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Performance of Three Warm Season Turfgrasses under Linear Gradient Irrigation

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ABSTRACT. The appropriate level of irrigation for turfgrasses is vital to the performance of the turfgrass as well as conservation of water. Linear gradient irrigation system (LGIS) facilitates long-term study of turf performance under continuous irrigation gradients at extreme ends of the irrigation scale. The objectives of this study were to: a) determine the minimum irrigation requirements and relative drought resistance in three warm season turfgrasses; and b) evaluate the medium to long-term effects of irrigation levels on turf persistence, weed invasion, and susceptibility to diseases. Results suggest that grasses differed in drought resistance and persistence under variable irrigation regimes. Irrigation (Ep) required for consistent acceptable turf quality for respective grasses was *Cynodon dactylon x C. transvaalensis* (61%), *Zoysia matrella* L. Merr (73%), and *Stenotaphrum secundatum* 'Palmetto' (86%). Brown patch infection was most prevalent in *Stenotaphrum secundatum* 'Palmetto' at 12 and 125% Ep irrigation. *Cynodon dactylon x C. transvaalensis* and *Zoysia matrella* L. Merr were better able to adapt to the various irrigation regimes, and this ability allowed these species to resist drought, and maintain turf coverage which in turn, kept weeds and the occurrence of diseases at bay. Ranking these grasses for their drought tolerance abilities showed that *Cynodon dactylon x C. transvaalensis* had the most outstanding resistance against drought, followed by *Zoysia matrella* L. Merr, and lastly, *Stenotaphrum secundatum* 'Palmetto'. Despite having the highest irrigation requirement, *Stenotaphrum secundatum* 'Palmetto' was still not able to maintain persistence at high irrigation regimes. Likewise, this grass also lost turf coverage at low irrigation levels.

***Key words*:** Drought resistance, Linear gradient irrigation, Minimum water requirements, Turf performance

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Introduction

Drought is an environmental stress that will lead to the decline and loss of turfgrass. Most areas of Singapore, require irrigation to maintain desirable turfgrass quality. As water conservation has become an important issue, researchers have put significant effort into developing and evaluating turf species with exceptional drought resistance (Carrow, 1995; Peacock, 2001; Fu et al., 2004; Barton and Colmer, 2006; Huang, 2008). The results from these studies suggest that turfgrasses differ in their performance during drought stress. In a study by Songul et al. (2011), rankings of relative drought resistance under Mediterranean conditions of Turkey indicated that relative drought resistance was superior for *Cynodon dactylon x C. transvaalensis* (Hybrid green couch), *Bouteloua dactyloides* (buffalo grass), and *Paspalum notatum* (bahia grass). Conversely, drought resistance was less ideal for *Paspalum vaginatum* (seashore paspalum), *Eremochloa ophiuroides* (centipede grass), *Zoysia matrella*, and *Festuca arundinacea* (tall fescue). In another field observation by SeedLand® (LawnGrasses.com), grasses for drought resistance were ranked in the order of *Cynodon dactylon x C. transvaalensis*, *Paspalum notatum*, *Zoysia matrella*, *Eremochloa ophiuroides*, *Festuca spp*, and *Stenotaphrum secundatum* (St. Augustine grass). Noteworthy however, that Morris and Shearman (2007) suggested that variations in the rankings of drought resistance may be a result of the varying climatic conditions of the various sites, the assessment method, and duration of the drought.

Zoysia matrella, *Stenotaphrum secundatum*, and *Axonopus compressus* (broadleaf carpet grass) are the most commonly used turfgrass species in Singapore, but the use of *Cynodon dactylon* has increased in recent years because of the ability to tolerate drought. This grass has been used as an alternative to the *Axonopus compressus* because this grass is highly sensitive to dry conditions. However, a key drawback with *Cynodon dactylon* is its high maintenance requirement. Therefore, long-term field assessment will be necessary to identify drought-resistant and water-saving grasses, so as to provide better irrigation management recommendations.

