5.0	36	7.0	0.58	5.0	46	6.4
	IC	0.66	7.0	87	9.8	0.65	7.0	68	8.2
	KBG	0.59	5.0	50	13.8	0.57	5.0	49	13.9
	L36	0.65	7.0	71	8.3	0.65	7.0	73	11.5
	NB	0.68	6.7	79	7.6	0.65	6.7	59	8.3
	O66	0.52	6.0	39	5.6	0.46	6.0	39	6.3
	Pat	0.62	6.7	54	7.0	0.57	6.7	40	8.3
	T31	0.69	7.0	77	8.5	0.66	7.0	57	8.4
10/28	ABG	0.54	4.3	n/a	n/a	0.59	4.3	n/a	n/a
	CBG	0.42	4.3	n/a	n/a	0.49	4.3	n/a	n/a
	IC	0.70	6.0	n/a	n/a	0.63	6.0	n/a	n/a
	KBG	0.66	7.0	n/a	n/a	0.61	7.0	n/a	n/a
	L36	0.67	5.7	n/a	n/a	0.68	5.7	n/a	n/a
	NB	0.66	6.3	n/a	n/a	0.58	6.3	n/a	n/a
	O66	0.56	5.0	n/a	n/a	0.48	5.0	n/a	n/a
	Pat	0.57	5.3	n/a	n/a	0.51	5.3	n/a	n/a
	T31	0.66	5.0	n/a	n/a	0.62	5.0	n/a	n/a