Despite water being considered the most precious and limited resource, there are many situations where excess water is applied without considering the requirement of the grasses. Much like the leaching and surface runoff of chemicals, excessive irrigation may also negatively impact on the growth of turf, such as making it more susceptible to pests (Cathey et al., 2013). Much work has been carried out on the effects of drought stress on turf, but little is known about the responses of turfgrass to excess irrigation. Information pertaining to how each species will survive under various irrigation regimes will be useful for turf management. The linear gradient irrigation system (LGIS), described by Hanks et al. (1976), generates uniform irrigation gradients and allows for the determination of turfgrass drought resistance and water requirements under in situ conditions (Zhang & Unruh, 2015). It exemplifies the evaluation of turf persistence under continuous moisture gradients. This study was set up with the LGIS applied on three commercially available turfgrasses in Singapore to: a) determine the minimum irrigation requirements and relative drought resistance; and b) evaluate the medium to long-term effects of irrigation levels on turf persistence, weed invasion, and susceptibility to disease.

Materials and Methods

Experimental design

The experiment was conducted at the Nanyang Technological University Research Centre on clay soil. The proportion of soil is made up of 60% clay, 25% loam, and 15% organic matter (by volume). The LGIS was installed in 2014, and it consisted of a single row of in-ground irrigation heads (rotor pop-up sprinklers, gear drive, Rain Bird, Tucson, Arizona.) sited in the middle of the study site, spaced 3 m apart (Fig. 1), which is approximately one-third the maximum throw of each head. The sprinkler arrangement was set up to generate a perpendicular irrigation gradient with decreasing irrigation volumes as distance from the irrigation source increased (Hanks et al., 1976). Three warm-season grasses *Cynodon dactylon x C. transvaalensis*, *Stenotaphrum secundatum* 'Palmetto', and *Zoysia matrella* L. Merr were sodded in November 2013 into three 9 by 9 m plots perpendicular to the centre irrigation line, using a randomized complete block design with 6 replicates. During establishment, all grasses were uniformly watered. Irrigation was applied twice weekly at a rate of 120% of reference evapotranspiration (ET_0) accumulated since the previous irrigation event. The

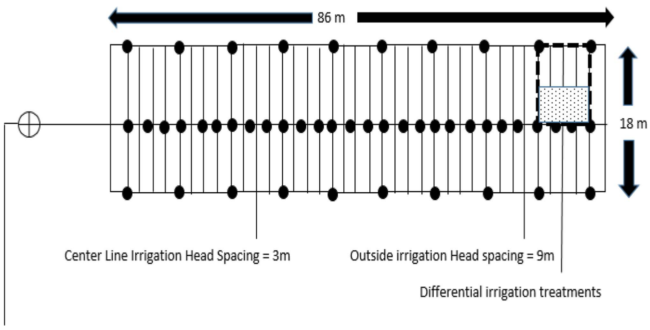

Fig. 1. Diagram of the Linear Gradient Irrigation System (LGIS) indicating the positions of the irrigation sprinkler heads in the central line, and the outside edge. Each individual plot which is aligned perpendicular to the central irrigation line is highlighted in dash lines.

120% ET_0 kept the soil nearest the line close to field capacity (Horst et al., 1989; Qian and Engelke, 1999), and the portion of the plot farthest from the centre line received no supplemental irrigation. Efforts were made to irrigate only when wind was minimal. Rain gauges which helped determine the volume of soil water was located approximately 10 m north of the experimental site. *Stenotaphrum secundatum* 'Palmetto' was mowed weekly at 4 cm, whereas *Cynodon dactylon x C. transvaalensis* and *Zoysia matrella* L. Merr were mowed at 2.5 cm with all clippings removed. Nitrogen was applied at rates and times based on requirements of the grasses, adhering to extension recommendations for lawn grasses issued by the National Parks Board, Singapore. Annual fertilisation rates averaged 120, 35 and 70 kg ha^{-1}, for nitrogen, phosphorus and potassium, respectively. Since one of the objectives was to assess the irrigation effects on disease and weed susceptibility, no chemicals were used.

Exposure to water, and minimum water requirements

Mean precipitation and ambient temperatures were determined on a monthly basis using rain gauges and a weather station positioned at 10 m from the irrigation line. Periodic calibrations were made to ensure that the desired water distribution was held constant. Data on irrigation output along the gradient were converted to an equivalent of Class A pan evaporation (% Ep). Least square, nonlinear regression of irrigation level vs. distance from the line source was used to predict irrigation distribution along the gradient (Fig. 2). Effort was made to water only when wind was minimal still, the water distribution curve was skewed very slightly towards the west side of the LGIS.

By substituting the value of distance in Fig. 2, the minimum water requirement as a proportion of the % Ep for each turfgrass was determined on a handful of evaluation dates (Table 1).The distribution of irrigation between the central line and that of the experimental turfgrasses are represented in fig. 2.

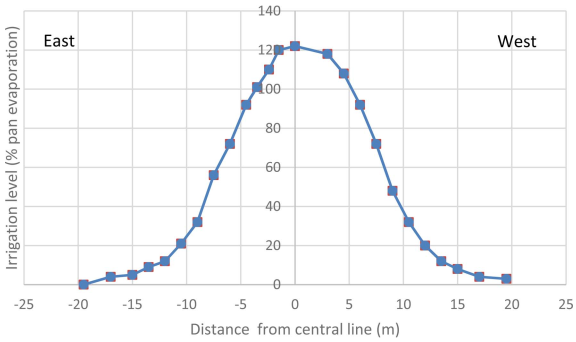

Fig. 2. Irrigation distribution of the linear Gradient Irrigation System (LGIS). Fitted equation: $\%Ep=120+1.85X-0.9X^2-0.03X^3+5.5E\text{-}4X^4+6.75E\text{-}8X^5-1.45E\text{-}8X^6-6.22E\text{-}9X^7+11.43E\text{-}9X^8$. $R^2= 0.9$.

Three irrigation levels-turf performance

Within each plot, 20.25 m^2 subplots were selected along the irrigation gradient to represent three irrigation regimes (high, moderate, and low). The amount of water received by these subplots were approximately 125%, 45%, and 12% Ep, respectively.

Turf performance, including turf quality, density, ground coverage, disease incidence, and weed invasion, were evaluated within these subplots. Turf quality was evaluated on a monthly basis using a scale of 1 to 9, where 6 was taken as the minimum acceptable turf quality and 9 was regarded as outstanding. Turf density was also rated using a 1 to 9 scale, where 9 was also regarded as outstanding. Turf ground coverage was rated based on percentage of area covered by living turf, and this parameter was considered to be an indicator of turf persistence at the end of this experiment. Similarly, weed invasion was rated based on percentage of area infested with weeds while disease incidence was determined through the counting of diseased lesions or patches on the blades of turfgrasses. Grasses were harvested at the end of the experiment, and the roots sampled for length measurements. Roots were washed and oven-dried at 70°C for 48-72 h (Huang, 2008), and dry weights recorded. Lastly, for yield data, clippings were harvested twice a month from the irrigation treated sub plots for each of the three irrigation levels. Thereafter, clippings were dried at 70°C for 24 h prior to weighing (Morris et al., 2007).

Data analysis

Analysis of variance (ANOVA) was used to test the effects of turfgrass species, irrigation regime, and any interaction (SAS Institute, ver. 9). A single factor ANOVA was used for data on minimum irrigation requirements. All hypotheses were tested at $P \le 0.05$. Percent data were arcsin transformed to satisfy the normality assumption of ANOVA. F values that were significant had their means separated using a least significant difference test at $P \le 0.05$.

Results and Discussion

Minimum water requirements and drought resistance.

LGIS commenced in December 2014 and significant turfgrass wilting was observed in February 2015 indicating that stress gradients had been established. Analysis of the minimum irrigation required for acceptable turf quality suggested that there were significant effects for species, evaluation dates, as well as species-date interactions. The minimum irrigation requirement for each species on each evaluation date is presented in Table 1. A range of water requirements is presented here for each species because the water required to prevent drought stress tended to vary with the date of evaluation, suggesting that the amount of water needed to maintain acceptable turf quality depended on weather, and the duration of drought. Minimum irrigation requirements to prevent drought stress for *Cynodon dactylon x C. transvaalensis* was 45 to 61% Ep; *Stenotaphrum secundatum* 'Palmetto' was 62 to 86% Ep and *Zoysia matrella* L. Merr was 53 to 73% Ep (Table 1). Essentially, for acceptable turf quality, the amounts of water necessary would lie in the upper end of each range for each species.

Meyer and Gibeault (1986) reported that the water requirements for cool-season grasses ranged from 43 to 63% Ep, while for warm-season grasses, the range was from 49 to 83% Ep. On the other hand, Qian and Engelke (1999)

Table 1. Irrigation requirements [% pan evaporation (Ep)] of three turfgrasses under a linear gradient irrigation system.

Grass	2 Feb 2014	23 Jun 2014	22 Oct 2014	5 Feb 2015	16 Jun 2015	23 Oct 2015	Range
Cynodon dactylon x C. *transvaalensis*	$45.4^{B(c)**}$	$60.9^{A(c)*}$	$43.7^{B(c)**}$	$45.0^{B(b)**}$	$61.3^{A(c)*}$	$46.6^{B(c)**}$	45-61
Stenotaphrum secundatum 'Palmetto'	$65.9^{B(a)**}$	$84.0^{A(a)*}$	$68.9^{B(a)**}$	$62.0^{B(a)**}$	$85.8^{A(a)*}$	$65.4^{B(a)**}$	62-86
Zoysia matrella L. Merr	$54.8^{B(b)**}$	$72.7^{A(b)*}$	$56.2^{B(b)**}$	$58.0^{B(a)**}$	$73.1^{A(b)*}$	$52.7^{B(b)**}$	53-73

Mean separated using Fisher's LSD test.
Uppercase letter indicate mean separation across days for a given turfgrass species; lowercase letters indicate mean separation among turfgrass species within a column (within each day).

Table 2. Mean visual quality, density, and clipping yields (g/m^2/day) of three turfgrasses under a linear gradient irrigation system during the growing season 2014-2015.

Grass	Turf quality (125)	Turf quality (45)	Turf quality (12)	Turf density (125)	Turf density (45)	Turf density (12)	Clipping yield (125)	Clipping yield (45)	Clipping yield (12)
Cynodon dactylon x *C. transvaalensis*	7.9 $^{A(a)}$	7.1 $^{A(a)}$	5.8 $^{B(a)*}$	8.5 $^{A(a)}$	8.0 $^{A(a)}$	6.5 $^{B(a)*}$	5.77 $^{A(a)}$	4.89 $^{A(a)}$	2.17 $^{B(a)*}$
Stenotaphrum secundatum 'Palmetto'	6.0 $^{A(b)*}$	5.0 $^{B(b)**}$	4.5 $^{C(c)**}$	5.8 $^{A(b)*}$	6.0 $^{A(b)*}$	6.0 $^{A(b)*}$	2.33 $^{A(b)*}$	2.31 $^{A(b)*}$	2.03 $^{B(b)**}$
Zoysia matrella L. Merr	7.0 $^{A(a)}$	6.3 $^{B(b)**}$	5.4 $^{C(b)**}$	7.9 $^{A(a)}$	7.6 $^{A(a)}$	6.4 $^{B(a)*}$	5.31 $^{A(a)}$	4.75 $^{A(a)}$	2.35 $^{B(a)*}$

Mean values across monthly ratings of turf performance. Turf quality and density were rated on scales of 1 to 9, where 6 is the minimum acceptable quality and 9 are most ideal. Yield is made up of a mean of 42 clipping occurrences.
Means were separated using LSD for each parameter.
Uppercase letter indicate mean separation among irrigation regimes for a given turfgrass species (across a single row); lowercase letters indicate mean separation among turfgrass species within a column (within each irrigation regime).

reported 39 to 68% Ep for *Zoysia matrella*, 12 to 44% Ep for *Stenotaphrum secundatum* 'Palmetto', and 12 to 35% Ep for *Cynodon dactylon x C. transvaalensis*. Likewise, Carrow (1995) reported that the average water requirements was 66%, 80%, and 76% Ep for *Cynodon dactylon x C. transvaalensis*, *Zoysia spp* 'Meyer', and *Stenotaphrum secundatum* 'Raleigh', respectively. The values in this report are greater than those reported for the same species in the northern hemisphere. This was expected because of the high humidity in the equatorial tropical environment and the higher year round temperatures, and the year round growing season (without any period of dormancy). These reasons together with the very limited scientific information pertaining to turfgrass irrigation requirements within the equatorial tropical regions allow for a very limited comparative analysis to be carried out. This however, paves the way for future work in this area.

The minimum irrigation requirements were suggestive that, under the conditions of this study, the ranking for relative drought resistance was *Cynodon dactylon x C. transvaalensis*, *Zoysia matrella* L. Merr, and lastly, *Stenotaphrum secundatum* 'Palmetto'. This ranking was consistent with the findings of Sifers et al. (1990), Carrow (1996) and Qian and Engelke (1999) though some of the cultivars used in these reports were different. The clay soil used in this study assisted to some extent with water retention. In comparison, soils with high sand composition which is free draining will have greater demands on drought tolerance as well as minimum water requirements. Despite these discrepancies, the work was still carried out using clay soils because such soils were the primary type of soils in Singapore in which most lawns were constructed and grown from. In addition, it is noteworthy that apart from the soil and climatic environment, the ability for deep rooting is another important component of drought resistance in turfgrasses (Huang et al., 1997; Qian and Engelke, 1999; Zhang et al., 2013; Zhang and Unruh, 2015). Drier conditions tended to stimulate greater allocation towards root rather than shoot biomass (Table 5). Here, all three grass species tended to enhance root length to explore greater depths for moisture when irrigation was at 12% Ep (Table 2 & 5). Although previous work by Carrow (1996) had observed weaker rooting abilities in *Zoysia spp* here, both the *Cynodon dactylon x C. transvaalensis* and *Zoysia matrella* L. Merr were found to have similar rooting abilities. However, despite higher root length and biomass, *Stenotaphrum secundatum* 'Palmetto' was still not able to maintain persistence at each ends of the irrigation scale.

Three irrigation levels- Turf performance

Turf visual quality differed with the three irrigation regimes across grass species (Table 2). A statistical significance was observed with differential irrigation on turf quality but a more pronounced effect was observed with species coupled with differential irrigation (Table 4). Turf quality of *Cynodon dactylon x C. transvaalensis* and *Zoysia matrella* L. Merr improved with increasing irrigation (Table 2). This was in contrast to findings in Zhang et al. (2013) where they reported that turf performance of *Zoysia spp* declined at 120% Ep. Noteworthy though that quality improvement was more gradual for *Zoysia matrella* L. Merr and *Stenotaphrum secundatum* 'Palmetto' when watered at a rate of >45% Ep (Table 2). All species exhibited poor turf quality when irrigated at 12% Ep in comparison to areas irrigated at 45 and 125% Ep (Table 2). *Stenotaphrum secundatum* 'Palmetto' had the lowest visual quality rating at 125% Ep (Table 2).

Turf density was greater at 125% Ep for *Cynodon dactylon x C. transvaalensis* and *Zoysia matrella* L. Merr (Table 2). In contrast, *Stenotaphrum secundatum* 'Palmetto' exhibited unacceptable turf density at 125% Ep, but improvement in turf

Table 3. Mean turf (%), weed ground coverage (%), and diseased patches of three turfgrasses under a linear gradient irrigation system during the growing season (2014-2015).

Grass	Turf coverage (125)	Turf coverage (45)	Turf coverage (12)	Weed coverage (125)	Weed coverage (45)	Weed coverage (12)	Diseased patches (125)	Diseased patches (45)	Diseased patches (12)
Cynodon dactylon x C. *transvaalensis*	68 A(a)	59B(a)	38 C(a)	17 B(c)	25 A(b)	28 A(b)	2 B(c)	2 A(c)	3 A(c)
Stenotaphrum secundatum 'Palmetto'	30 B(b)	40 A(b)	25 B(c)	43 B(a)	39 B(a)	55 A(a)	10 A(a)	7 A(a)	11 A(a)
Zoysia matrella L. Merr	67 A(a)	53 B(a)	33 C(b)	24 B(b)	30 A(b)	35 A(b)	5A(b)	5 A(b)	6 A(b)

Means are based on monthly ratings of turf performance.
Means were separated using LSD for each parameter.
Uppercase letter indicate mean separation among irrigation regimes for a given turfgrass species (across a single row); lowercase letters indicate mean separation among turfgrass species within a column (within each irrigation regime).

Table 4. Treatment comparisons for turfgrasses grown for a 12-month period under various irrigation treatments mimicking low, moderate and high.

Source of variation biomass	Turf quality	Turf density	Clipping yield	Turf coverage	Weed coverage	Diseased patches	Root length	Root
Species	ns	ns	ns	ns	ns	ns	ns	ns
Irrigation rates	*	*	*	***	**	**	**	**
Species & Irrigation rates	**	**	**	**	*	*	**	**

N = 6, *P* values of contrasts were calculated by PDIFF within the GLM procedure of SAS.

Table 5. Mean root length (cm), root biomass (g) of three turfgrasses exposed to three different irrigation regimes.

Grass	Root length (125)	Root length (45)	Root length (12)	Root biomass (125)	Root biomass (45)	Root biomass (12)
Cynodon dactylon x C. *transvaalensis*	7 B(b)	8B(b)	10 A(b)	120 B(b)	126 A(b)	128 A(b)
Stenotaphrum secundatum 'Palmetto'	12 A(a)	12 A(a)	15 B(a)	143 B(a)	139 B(a)	156 A(a)
Zoysia matrella L. Merr	8 B(b)	8 B(b)	10 A(b)	122 A(b)	124 A(b)	130 A(b)

Means were separated using LSD for each parameter.
Uppercase letter indicate mean separation among irrigation regimes for a given turfgrass species (across a single row); lowercase letters indicate mean separation among turfgrass species within a column (within each irrigation regime).

density was observed at 45 and 12% Ep (Table 2). Similarly, clipping dry weight showed that apart from *Stenotaphrum secundatum* 'Palmetto', all other species improved with increasing irrigation (Table 2). Weed yield was highest in *Stenotaphrum secundatum* 'Palmetto' at 12 and 125% Ep (Table 3) supporting the need to ensure good turf density and coverage to keep disease incidence and weed invasion at bay. Likewise, increasing irrigation also significantly benefited turf recovery for *Cynodon dactylon x C. transvaalensis* and *Zoysia matrella* L. Merr (Table 3). Enhanced recovery was observed at 125% Ep for *Cynodon dactylon x C. transvaalensis* and *Zoysia matrella* L. Merr, and improvements were clearly visible within 24 h. The same benefit of irrigation at 125% Ep was far less evident with *Stenotaphrum secundatum* 'Palmetto' which had a slow response to recovery (Table 3).

On average, *Cynodon dactylon x C. transvaalensis* and *Zoysia matrella* L. Merr had some 56% turf coverage at 45% Ep, and 35.5% turf coverage at 12% Ep (Table 3). Coverage increased to 68% at 125% Ep (Table 3). *Stenotaphrum secundatum* 'Palmetto' had some 40% turf coverage at 45% Ep, and 25% turf coverage at 12% Ep. Coverage at 125% Ep was approximately 30% (Table 3), suggesting that this grass was far less adaptable to irrigation levels at either ends of the scale but had preference for irrigation levels at moderate regimes.

Cynodon dactylon x C. transvaalensis had the highest turf density at 125% Ep and showed outstanding persistence at high irrigation levels, but deteriorated much like the *Zoysia matrella* L. Merr when subjected to 12% Ep. (Table 2). Nonetheless, *Cynodon dactylon x C. transvaalensis* exhibited greater resistance against susceptibility to diseases (Table 3). Broadleaf weeds such as *Mimosa pudica* and *Synedrella nodiflora* as well as sedge weeds such as *Cyperus rotundus* were the key species that invaded the bare patches between the grasses.

Clearly, *Stenotaphrum secundatum* 'Palmetto' had a relatively narrow range of adaptation. The deficit irrigation regimes facilitated the incidence of diseases observed in the warmer months of June and July 2015. Yellow patches that eventually turned reddish brown emerged at low and high levels of irrigation (Table 3). Apart from diseases, weed invasion was another challenge affecting the turf quality and density of *Stenotaphrum secundatum* 'Palmetto' at low and high irrigation regimes.

During the experimental period, all three grasses appeared to be susceptible to the brown patch disease with *Stenotaphrum secundatum* 'Palmetto' showing greater susceptibility to the disease. In fact, brown patch is a very common disease with *Stenotaphrum secundatum* 'Palmetto'. Jing et al. (1998) reported an outbreak of brown patch symptoms in *Stenotaphrum secundatum* 'Palmetto' when irrigated at >80% Ep. This observation allowed for the inference that moist conditions were ideal for the fungus which may have been exacerbated by the slow percolation rate of the clay soils (0.1 cm h^{-1}) used in this study.

In conclusion, amongst the three grasses tested, *Cynodon dactylon x C. transvaalensis* had the most outstanding drought tolerance followed by *Zoysia matrella* L. Merr, and lastly, *Stenotaphrum secundatum* 'Palmetto'. Noteworthy also that despite having the highest irrigation requirement, *Stenotaphrum secundatum* 'Palmetto' was still not able to maintain persistence at 125% Ep, and this grass also lost turf coverage at 12% Ep.

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